Micro Flow and Interfacial Phenomena

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Abstract Book

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PolyU Academy for Interdisciplinary Research 香港理工大學高等研究院

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9156 Ben Xu *Graduate School of China Academy of Engineering Physics, CHINA*

PAIR Distinguished LECTURE SERIES

Some Puzzles and Flow Research Opportunities in Soft Matter Science

Steve Granick

Robert K. Barrett Endowed Chair of Polymer Science and Engineering, Chemical Engineering, Biomedical Engineering, Chemistry, and Physics University of Massachusetts, USA

Abstract

A fundamental challenge of modern physical science is to form a structure that is not frozen in place but instead reconfigures internally driven by energy throughput and adapts to its environment robustly. With catalytic enzymes, we find problems of mechanobiology. With chemical reactions, we find problems of active matter. Exploring the potential of liquid-phase TEM to image individual molecules and their mutual interactions, we analyze failed and successful encounters of polymers and proteins, and visualize enzyme conformational changes in real time. A picture emerges in which simple experiments, performed at single-particle and single-molecule resolution, can dissect macroscopic phenomena in ways that surprise.

Biography

Steve Granick is a member of the U.S. National Academy of Sciences and American Academy of Arts and Sciences. Among his other major awards are the Paris-Sciences Medal, APS Polymer Physics Prize, and ACS Colloid and Surface Chemistry Prize.

He worked at the University of Illinois at Urbana-Champaign (30 years) and as Director of the IBS Center for Soft and Living Matter, which is the Korean version of a Max-Planck Institute (8 years). In 2023, he joined the University of Massachusetts.

PAIR Distinguished LECTURE SERIES

Super-wettability and Beyond

—— Quantum-confined Superfluid: Biological Energy Conversion, Chemical Reaction and Information Transfer

Lei Jiang

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Abstract

Life system presents an ultralow energy consumption in high-efficiency energy conversion, information transmission and bio-synthesis. The total energy intake of human body is about 2000 kcal/day to maintain all our activities, which is comparable to a power of ~ 100 W. The energy required for brain to work is equivalent to ~ 20 W, while the rest energy (~ 80 W) is used for other activities. All in vivo bio-syntheses take place only at body temperature, which is much lower than that of in vitro reactions. To achieve these ultralow energy-consumption processes, there should be a kind of ultralow-resistivity matter transport in nanochannels (e.g., ionic, molecular channels), in which the directional collective motion of ions or molecules is a necessary condition, rather than the traditional Newton diffusion. Directional collective motion of ions and molecules are considered as ionic/molecular superfluid. The research of ionic/molecular superfluid will promote the development of neuroscience and brain science, develop quantum ionic technology, construct future chemical reactors with high flux, high selectivity and low energy consumption, and produce a series of disruptive technologies.

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Biography

Lei Jiang is a Professor at the Technical Institute of Physics and Chemistry, Chinese Academy of Sciences (TIPC). He is an academician of the Chinese Academy of Sciences, Academy of Sciences for the Developing World, National Academy of Engineering (USA), Australian Academy of Science and Academia Europaea. He received his Bachelor's and Master's degrees from Jilin University, and PhD from the University of Tokyo. He worked as a post-doctoral fellow with Prof. Akira Fujishima and then as a senior researcher in the Kanagawa Academy of Sciences and Technology. In 1999, he joined Institute of Chemistry, Chinese Academy of Sciences. In 2015, he and his group moved to TIPC. His scientific interests focus on bio-inspired, smart, multi-scale interfacial materials with superwettability. Prof. Lei Jiang has discovered and established the basic principle of the interfacial material systems with superwettability and extended them to successful innovative applications. His work has been followed by more than 1,400 research institutions in 94 countries around the world. He is the most original and influential scientist in the field of material science in China. Due to his contribution to the development of superwettability, he won the "TWAS Prize in Chemistry" in 2011, the Advanced Science and Technology Award of "THE HO LEUNG HO LEE FUNDATION" in 2013 and the "Outstanding Achievement Award" of the Chinese Academy of Sciences in 2014. In 2016, he won the "UNESCO Medals" for contributions to the development of nanoscience and nanotechnologies, and the "Nikkei Asia Prize". In 2017, he won the "Humboldt Research Award" in Germany. In 2018, he was awarded the "Qiu Shi Outstanding Scientist Award" and "Nano Research Award". In 2020, he won the "ACS Nano Lectureship Award". In 2022, he won Tan Kah Kee Science Award.

PAIR Distinguished LECTURE SERIES

AI for turbulence modelling and computational fluid dynamics

Shiyi Chen
Eastern Institute of Technology, Ningbo, China

Abstract

In this talk, I will briefly present some recent developments of AI for turbulence modeling and computational fluid dynamics. In particular, I will show some new AI applications for fluid mechanics, including AI models for large eddy simulation, using resolved scale information to obtain smaller scale dynamics in fluid turbulence and PINN for turbulence. I will also discuss some possible research directions on tackling complex engineering problems via combining CFD and Al mythologies.

Biography

Chen Shiyi, President of Eastern Institute of Technology, Ningbo (tentative name), holds a doctoral degree in Science from Peking University and is a member of the Chinese Academy of Sciences as well as the Academy of Sciences for the Developing World (Third World Academy of Sciences). He is an internationally renowned scholar in mechanics and an eminent educator with extensive experience in university administration. After China's reform and opening up, he was the first mainland Chinese scholar to be elected as a fellow of the American Physical Society. He was also selected as one of the "40 Returnees in 40 Years of China's Reform and Opening Up".

His main research areas include turbulence theory and computational fluid dynamics, and industrial software. He is one of the pioneers of the lattice Boltzmann method in numerical methods, and has made a series of outstanding contributions in the fields of turbulence, large eddy simulation, and subgrid-scale models.

He has served as the Chair of the Department of Mechanical Engineering at Johns Hopkins University, the Founding Dean of the School of Engineering at Peking University, and the Vice President and Dean of Graduate School at Peking University. In 2015, he served as the President of the Southern University of Science and Technology, leading the university to enter China's "Double First-Class" initiative and achieving remarkable results. In 2021, he was invited to return to Zhejiang Province and appointed as the Director of the Ningbo University of Technology Research Institute, leading the establishment of Ningbo University of Technology.

PAIR Distinguished LECTURE SERIES

Hydrovoltaics: from green energy to intelligence

Wanlin Guo

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Abstract

Since the beginning of this century, the development trend of information technology to intelligent technology is increasing, the sustainable development problems, such as climate, green energy and how to understand human brain, become increasingly urgent. This trend makes scientists face the challenge of multi-phase media, multi-scale strong nonlinear coupling, especially the force-electric-magnetic-light-thermal coupling at the solid-liquid interface.

Water is not only the essence of life, but also the largest energy carrier on the earth as it covers about 70% of the earth's surface, absorbing 70% of the solar energy arriving the earth. In contrast to conventional technologies that harvest solar energy by directly converting the energy of light into electrical energy through the photovoltaic effect and kinetic energy of water by mechanical systems, **hydrovoltaic effects** generate electricity from the direct interaction of materials with water, using the solar energy arriving the Earth indirectly[1]. Through a variety of scientific principles, such as running water driven wheel, steam locomotives, water driven generator as well as the electrokinetic effects, the potential energy or kinetic energy of water can be converted into useful mechanical motion and electrical energy according to the principles of classical mechanics and electromagnetic dynamics[2]. In the recent decade, novel hydrovoltaic effects include waving potential[3], drawing potential[4], evaporation-induced electric potential[5] or evaporating potential[6] have been found. With the hydrovoltaic effects, energy from flowing, waving, dropping, condensing, as well as evaporating water can now be harvested, significantly extending our capability in harvesting environmental energy, leading to the **emerging hydrovoltaic technology**[7] and **hydrovoltaics: New ways of harvesting electricity from water**[8,9].

Here, we will review the recent advances in hydrovoltaics for harvesting environmental energy[10,11], serving as a potential **Negative thermal emission energy technology**[12], and briefly discuss the role of confined water in our brain and envision the hydrovoltaic intelligence.

Especially, the multi-field coupling effect at the solid-liquid interfaces of nanomaterials and water, especially the recent advances in hydrovoltaic effects will be discussed; the sustainable development challenges, the basic scientific questions of hydrovoltaic energy, ecology, and intelligence will finally be outlined.

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Biography

Dr. Wanlin GUO, Academician of Chinese Academy of Sciences, Chair Professor in mechanics and nanoscience, founder and director of the Key Laboratory of Intelligent Nano Materials and Devices of Ministry of Education and the Institute of Nanoscience of Nanjing University of Aeronautics and Astronautics. His current research focuses on intelligent nano materials and devices, novel conception and technology for efficient energy conversion, molecular physical mechanics for neuronal signaling and molecular biomimics, as well as strength and safety of aircraft and engine. He has published more than 400 peer-reviewed journal papers on *Nature* series, *Phys. Rev. Lett., J. Am. Chem. Soc., Adv. Mater., J. Mech. Phys. Solids, Nano Lett.*, etc. He received the National Science Foundation of China for Distinguished Young Scholars in 1996 and the honor of Cheung Kong Scholars in 1999. In 2012, he obtained the National Nature Science Prize of China.

PAIR Distinguished LECTURE SERIES

Photomolecular Evaporation from Hydrogels and Pure Water

Gang Chen
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Abstract

In recent years, experiments from different groups have reported that evaporation under sunlight from hydrogels and other porous materials can exceed the thermal evaporation limit by several times, i.e., super-thermal. Although possible reduction of latent heat in hydrogels was widely used as an explanation for the high evaporation rate, our experiments and modeling do not support this interpretation. We hypothesize that photons can directly cleave off water clusters at the liquid-vapor interface in a way similar to the photoelectric effect, which we call the photomolecular effect. We carried out over 20 different experiments on both hydrogel and a water-air interface to demonstrate this effect. Some key experiments include: (1) partially wet hydrogels become absorbing despite their constituent materials are transparent; (2) super-thermal evaporation; (3) polarization, angle-of-incidence, and wavelength dependences of optical responses at a single air-water interface to visible-light where bulk water does not absorb; (4) cooling of air under visible light irradiation; and (5) Raman and IR signatures of water clusters in the air. We also demonstrate that visible light heats up a thin layer of fog, with temperature rise peaking at the green wavelength where water is least absorbing. Our work provides a possible explanation for an 80-year puzzle in atmospheric science: experiments reported more cloud absorption than theory could predicts. Progress in theoretical description of the photomolecular effect will also be summarized. Our study suggests that the photomolecular effect should happen widely in nature, from clouds to fogs, ocean to soil surfaces, and plant transpiration, and can also lead to new applications in energy and clear water.

Biography

Gang Chen is the Carl Richard Soderberg Professor of Power Engineering at Massachusetts Institute of Technology (MIT). He served as the Department Head of the Department of Mechanical Engineering at MIT from 2013 to 2018. He obtained his PhD degree from the Mechanical Engineering Department at UC Berkeley. He was a faculty member at Duke University and UCLA, before joining MIT in 2001. He received an NSF Young Investigator Award, an R&D 100 award, an ASME Heat Transfer Memorial Award, an ASME Frank Kreith Award in Energy, a Nukiyama Memorial Award by the Japan Heat Transfer Society, a World Technology Network Award in Energy, an Eringen medal from the Society of Engineering Science, and the Capers and Marion McDonald Award for Excellences in Mentoring and Advising from MIT. He is a fellow of American Association for the Advancement of Science, the American Physical Society, The American Society of Mechanical Engineers, and the Guggenheim Foundation. He is an academician of Academy Sinica, a fellow of the American Academy of Arts and Sciences, a member of the US National Academy of Engineering and the US National Academy of Sciences.

PAIR Distinguished LECTURE SERIES

Interfacial Flow Over Hierarchically Structured Surface: Slip Boundary, Flow Separation Control, and Drag Reduction

Huiling Duan
Boya Chair Professor, Dean, College of Engineering, Peking University

Abstract

Interfacial flow is involved in varieties of natural phenomena and plays important roles in industrial applications. Boundary slippage provides a promising method to regulate interfacial flow and even complex bulk fluid transport by controlling the development of boundary layers, changing the near-wall flow structures, and reducing the viscous drag. Underwater superhydrophobicity provides a convenient way to realize slip boundary. However, the fundamental understanding of slip mechanism is still not clear, and the metastability of entrapped liquid-gas interfaces largely limits the practical applications. Besides, there still lacks of a versatile method to achieve flow control through managing interfacial slippage. In this talk, a systematic study is presented on the fundamental model, stability, and flow control of slip boundary over hierarchically structured surfaces. Multi-scale homogenization approach is developed to theoretically formulate the effective slip boundary over hierarchically structured surface. Nonlinear behaviors of slip boundary are revealed by establishing fundamental framework of slip boundary. Basic physical laws underlying the dynamic evolution of the metastable states are revealed, enabling the prediction of plastron longevity and the realization of ultimate stable state. Slip boundary is finally implemented to regulate flow separation and reduce drag in turbulent boundary layer flow. The current work paves the way for practical applications of Navier-slip boundary in flow control.

Biography

Prof. Huiling Duan is a Boya Chair Professor at Peking University, a member of the Chinese Academy of Sciences, and the Dean of the College of Engineering at Peking University. Prof. Duan’s main research interests lie in interface mechanics and fluid-structure interaction mechanics. She has received prestigious awards including the second prize of the State Natural Science Award (2020), Alexander von Humboldt Research Award in Germany (2023), National Outstanding Young Scholar of China (2015), and National Outstanding Young Female Scientist of China (2014), etc. She serves as Member of the International Union of Theoretical and Applied Mechanics (IUTAM) Symposia Panel for Solid Mechanics, Executive Member of Global Engineering Deans Council. She was elected a Fellow of the American Society of Mechanical Engineers (ASME) in 2020.

PAIR Distinguished LECTURE SERIES

Exploring 2D Empty Space

Sir Andre GEIM

Regius Professor at the University of Manchester, United Kingdom

Abstract

It is now possible to create angstrom-scale channels that can be viewed as if one or a few atomic planes are pulled out of a bulk crystal leaving behind a two-dimensional space. I shall overview our recent work on this subject, which covers the properties of gases, liquids and ions under the extreme confinement.

Biography

Sir Andre Geim is Regius Professor at the University of Manchester, United Kingdom. He was awarded the 2010 Nobel Prize for his groundbreaking research on grap hene, a one-atom-thick material made of carbon. He also received numerous international awards and distinctions, including medals from the Royal Society and the US National Academy of Sciences, and holds honorary doctorates and professorships from many countries and universities. Sir Andre is a member of the British, Chinese and American academies of science, among others.
Thomson-Reuters repeatedly named Geim among the world's most active scientists and attributed to him three new research fronts – diamagnetic levitation, gecko tape and graphene. More than 40 of his papers were cited >1,000 times with nine of them >10,000 times. Two of the latter are among 100 most cited research papers in human history, according to journal Nature. He was also awarded the 2000 Ig Nobel prize for his work on levitation, becoming the first and only recipient of both Nobel and Ig Nobel Prizes. Sir Andre was knighted twice, by Dutch and British monarchs.

Hydrogen Micro/Nanobubbles in Interfacial Gas Evo- lution Reaction

Xuehua Zhang
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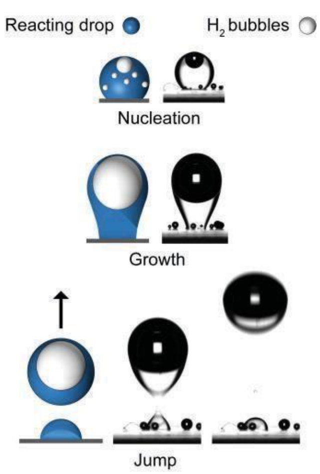
ABSTRACT

(250 Words Max, optional to include figure/caption)

Liquid organic hydrogen carrier is a promising option for the transport and storage of hydrogen as a clean energy source. This study examines the stability and behavior of organic drops immobilized on a substrate during an inter- facial hydrogen-evolution reaction (HER) at the drop surface and its surrounding aqueous solution. Hydrogen mi- crobubbles form within the drop and rise to the drop apex. The growth rate of the hydrogen in-drop bubble increases with the concentration of the reactant in the surrounding medium. The drop remains stable till the buoyancy acting on the in-drop bubble is large enough to overcome the capillary force and the external viscous drag. The bubble spontaneously rises and carries a portion drop liquid to the solution surface. These spontaneous rising in-drop bubbles are detected in measurements using a high-precision sensor placed on the upper surface of the aqueous solution, reversing the settling phase from phase separation in the reactive emulsion. The finding from this work provides new insights into the behaviors of drops and bubbles in many interfacial gas evolution reactions in clean technologies.



BIOGRAPHY

(150 Words Max, optional to include photo/head-shot)

Professor Xuehua Zhang completed her PhD in Biomedical Engineering from Shanghai Jiao Tong University. Af- ter her PhD study, she first worked as an Endeavour Research Fellow in Department of Applied Math, Australian National University in Canberra (capital of Australia), and then was a postdoctoral fellow in University of Mel- bourne. She was awarded with a prestigious ARC Postdoctoral Fellowship and then with also ARC Future Fellow- ship. In 2017, she was appointed as a Professor at the Department of Chemical and Materials Engineering, Uni- versity of Alberta. She is a Canada Research Chair (Tier 1), and an Associate Editor for *Soft Matter*, a RSC journal. Her research areas lie in colloid and interface sciences, nanomaterials and fluid dynamics.

Dynamics of bubble bursting jet at a complex liquid surface

Bingqiang Ji
Beihang University

ABSTRACT

(250 Words Max, optional to include figure/caption)

Bubble bursting at a free liquid surface mediates the mass transfer across interfaces over a wide range of nature and industrial processes, where the jet drop aerosols generated by bubble bursting jet play an important role. However, how a complex liquid surface, formed by the contamination of insoluble liquids or surfactants, affects the bubble bursting jet remains largely unexplored. Here we show our recent progresses on this topic: 1) the thin oil layer at the water surface results in a thinner and faster compound jet from a bare bubble bursting, by quickly spreading along the cavity surface and introducing a surface viscosity, which increases the viscous dissipation on the capillary waves; (2) an thin oil coating around a millimeter-sized bubble facilitates the singularity of cavity collapse and thus a micron sized jet, two order of magnitude smaller than that from a bare bubble bursting. We show this distinct dynamics comes from the selective viscous dissipation mechanism that smooth out the precursor waves, leading to a more efficient focusing of the dominant wave; (3) a protein-laden surface entraps a daughter bubble jet drop ejection after bubble bursting, contrary to the jetting phenomenon at a Newtonian surface. We theoretically show that the interplay between the surface viscoelasticity and surface tension change the velocity and viscous damping of the capillary waves, determining the onset of bubble entrainment. These findings provide theoretical understanding for the prediction of aerosol generation and pathogen transmission by bubble bursting in practical situations.

BIOGRAPHY

Dr. Bingqiang Ji is a Professor in the School of Astronautics at Beihang University. Before he joined Beihang, he was a Research Associate with Prof. Zuankai Wang and Prof. Steven Wang at City University of Hong Kong since May 2022, and he also did postdoctoral research at the University of Illinois at Urbana-Champaign for more than 2 years. He received his Ph.D. degree from Tsinghua University in 2019. His research mainly focuses on multiphase flow, interface phenomena, interfacial rheology, and jet/droplet/bubble/particle dynamics. As the first/corresponding author, he has published more than 20 papers in journals including *Nature Physics*, *Nature Communications*, *Physical Review Letters*, *Journal of Fluid Mechanics*, and *Nano Letters*.

PIV analysis of bubble necking on hydrophobic and superhydrophobic surfaces

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ABSTRACT

Bubble necking constitutes a recognized behavior within the study of bubble dynamics. However, the physical mechanisms underlying the formation of necking on different wetting surfaces have yet to be fully defined. To address this knowledge gap, we analyzed the bubble necking on two low surface energy substrates by employing particle image velocimetry (PIV) and shadowgraph techniques to simultaneously measure the liquid phase velocity and the instantaneous bubble shape during its formation. Two wetting surfaces were prepared for this study: 1) The hydrophobic surface is fabricated by applying a self-assembling monolayer coating; 2) The superhydrophobic surface was created through laser ablation followed by chemical vapor deposition. The two-dimensional velocity data obtained from PIV facilitated the refinement of the surrounding pressure field and stress tensor. Then, the shadow images enabled the reconstruction of the three-dimensional bubble profile to allow the precise estimation of capillary pressure along the bubble interface. This methodology allows for an accurate determination of the relevant forces acting on the bubble during formation and offers insights into the local stress and pressure balance at the necking area.

ABSTRACT FIGURE (OPTIONAL)

We are holding a **student keynote abstract competition** in which students and postdocs will have the opportunity to showcase their work with a formal talk. If you want to be considered for this competition, you need to submit an abstract figure and integrate it with the abstract. If you want to be considered for a poster only, then no figure is required and a word-only abstract is required.

SINGLE BUBBLE RISING IN A HELE-SHAW CELL

Zhen Jian*, 1, 2, Shiping Xiang[1], Ruixuan Li[1], and Zhen Jiang[1]

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[2]*Research Institute of Xi'an Jiaotong University Zhejiang, Hangzhou 311215, China*

ABSTRACT

Single bubble rising in a Hele-Shaw cell was investigated experimentally. A vertical wall was inserted in the cell, and the initial distance between the wall and the bubble releasing position was changed systematically, as well as the bubble diameter varying from 3.65mm to 21.68mm. The rising dynamics were studied and the bubble was found to migrate away from the wall. The rising trajectory transits from rectilinear path to zigzag, and two mechanisms of zigzag were revealed as rigid zigzag and contracting zigzag depending on the bubble size. It is found that the zigzag is easier to start for a more rounded bubble, and the migration is stronger at a smaller normalized initial distance.

BIOGRAPHY

Zhen Jian is an Associate Professor of Fluid Mechanics at Xi'an Jiaotong University, China. He received his Bachelor's and Master's degrees from Xi'an Jiaotong University, his diplôme d'ingénieur généraliste from Ecole Centrale de Lyon, France, and his Ph.D. in Fluid Mechanics from University Paris 6 – Pierre and Marie Curie, France. His research focuses on high-speed imaging experiments and numerical simulations on multiphase flow and heat and mass transfer problems, such as droplet/bubble dynamics and microfluidics. More information can be found at his faculty website: https://gr.xjtu.edu.cn/web/zhenjian.

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Dancing Bubble and Self-lifting Droplet

Daosheng Deng
Fudan University, Shanghai, China

ABSTRACT

Many intriguing phenomena will occur in the mesoscopic fluids by utilizing various physical fields, resulting from its unique length scale, and holding promising for the diverse applications. Two examples will be presented in this talk. In the first example, arising from the strong photothermal response of near-infrared laser in pure water and the efficient heat conduction at the solid/liquid interface, a temperature inversion layer is formed, and the danc- ing bubble is produced, enabling the precise control of underwater bubbles. In the second example, a binary droplet subjected to the supercooling can nearly double its height, in a fashion that defies against the gravitational effect. This counterintuitive observation is attributed to an internal solutal Marangoni flow, which is driven by the enriched solute concentration locally in the vicinity of the solidification front.

BIOGRAPHY

Daosheng Deng is a Professor at Fudan University. He received his Ph.D. in Materials Science at MIT, followed by postdoctoral research in Chemical Engineering at MIT and Harvard University. His research primarily focuses on fluid physics and technology applications. His publications include Nature, Nature Communications, Phys. Rev. Lett, Nano Lett., and J. Fluid. Mech, and his work has been featured by Phys.org, Science Daily, Technology Review, and Physics Today.

HOT WATER REPELLENCIES

Timothée Mouterde
Department of Mechanical Engineering, The University of Tokyo

ABSTRACT

Covering a solid with hydrophobic micrometric or nanometric-scale roughness gives rise to a strong water-repellent property known as superhydrophobicity. On such surfaces, water contacts only the tops of the roughness, forming an air layer between the liquid and the surface. This confers vanishing adhesion and exceptional mobility to drops on solids, two properties which are useful for preventing undesired liquid accumulation and for manipulating small liquid volumes in chemical or biological applications.

While such surfaces can efficiently repel water, it is less known that they often fail to repel hot liquids. When a hot drop contacts a colder substrate, the water vapor contained in the surrounding humid air can recondense within the surface roughness, destroying the air layer responsible for liquid repellency.

In this presentation, we will study how the adhesion of drops in non-wetting states is affected by their temperature. We will first explore the adhesion of hot water drops on superhydrophobic surfaces with model surface nanostructures and discuss how the structures' size and shape can be engineered to give rise to hot liquid repellency. Then we will consider the case of hot drops impacting colder superhydrophobic substrates. For this dynamic situation, we will show that a second route can achieve hot liquid repellency. Finally, we will discuss how other non-wetting states are affected by temperature differences.

BIOGRAPHY

Timothée Mouterde graduated from École polytechnique (France) and received his PhD from Université Paris-Saclay in 2017. During his PhD, supervised by David Quéré, he worked on antifogging surfaces and the dynamics of Leidenfrost and superhydrophobic drops. He then joined the group of Lydéric Bocquet at École Normale Supérieure Paris (ENS) to study experimentally fluid transport inside angstrom-scale channels, in collaboration with Radha Boya, Ashok Keerthi, and Andre Geim (University of Manchester). By 2019, he moved tothe University of Tokyo, joining Takuro Ideguchi's laboratory, where, with the support of JSPS and MSCA postdoctoral fellowships, he focused on developing new optical techniques for nanofluidics. In 2021, he was selected for the University of Tokyo's Excellent Young Researcher program and started his research group within the Department of Mechanical Engineering. His research focuses on fluid/solid interactions, from wetting phenomena to nanofluidics.

Pancake Jumping of Sessile Droplet

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ABSTRACT

Rapid droplet shedding from surfaces is fundamentally interesting and important in numerous applications such as anti-icing, anti-fouling, dropwise condensation, and electricity generation. Recent efforts have demonstrated the complete rebound or pancake bouncing of impinging droplets by tuning the physicochemical properties of surfaces and applying external control, however, enabling sessile droplets to jump off surfaces in a bottom-to-up manner is challenging. In this talk, I will report a novel phenomenon, *i.e.*, rapid jumping of sessile droplets (even cold droplets) in a pancake shape, which is achieved by engineering superhydrophobic magnetically responsive blades arrays. This pancake jumping droplet behavior exhibits many advantages such as short interaction time and high energy conversion efficiency.

BIOGRAPHY

Biography: Dr. Xuemei Chen is currently a professor in the School of Energy and Power Engineering at the Nanjing University of Science and Technology. She received her Ph.D. degree in the Mechanical and Biomedical Engineering from City University of Hong Kong (2013). Prior to joining Nanjing University of Science and Technology in 2017, she did her postdoctoral work in School of Mechanical Engineering at Purdue University. Her research interests include bioinspired materials, interfacial science, thermal management, microscale fluid flow, heat transfer, *etc*. Her research has been honored with awards including Young 1000 Talent Plan, Outstanding Scientific Innovation Achievement Award of Shandong Province. Her work has been reported by several media outfits and magazines.

LOW-PRESSURE PANCAKE BOUNCING ON SUPERHYDROPHOBIC SURFACES

Zunru Fu[1], Dongsheng Wen[1,2]
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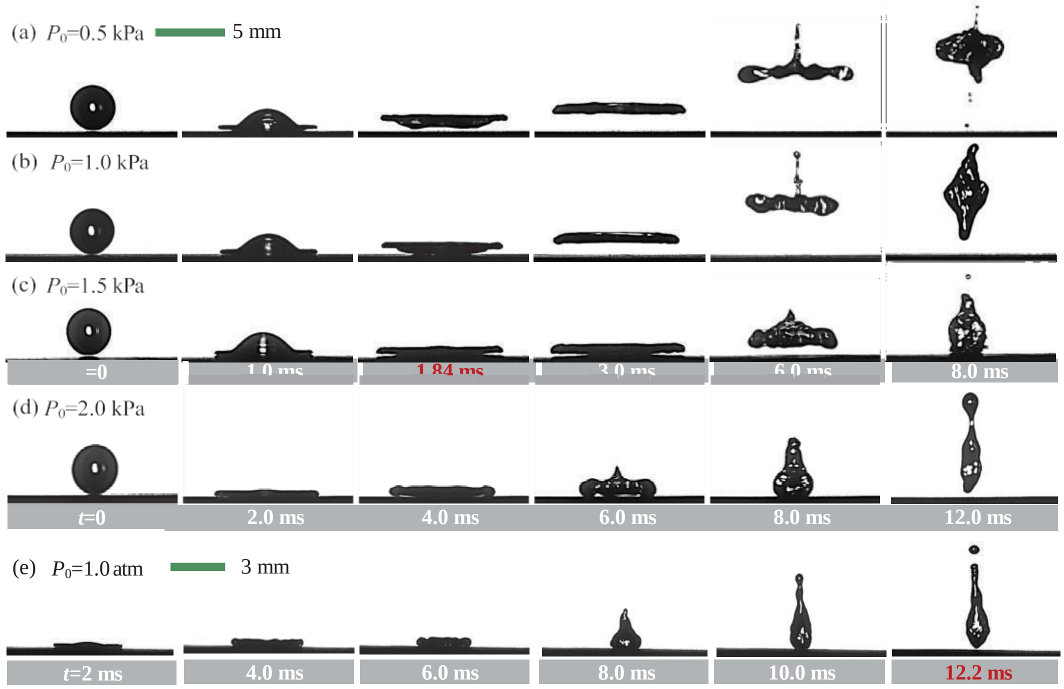
ABSTRACT

A new form of pancake bouncing is discovered in this work when a droplet impacts onto micro-structured superhydrophobic surfaces in an environment pressure, i.e., P_0 less than 2 kPa in room-temperature, and an unprecedented reduction of contact time by 85% is obtained[1]. The mechanisms of forming this unique phenomenon are examined by combining experimental observation, numerical modelling and an improved theoretical model for the overpressure effect[2] arising from the vaporisation inside micro-scaled structures. The competition among the vapor overpressure effect, the droplet impact force, and the surface adhesion determines if the pancake bouncing behavior could occur. After the lift-off the lamella, the pancake bouncing is initiated and its subsequent dynamics is controlled by the internal momentum transfer. Besides, the strategy for resisting the compressed-condensation induced superhydrophobicity failure[3] nearby the central entrapped gas film in low pressure environment is further clarified, and the local distribution characteristic of kinetic pressure along the substrate is revealed for the first time. Complementary to the prior studies, this work enriches the knowledge of droplet dynamics in low pressure, which allows new strategies of surface morphology engineering for droplet control, an area of high importance for many engineering applications.

ABSTRACT FIGURE



Abstract Figure**. Typical snapshots of low-pressure pancake bouncing in different air pressure conditions, as compared with conventional rebound in atmospheric environment.** Droplet diameter D_0=2.5 mm, impact velocity V_0=1.5 m/s. The superhydrophoboic surfaces were prepared by laser ablation method with micro-channel structures inspired by wheat leaves.

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Understanding the Dynamics of Self-Cleaning by Coalescence-Induced Jumping Droplet on a Superhydrophobic Surface

Seokhyun Noh[1], Donald M. Cropek[2], Marianne Alleyne[3], Nenad Miljkovic[3], and Junho Oh[1]
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[2]Construction Engineering Research Laboratory, U.S. Army Engineer Research and Development Center, Champaign, IL, 61822, USA
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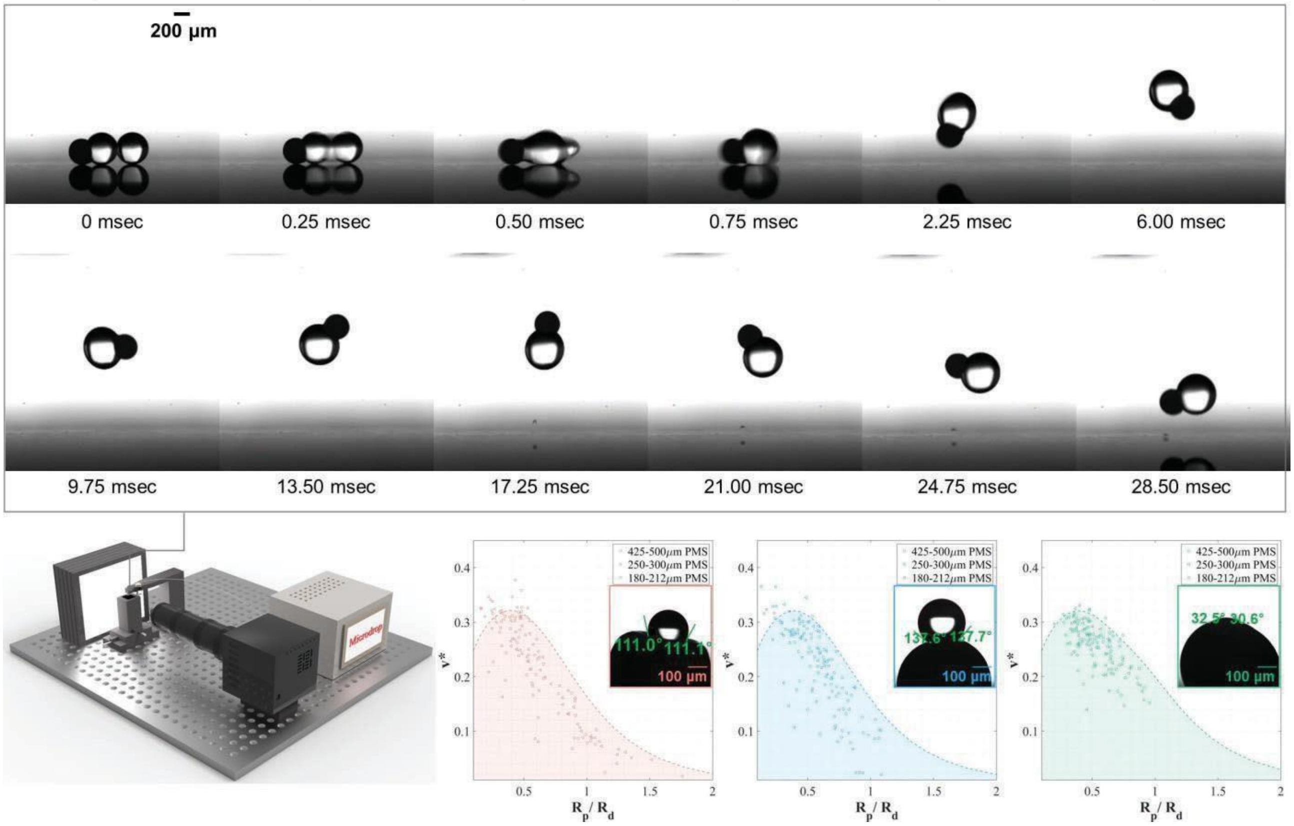
ABSTRACT

Self-cleaning superhydrophobic surfaces have garnered significant attention across various applications, including heat exchangers, semiconductors, and medical devices. These surfaces exhibit self-cleaning properties by shedding droplets that incorporate contaminants. Previous studies observed similar behavior in natural superhydrophobic surfaces, such as plant leaves and insect wings, which remove foreign materials. Despite efforts to understand jumping droplet dynamics and their impact on particle removal, the detailed mechanisms remain poorly understood. In this study, we investigate the dynamics of droplet-particle aggregates with varying sizes, densities, and wettabilities with respect to the kinetic energy provided by the coalescing droplets. We use different particle sizes of polyethylene microspheres (PMS) and stainless steel (SS) particles, each modified for wettability by surface treatment. High-speed imaging captures the movements of the aggregates, allowing us to understand the behavior during particle entrainment by merged droplets and the subsequent jumping of droplet-particle aggregates. Our results reveal that the particle/droplet weight ratio plays a crucial role in determining the movement of aggregates. For weight ratios less than 0.2, the aggregates exhibit linear jumping behavior, and for weight ratios greater than 1, rotational motion dominates.

Energy analyzes demonstrate that PMS particles achieve 7% of the maximum conversion rate from surface energy to kinetic energy, while SS particles achieve 5%. Results align with prior studies for droplet coalescence, reporting 6–8% conversion.

Additionally, we observe that energy dissipation during particle entrainment increases significantly with higher particle density and more wetting surface chemistry. This study improves understanding of self-cleaning dynamics and encourages practical applications.

ABSTRACT FIGURE



4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Dancing Drops on Lubricated Surfaces

Marcus Lin[1], Philseok Kim[2], Sankara Arunachalam[1], Fauzia Wardani[1], Rifan Hardian[1], Solomon Adera[2], Joanna Aizenberg[2,3,*], Xi Yao[2,4,*], and Dan Daniel[1,*]
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[3]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, Massachusetts 02138, USA and
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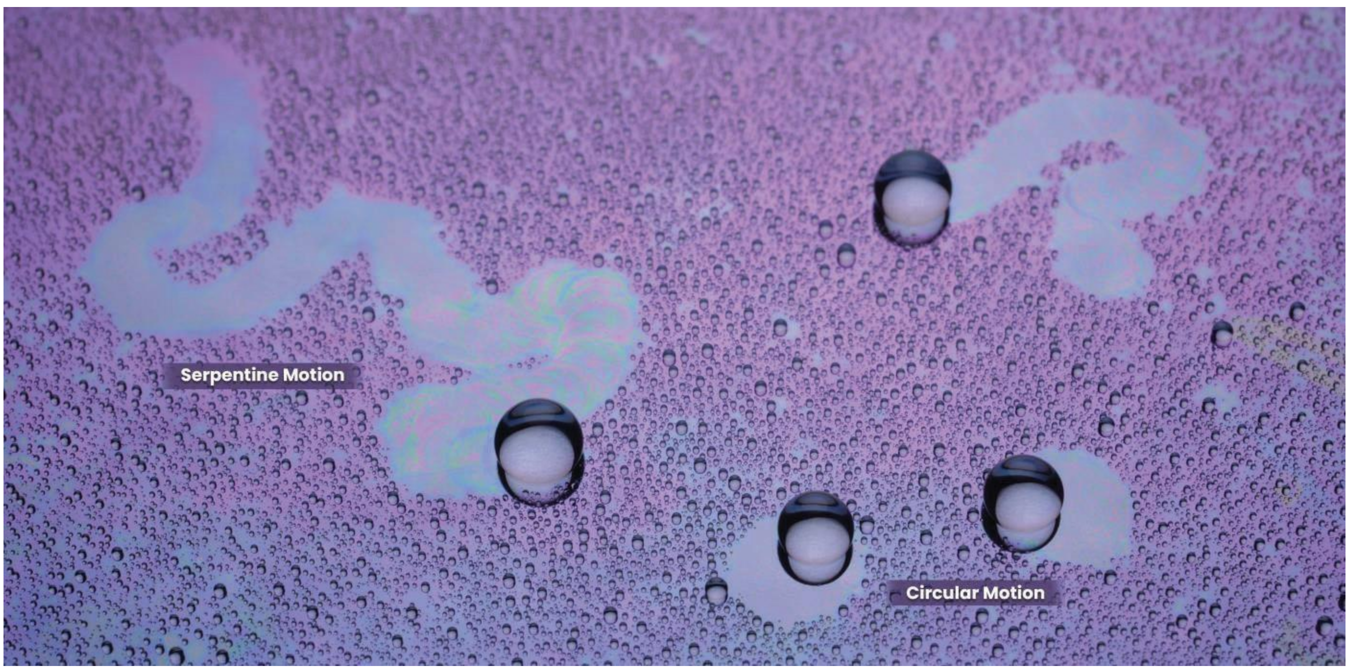
ABSTRACT



Recently, there is much interest in droplet condensation on soft or liquid or liquidlike substrates. Droplets can deform soft and liquid interfaces resulting in a wealth of phenomena not observed on hard, solid surfaces (e.g., increased nucleation, interdroplet attraction). Here, we describe a unique collective motion of condensate water droplets that emerges spontaneously when a solid substrate is covered with a thin oil film. Droplets move first in a serpentine, self-avoiding fashion before transitioning to circular motions. We show that this self-propulsion (with speeds in the 0.1–1 mm s^{-1} range) is fueled by the interfacial energy release upon merging with newly condensed but much smaller droplets. The resultant collective motion spans multiple length scales from submillimeter to several centimeters, with potentially important heat-transfer and water-harvesting applications.

Exploding drops on lubricated surfaces

Marcus Lin, Peng Zhang, and Dan Daniel*
King Abdullah University of Science and Technology,
Saudi Arabia

ABSTRACT

Traditionally, investigations of Coulomb explosions have focused on charged microdrops levitated using quadrupole electric fields, i.e., a Paul trap. In a surprising twist, our work introduces a simple method to observe Coulomb explosions, with no drop levitation and no external electric field. Instead, we generate a charged water drop using a conventional micropipette, which we then deposit on a plastic petri dish lubricated with a thin oil film. As the droplet evaporates, its radius shrinks until it reaches the Rayleigh limit at which point we observe multiple, highly periodic Coulomb explosions (> 60 events over 20 mins)—the first time Coulomb explosions have been reported for a sessile drop on a surface. Each event produces a finely ejected liquid jet, which disintegrate into microdroplets explosively within microseconds. Our Coulomb explosions span diverse length scales (from micron to millimetres) and time scales (from microseconds to minutes), with potentially wide-ranging applications from nanoscopic material fabrication to electrospray ionization.

BIOGRAPHY

Dan Daniel was born in Indonesia, but spent most of his formative years outside the country: first in Singapore, followed by undergraduate training in the UK (BA in Physics, Cambridge) and graduate training in the US (PhD in Applied Physics, Harvard). He is now an assistant professor at KAUST (Saudi Arabia), leading a small (but highly talented) research group, the Droplet Lab (https://dropletlab.science/). His main research interests are in physics of droplets, wetting/adhesion science, and soft matter.

NANO GREEN PRINTING AND MANUFACTURING TECHNOLOGY

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CAS Key Laboratory of Green Printing, Institute of Chemistry, Chinese Academy of Sciences

ABSTRACT

Based on the fundamental scientific issues of nanomaterial preparation and functional inkjet patterning, a systematic Nano Green Printing technology has been developed by studying the construction of nanomaterials with differential wettability on material surfaces. The precise control of the conversion from translational kinetic energy to rotational kinetic energy before and after droplet collision has been achieved using patterned wettability surfaces. This process breaks through the scope of classical Newton's collision law and realizes a change in the motion mode of droplets before and after collision, providing new ideas for the preparation and precise control of high-precision patterns. Starting from the manipulation of droplets for three-dimensional shaping, spontaneous contraction of droplets in three-dimensional space has been achieved by using templates, enabling rapid assembly and shaping of three-dimensional micro/nano structures using single or multiple materials. Furthermore, the evolution of foam has been controlled using micro-templates, overcoming the long-standing challenge of patterned control of bubbles, and realizing the anti-Oswald ripening and patterned printing of bubbles. This has been used as a printing template for the assembly of multiple functional materials. In particular, by utilizing the advantages of droplet manipulation in nanoscale green printing and discovering the critical conditions for the scattering-diffraction transition of nano-photonic structures, an optical metamaterial detection chip has been developed for ultra-sensitive and rapid detection of novel coronavirus, influenza virus, and tumor markers. This opens up new ideas for the printing preparation of functional devices and micro/nano chips, and establishes the theoretical and technical system of nanoscale green printing technology.

Short BIOGRAPHY

Yanlin Song is currently the director of the Key Laboratory of Green Printing at the Institute of Chemistry, Chinese Academy of Sciences. He has been engaged in interdisciplinary research on materials science and printing technology, and has made systematic innovative achievements in the creation of nanomaterials, interface droplet manipulation, and printing micro/nano manufacturing. He has published over 500 SCI papers, with over 36,000 citations and an H-index of 100. He has been granted more than 170 Chinese invention patents and 11 international invention patents.

FLEXIBLE LIQUID MARBLES FOR NON-WETTINGDROPLET MANIPULATION

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ABSTRACT
Despite being a tiny volume of liquid, a droplet may contain a wealth of physical or biochemical information. Like a naked droplet wrapped in a stretchable particle shell, liquid marbles (LMs) are artificial non-wetting microsystems with widespread applications in sample transport, material synthesis, and real-time sensing. Inspired by the aphids in nature that secrete wax films to wrap their honeydew for survival, LMs with variable particle shells are a promising solution for droplet manipulation, offering greater flexibility and ease of use over conventional droplet-based microfluidic platforms. However, controlling the distribution of shell particles remains a technical challenge, mainly due to their limited usage and tendency to aggregate. This work outlines a simple yet efficient method to fabricate monolayer LMs with tunable particle coverage. These LMs are softly encapsulated by modified PS microspheres and exhibit excellent stability in the atmosphere. The overall performance of flexible LMs with a wide range of coverage rates was then qualitatively and quantitatively characterized. Contrary to common perception, such marbles with transparent apertures not only exhibited remarkable maneuverability and unpredictable vitality on hydrophilic surfaces, but also excelled in fusion, reaction, and surface cleaning, with an elongated operational lifetime and a wide visualization range. The study presented here provides new insights into exploring environmentally friendly implementations of LM-based miniaturized platforms, and encourages more researchers from physics to engineering to pay due attention to such particle-laden droplet systems.

BIOGRAPHY

Dr. Jing Jin is now a full-time assistant professor at Harbin Institute of Technology, Shenzhen (HITsz). His research areas focus on multiphase interface, soft matter, droplet microfluidics and lab on a chip. In the recent five years, he has published over 30 papers (*h*-index: 17) in a series of renowned journals, such as *Lab on a Chip*, *Analytical Chemistry*, *Physical Review Applied*, *ACS Applied Materials & Interfaces*, *Biosensors*, etc. Dr. Jin currently receives financial support from National Natural Science Foundation of China, Basic and Applied Basic Research Foundation of Guangdong Province, and Shenzhen Science and Technology Innovation Committee, with the total funding amount up to ¥5,000,000. He has served as a guest editor and peer reviewer for numerous related journals, and has been invited to speak at various reputable conferences and symposiums both domestically and internationally.

High Throughput Modifiable Hydrogel Screen of Secretory Phenotypes Applied to Synthetic Biology

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ABSTRACT

Synthetic biology offers genetically engineered microbes for production of natural chemicals, which show advantages in low cost and rapid scaling for large-scale manufacturing of value compounds. Through a design-build-test cycle paradigm, the secretory phenotypes can be selected in a mutant library for directed evolutions of bio-fabrication. Recently, the microfluidic droplet technology was investigated to successfully demonstrate high throughput single cell secretory screening. However, the assay flexibility was limited. Here, a novel modifiable droplet aptamer alginate microbead (AAM) assay was developed for flexible single microbe secretion screen. As a demonstration, engineered E. coli (Gib cells) harboring chalcone synthase (CHS), malonyl-CoA synthase (MCS), phenylalanine ammonia-lyase (PAL), and 4-coumaroyl-CoA ligase (4CL) were screened for the secretion of naringenins to generate flavonoid-related compounds. Single E. coli cells were encapsulated alginate microbeads for incubation (~1 day), in which, the aptamers captured the target secretions to induce the configuration change of aptamer, showing fluorescent signals. The droplet aptamer microbead approach offers a flexible tool to identify critical mutants that can potentially produce a wide range of valuable chemicals towards advanced bio-fabrication.

ABSTRACT FIGURE (OPTIONAL)

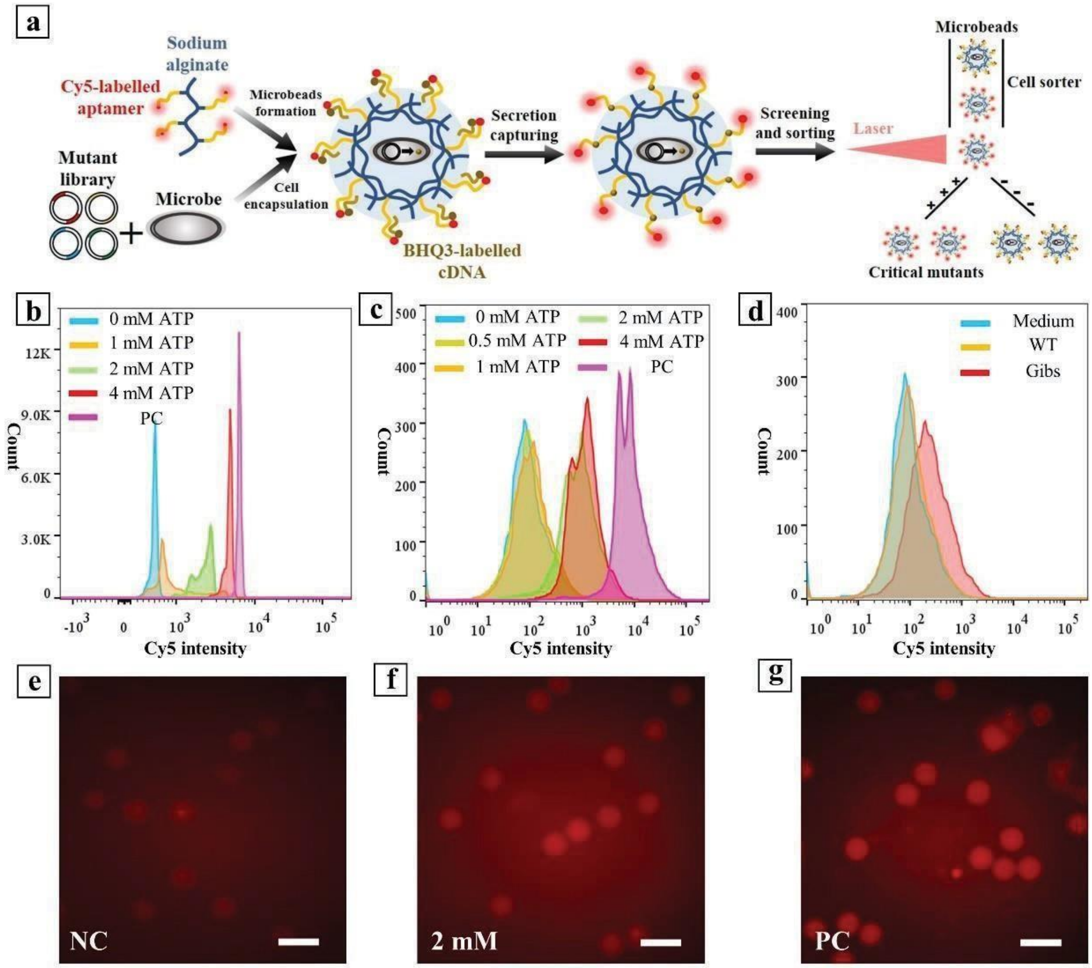

Figure 1: (a) Schematic for aptamer anchored alginate microbeads (AAM) assay, (b) commercialized microbeads assay for ATP sensing, (c) AAM assay for ATP sensing, (d) AAM assay for culture medium and cell culture supernatant (naringenin sensing). Fluorescent microscope images of AAM for (e) negative control, (f) incubation with 2 mM ATP and (g) positive control (scale bar: 50 μm).

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

EXPERIMENTAL INVESTIGATION OF DROPLET GRAVITATIONAL SHEDDING ON INCLINED FUNCTIONAL SURFACES

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[1]Department of Mechanical Engineering, Bilkent University, TURKIYE and
[2]Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, USA
[*]Corresponding author
[†]Equal contribution

ABSTRACT

Dropwise condensation has been extensively investigated for applications ranging from steam-based power generation to thermal desalination because it has been showed to possess 5-10 times higher heat transfer compared to filmwise condensation due to the rapid shedding of discrete droplets and clearing of the surface for re-nucleation. Hence, much research effort has focused on creating surfaces with ultra-low adhesion, and ultra-high droplet shedding rates. Although fabrication of rapid-shedding surfaces has seen success, theoretical understanding of the forces governing the droplet departure size as a function of wettability and surface inclination and geometry have lagged. Existing analytical based models balancing the gravitational force with the surface force typically overestimate/underestimate the droplet departure size by up to 50%. To better elucidate the droplet shedding process, we experimentally study droplet departure on a variety of functional surfaces for different surface inclinations (15˚-90˚) in ambient conditions. To eliminate the interference of coalescence and inertial effects, we utilize a piezoelectric dispenser to grow singular droplets on the surfaces of interest and observe from the side to characterize their geometries during departure. By obtaining high accuracy experimental characterizations of the departure radius, and knowing the advancing and receding contact angles as well as the surface inclination, we develop both a correlative and physics based modeling framework to accurately predict and better understand droplet departure dynamics. Our work sheds light on the physics of droplet departure and offers a modeling framework to better understand droplet-surface adhesion and the interplay between surface contact line forces and body forces.

Thickness of nano-scale poly(dimethylsiloxane) layers affects the motion of sliding drops

Xiaoteng Zhou,[1] Yongkang Wang,[1,2] Xiaomei Li,[1] Pranav Sudersan,[1] Katrin Amann-Winkel,[1,3] Kaloian Koynov,[1] Yuki Nagata,[1] Rüdiger Berger,[1] Hans-Jürgen Butt[1,*]

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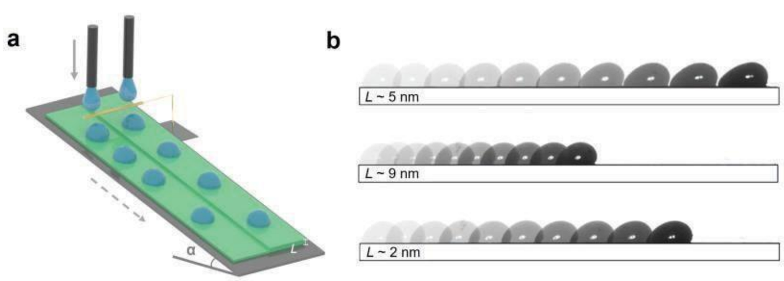
[3] *Institute for Physics, Johannes Gutenberg University Mainz, Staudingerweg 10, 55128 Mainz, Germany.*

ABSTRACT

Nanometer thick layers of polydimethylsiloxane (PDMS) are widely applied as hydrophobic coatings because they are environmentally friendly and chemically inert. In many applications, low friction of water drops is required. While the onset of motion (static friction) has already been studied, dynamic friction is less explored. It is not understood which processes lead to energy dissipation and cause friction. Such knowledge is important to minimize drop friction for applications such as heat exchangers or fog harvesting. Here, we measure dynamic friction of water drops on PDMS layers with different thickness and architecture over the whole available velocity regime. Layer thickness L turned out to be a good predictor for drop friction. 4-5 nm thick PDMS layers showed the lowest dynamic friction. A certain minimal layer thickness seems to be required to form homogeneous surfaces and reduce the attractive interaction between water and the underlying substrate. The increase of friction above L = 4-5 nm is attributed to meniscus formation at the contact line due to the surface tension of water. When the contact line moves, the meniscus is dragged across the surface. Energy is dissipated due to the stretching of chains and viscous dissipation. AFM force and friction experiments support this interpretation. The effect may be enhanced due to an increasing viscosity of the PDMS layer caused by the entanglement of the polymer chains.



Abstract figure. Drop motions vary on nano-scale PDMS coatings with different thicknesses. (a) The scheme to show the setup for observation. (b) The image series of drop moving on these surfaces when titling angle α is 60°.

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4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
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How a macro-ridge suppresses droplet penetration through meshes

Juan Li[1,2], Alexander Oron[2], and Youhua Jiang[1,2*]
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ABSTRACT

Upon the impact of a droplet onto a superhydrophobic mesh, liquid penetration through pores can be observed in both droplet spreading and retraction, and that it occurs easier in the retraction phase, which primarily determines the penetration threshold. It seems to be a common sense that decreasing the mesh pore size is the only way of suppressing liquid penetration. However, this results in a deterioration of mesh breathability, which is undesirable in the cases of face masks and textiles. Here, we demonstrate that a macro-ridge on the mesh surface can suppress liquid penetration by breaking the symmetry of droplet retraction. The force imparted to the mesh pores by the retracting droplet is decentralized because of the droplet splitting. Droplet dynamics and the impact force profiles are measured simultaneously for the impact of droplets onto flat, I-shape ridged, Y-shape ridged, and +- shape ridged substrates, corresponding to the jump-off of one, two, three, and four droplets, respectively. All forces can be predicted by a new scaling model based on the break of flow focusing during droplet retraction.

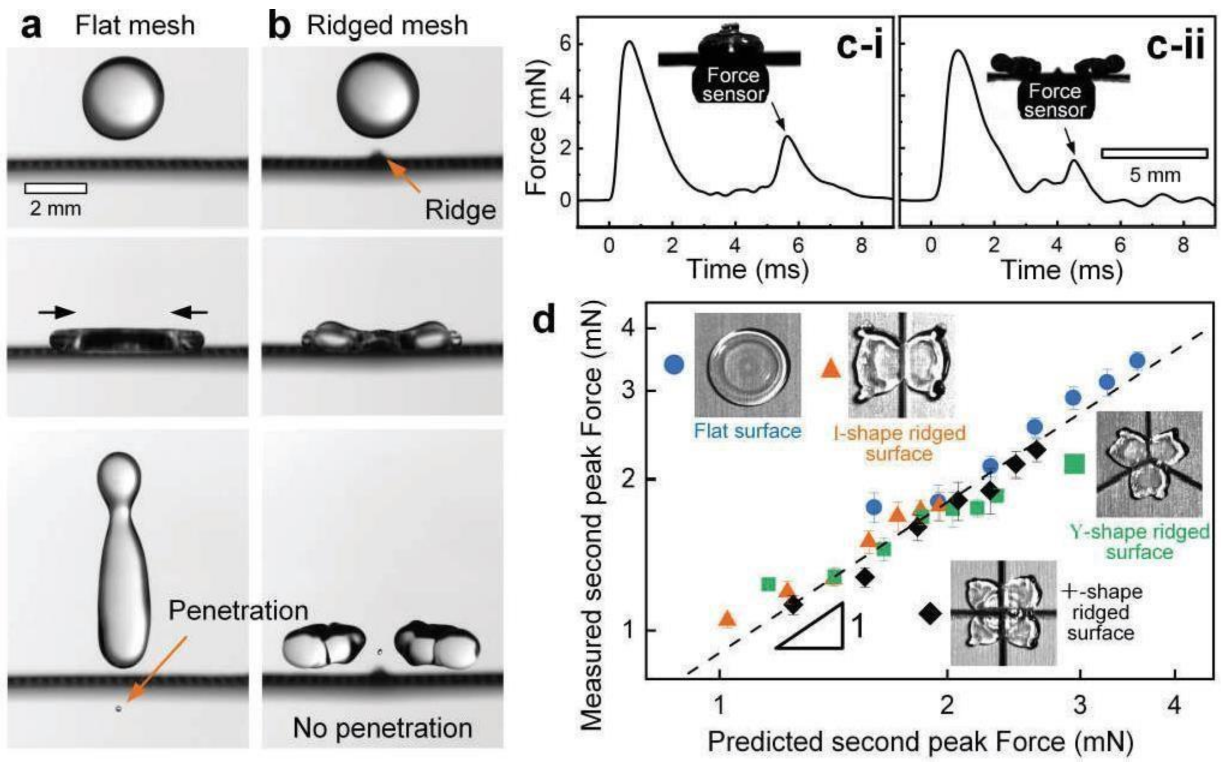

Figure 1. Droplet impact dynamics on (**a**) a flat meshed and (**b**) a ridged meshed substrate. (**c**) Temporal force evolution in the cases of an impacting droplet exerted onto (**i**) a flat and (**ii**) a ridge surface. (**d**) Measured second peak force imparted by an impacting droplet versus its predicted values for a flat surface and various ridged surfaces.

BIOGRAPHY

Prof. Jiang received his M.S. and Ph.D. degrees in Mechanical Engineering from the Stevens Institute of Technology in 2014 and 2018, respectively, followed by the Postdoctoral Training in the Department of Mechanical Engineering at Northwestern University. He joined the Mechanical Engineering Department at Guangdong Technion – Israel Institute of Technology (GTIIT) as the Tenure-Track Assistant Professor in 2020. His research focuses on surface engineering, droplet statics, and droplet dynamics with an emphasis in Smart and Soft Interfacial Phenomena and Mechanics. Prof. Jiang has authored more than 40 peer-reviewed papers mainly at the leading journals in interfacial phenomena, including *PRL*, *APL*, *Langmuir*, *Soft Matter*, *PRFluids*, *ACS AMI*, and *JCIS*. Prof. Jiang also served on the Editorial Board of *Surface Innovations*. Prof. Jiang has been awarded with various grants, including NSFC and Guangdong-NSF, and served as the reviewer for NSFC Young and General projects.

FEMTO-TO-ATTOLITER CHARGED DROPLETS IN COMPLEX GAS FLOWS

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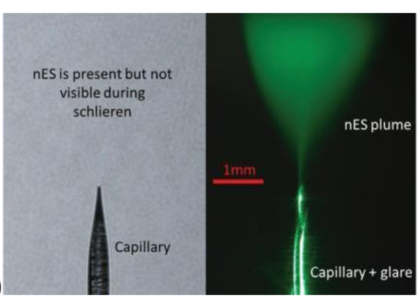
ABSTRACT

Nanoelectrospray (NanoES) generates an aerosol of highly charged, nano-to-micrometer size droplets from a conducting liquid dispersed from a tapered order-of-μm diameter capillary under the influence of an electric field. These droplets accelerate in the applied electric field, disperse due to the electrostatic inter-droplet interactions and charge-induced instabilities and fission, and engage in complex hydrodynamic interactions with the surrounding gas. The main forces acting on the droplets are the viscous drag and inertia. Depending on the hydrodynamic environment (i.e., stagnant or flowing gas), drag could either promote or impede droplet motions and/or result in the change of droplet trajectories. Reciprocally, the motion of droplets could induce motion of a surrounding gas via interfacial momentum transfer. The induced gas jetting has a complex structure with high kinetic energy, tightly confined (within 10s of micrometers) core and active suction of the surrounding gas from behind of the capillary emitter producing NanoES (Fig. 1a). When droplets are exposed to the coaxial vortical gas flow, the interplay between the centripetal motion and viscous drag yields a radially stratified flow separating droplets based on charge-to-mass ratio and size (Fig. 1b). We used the Schlieren flow visualization, ion current measurements, mass spectrometry, and multiphysics simulations to uncover the complex behavior and derive the governing laws for multiphase femto-to-nanoliter charged droplet-gas interactions. This fundamental understanding of gas-assisted NanoES enables development of new device concepts for a range of important applications from evaporative cooling to bioanalytical mass spectrometry to intracellular drug delivery to direct-write nanomanufacturing.

ABSTRACT FIGURE

(a) 

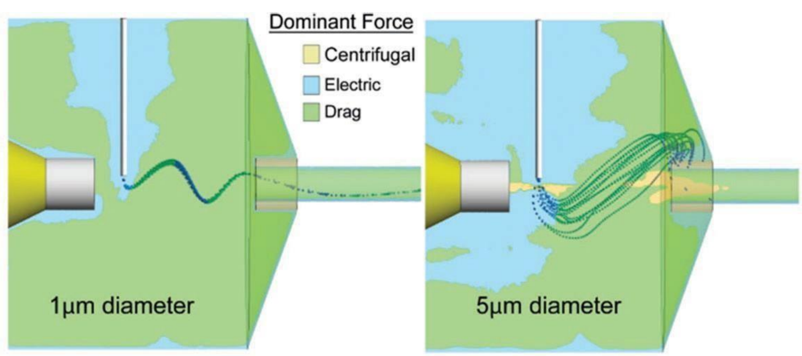
(b) 

Figure 1: Multiphase interactions of femto-to-attoliter charged droplets with surrounding gas. (a) Formation of high kinetic gas jet in stagnant gas [1,2]. (b) Size and charge-to-mass ratio separation in vortical gas flow [3,4].

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[2] Chapman, J. D., Kottke, P. A., and Fedorov, A. G., *Int. J. Multiphase Flow*, **174**, 104760-9 (2024)
[3] Lee, J., Kottke, P. A., and Fedorov A. G., *Phys. Fluids*, **32** (10), 103602 (2020).
[4] Lee, J., Kottke, P. A., and Fedorov A. G., *J. Am. Soc. Mass Spec*., **31** (10), 2073-2085 (2020).

Evaporation of Polymer Sessile Droplets and Formation of Diverse Deposit Structures

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[1]*Multicomponent Fluids group, Southern University of Science and Technology, Shenzhen, China*

ABSTRACT

The evaporation of polymer droplets significantly influences the resulting deposit structure, with wide-ranging applications in inkjet printing, diagnostics, surface coating, and functional material fabrication. Conventionally, sessile droplets of dilute solid suspensions exhibit the well-known "coffee-ring stain" effect, where particles accumulate predominantly at the contact line during the evaporation. However, the dynamic behavior of evaporating polymer droplet on surfaces has received less attention, and the impact of polymer weight on the evaporation dynamics remain unclear. This study focuses on the evaporation of sessile droplets containing dilute soluble polymer additives. Our findings demonstrate that the evaporation conforms to Popov's theory, albeit with noticeable alterations in contact line motion due to polymer additives. By varying the polymer molecular weight across four decades, we observed that drying polymer droplets yield distinct deposits with varied structures, including spherical-caps, upward pillars, and 2D flat films. Confocal microscopy was employed to quantify the morphology of these structures. Additionally, micro-particle image velocimetry (μ-PIV) was utilized to measure the inner flow during deposit pattern formation, revealing the distinct flow patterns corresponding to different deposit morphologies. This research enhances our understanding of the intricate interplay between polymer molecules, droplet evaporation dynamics, and controlled deposition processes.

Non-Contact Fluid-Substrate Effect for Super-Lubricated Transportation

Steven Wang
Department of Mechanical Engineering, City University of Hong Kong

ABSTRACT

The fluid-substrate interaction is ubiquitous in nature and industry, and it serves as a captivating field where scientists of interface significantly intersect, and as well as engineers involved in various disciplines such as coating, transportation, cleaning, 3D printing, advanced manufacturing, find great interests. In this talk, we will discuss about how a non-contact fluid-substrate phenomenon can be harnessed for contamination-free, super-lubricated transportation.

BIOGRAPHY

Prof. Steven Wang is the Associate Vice President (Resources Planning) of City University of Hong Kong and he is also an Associate Professor of Mechanical Engineering. At CityU, Steven's group aims to initiate practical engaged solutions to the real-world issues that combine different disciplines. In particular, we aim to tackle the heat/fluid/energy problems using experimental, computational and theoretical approaches.

Freezing or evaporation: Two fates for droplets during condensation frosting governed by the gradient droplet distribution

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ABSTRACT

The deposition of water vapor onto a subfreezing surface is a thermodynamically spontaneous process, as is the following freezing of the subcooled droplets. Therefore, freezing on the surface is almost inevitable, especially at the edges or defects of the surface where freezing occurs preferentially. Worse yet, frosting on the entire surface is the final fate for most passive anti-icing surfaces due to inter-droplet freezing wave propagation. However, we found that large-scale subcooled droplets can evaporate spontaneously and form a stable frost-free zone during condensation frosting on the macro-ridged surface. Here, we show that a macroscale ridge on the surface changes the spatial distribution of water vapor diffusion flux during the condensation stage, resulting in a gradient arrangement of condensate droplets according to their size. This allows numerous failures of local inter-droplet ice bridging in the area with a critical droplet coverage rate, which triggers the interruption of the global freezing wave propagation and the evaporation of the rest droplets to form a frost-free zone around the ridge corner. Whether the droplets evaporate or freeze depends on the inter-droplet configuration in the area. These findings extend our understanding of frost formation on the surface and provide a rationale for the surface design with impressive durable anti-frosting performance.

ABSTRACT FIGURE

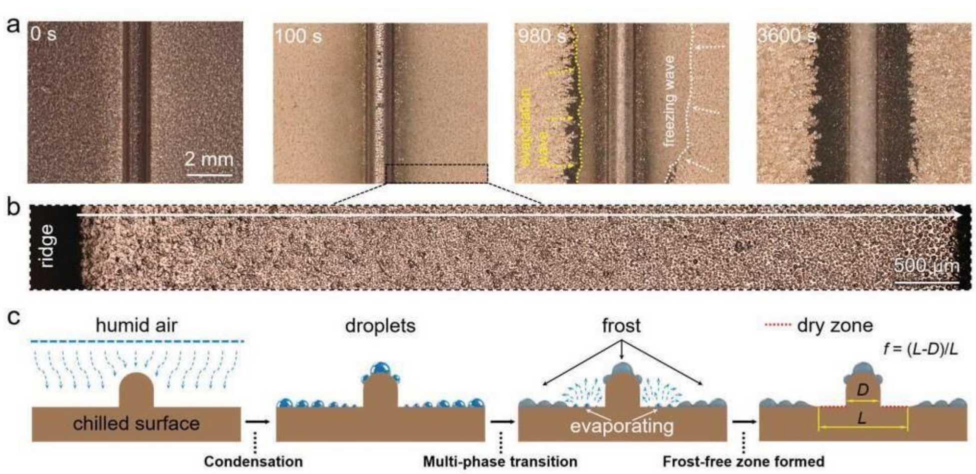

Fig. 1 **a** Condensation frosting on the macro-ridged surface. **b** Gradient distribution of condensate droplets on the macro-ridged surface. **c** Schematic showing the frost-free zone formation.

MASS TRANSPORT MECHANISM IN DROPLET DYNAMICS

Erqiang Li[1]
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ABSTRACT

Droplets exist widely in nature and our daily life. The study of droplet dynamics has been a hot topic in fluid mechanics and is playing an increasingly important role in the interdisciplinary fusion of fluid mechanics and energy, materials, meteorology, life sciences, mathematics, and medicine. In this talk, we will introduce our recent research on drop impact, evaporation, and manipulation, with a focus on the mass transport mechanisms such as diffusion and adsorption behavior in drop evaporation, splashing and air entrainment in drop impact, etc. These problems generally have the characteristics of multiscale, nonlinearity, multi-physical properties, and singularity, making it a challenging task to implement comprehensive studies. By combining high-temporal-spatial resolution experimental measurements and theoretical analysis, we have obtained a unified form of the force between evaporating droplets, and the unified criterion for predicting lamella detachment in drop impact and water entry problems. In the end, we will outlook the potential applications of the above findings in the prevention and control of infectious diseases, drag reduction, etc.

REBOUND SUPPRESSION BY BUBBLE-ENCAPSULATED HOLLOW DROPLETS

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ABSTRACT

Droplet rebound is ubiquitous on super-repellent surfaces. Conversion between kinetic and surface energies suggests that rebound suppression is unachievable due to negligible energy dissipation. We present an effective approach to suppressing rebounds by incorporating bubbles into droplets, even in super-repellent states. This suppression arises from the counteractive capillary effects within bubble-encapsulated hollow droplets. The capillary flows induced by the deformed inner-bubble surface counterbalance those driven by the outer-droplet surface, resulting in a reduction of the effective take-off momentum. We propose a double-spring system with reduced effective elasticity for hollow droplets, wherein the competing springs offer distinct behavior from the classical single-spring model employed for single-phasedroplets. Through experimental, analytical, and numerical validations, we establish a comprehensive and unified understanding of droplet rebound, by which the behavior of single-phase droplets represents the exceptional case of zero bubble volume and can be encompassed within this overarching framework.

BIOGRAPHY

Dr. Pingan Zhu received his Ph.D. degree in Mechanical Engineering from the University of Hong Kong (HKU) in 2017. He is currently an assistant professor in the Department of Mechanical Engineering at the City University of Hong Kong (CityU). Before joining CityU, he worked as a postdoctoral fellow at HKU and Harvard University during 2017-2020. His research interests focus on microscale fluid flows, including microfluidics, wettability, micro/nanorobots, and biomimetics, which aim to address key issues in multidisciplinary fields by combining fundamental and applied studies. He has published more than 40 papers in prestigious journals including *Science*, *Chemical Reviews*, *Nature Communications*, and *Advanced Materials*, 1 book at *Springer Nature*, and 1 filed PCT patent. His work has been recognized by many awards, such as *Lab on a Chip* Outstanding Reviewer, *Micromachines* Young Scientist Award, IAAM Young Scientist Medal, TechConnect Global Innovation Award, and Hong Kong Young Scientist Award (runner-up).

Droplet-droplet collision of hypergolic propellants

Peng ZHANG
Department of Mechanical Engineering, City University of Hong Kong

ABSTRACT

The advances in droplet-droplet collision of hypergolic propellants are important for modeling the real hypergolic impinging-jet (spray) combustion and for the design optimization of orbit-maneuver rocket engines. In this talk, droplet-droplet collision of nonreacting liquids in gases is first summarized in terms of basic phenomena and the corresponding nondimensional parameters. Then, two representative hypergolic bipropellant systems, TMEDA/WFNA and MEA-$NaBH_4$/H_2O_2, are discussed in detail to unveil the rich underlying physics such as liquid-phase reaction, heat transfer, phase change, and gas-phase reaction. The emphasis of the discussion is on quantifying and interpreting the parametric dependence of the gas-phase ignition induced by droplet-droplet collision of liquid hypergolic propellants.

BIOGRAPHY

Dr. Peng Zhang joined the City University of Hong Kong as an associate professor in 2022. Before that, he was an assistant and then associate professor at the Hong Kong Polytechnic University during 2012-2022. He received a Ph.D. degree in Mechanical and Aerospace Engineering from Princeton University in 2010 and worked as a Combustion Energy Research Fellow at Princeton University during 2010-2012. Dr. Zhang's current research areas are droplet and spray dynamics, theoretical and numerical combustion, and theoretical chemical kinetics. He has published more than 100 papers on international peer-reviewed journals in these areas (see https://www.rgcombustion.org/ for details).

Effect of Interfacial Flow on Mass and Energy Transfer in Droplet Evaporation

Fei DUAN

Nanyang Technological University, Singapore

Abstract

Droplet evaporation or phase change is one of comment widely phenomena in advanced manufacturing, thermal management, and the other industrial applications. However, the complex mechanisms at the interfaces are not fully understood so far. The study starts from the interfacial temperature measurement at the evaporating droplet to illustrate the occurrence of surface-tension driven convection at the droplet surface, it is found that the conductive energy cannot maintain the evaporation, the interfacial convective flow can transport up to 40% energy for evaporation. Secondly, the hydrothermal waves are analysis and linked to fluid flow patterns experimentally through the measure particle image velocimetry and thermographic techniques. Lastly, it will be briefly introduced on the diffusion-limited cluster-cluster aggregation model for understanding the depositions from coffee ring, uniform coverage, to disk-ring shape, and the kinetic Monte Carlo model for the branched particle self-assembly during the droplet evaporation. The further study on noncircular wetting and drying of droplets will be also briefly introduced.

Biography

Dr. Fei DUAN is a tenured faculty in School of Mechanical and Aerospace Engineering at Nanyang Technological University (NTU), Singapore. Dr. Duan obtained his Ph.D. degree in University of Toronto, Canada in 2005. Dr. Duan also worked as a visiting scientist in Institute of Fluid Mechanics at Friedrich-Alexander-University, Erlangen-Nuremberg, Germany. The topics of his research cover droplet wetting and evaporation dynamics, Marangoni flow energy transport, particle self-assembly, enhanced thermal management, efficient cogeneration system, etc. In NTU, Dr. Duan has secured over 11 million Singapore dollars on research funding from the governmental agencies and industries as a principal investigator. He has advised over 27 postdoctoral fellows or research associates, 18 Ph.D. students, and 14 Master's students. Dr. Duan has published over 170 peer-reviewed journal papers, 4 patents, 5 book chapters, and 120 conference presentations including 17 plenary lectures and keynotes. He serves as Subject Editor for Applied Thermal Engineering (Elsevier, Impact Factor: 6.4), at Editorial Board for Scientific Reports (Nature Portfolio, Impact Factor: 4.8) and Frontiers in Heat and Mass Transfer (Tech Science); and Editor at Large in Droplet (Wiley).

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

FLOW STRUCTURE AND SPREADING LAW – FROM OIL TO FLASH-EVAPORATING LIQUIDS

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[2] *International Institute for Carbon-Neutral Energy Research (WPI-I²CNER), Kyushu University, Nishi-Ku, Motooka 744, Fukuoka 819-0395, Japan*

[3] *Department of Chemical Engineering, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece*

[4] *Institute of Multiscale Thermofluids, School of Engineering, University of Edinburgh, Edinburgh EH9 3JL, United Kingdom*

ABSTRACT

Wetting presents the basic state when a finite volume of liquid contacts a solid substrate. The requirement for wetting differs for different applications, and hence the design principles. While the spreading of non-volatile droplets is quantitatively understood, the spreading and flow transition in volatile droplets remains elusive due to the complexity added by interfacial phase change and non-equilibrium thermal transport. Here we show, with numerical modelling, trajectory analysis, infrared thermography, and mathematical decomposition, that the wetting dynamics of volatile droplets can be scaled by the spatial-temporal interplay between capillary, evaporation, and thermal Marangoni effects. We elucidate and quantify these complex interactions using phase diagrams based on systematic theoretical and experimental investigations. A spreading law of evaporative droplets is derived by extending Tanner's law (valid for non-volatile liquids) to a full range of liquids with saturation vapor pressure spanning from 10^1 to 10^4 Pa and on substrates with thermal conductivity from 10^{-1} to 10^3 W/m/K. We further derive a universal criterion for the transition of flow pattern near three phase contact line of evaporating droplets, and quantify the spatiotemporal variations of capillary velocity and Marangoni velocity by mathematically decomposing the tangential velocity of interfacial flow. The findings here enable a unifying explanation to a series of individual works including the controversies on flow reversal as well as the state of dynamic wetting, making it possible to control liquid transport and drying patterns in diverse application scenarios.

ABSTRACT FIGURE

Fig. 1 Phase Diagram of Spreading Law

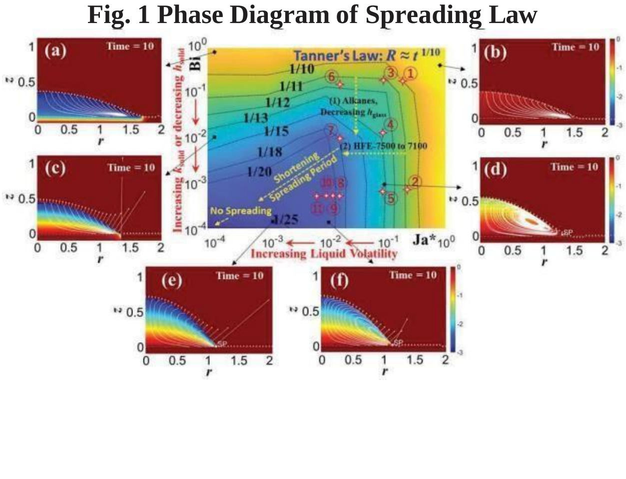
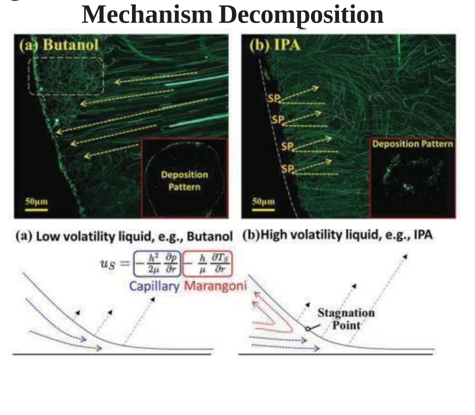


Fig.2 Flow Structure near Contact Line and Mechanism Decomposition



Self-Propelling Multicomponent Droplets and Marangoni Interfacial Flow Induced by Transverse Solute Transfer

Huanshu Tan[1]
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ABSTRACT

Self-propelling multicomponent droplets, comprising two or more chemical species, have attracted considerable attention in recent years. The underlying hydrodynamic processes primarily involve the solutal Marangoni flows, arising from non-uniform distribution of species at the interface and resulting surface tension gradients. In this presentation, we investigate the self-propulsion of suspended multicomponent droplets under a concentration gradient background. Numerical simulation reveal that larger droplets exhibit faster movement, leading to phenomena such as coalescence and separation of differently sized droplets. Furthermore, an increased Marangoni number shifts interface mass transfer from diffusion-dominated to advection-dominated, shedding light on the interplay among Marangoni interfacial flow, compositional fields, and interfacial deformation. We then explore how the transverse solute transfer induce Solutal Marangoni flows through a combination of direct numerical simulation and linear stable analysis. Results indicate that the induced Marangoni flows depend on the viscosity ratio and diffusivity ratio, with interfacial deformation playing an important role in flow stability and pattern oscillation. Based on these insights, we propose four types of instability mechanisms for the Marangoni interfacial flow that inducedby transverse solute transfer. Our findings contribute to a deeper understanding of solutal Marangoni interfacial flow in multicomponent droplet systems.

Enhanced droplet dynamics: Harnessing surface interactions for improved fluid transport

Chonglei Hao
School of Mechanical Engineering and Automation, Harbin Institute of Technology, Shenzhen

ABSTRACT

The dynamics of droplet interactions on various surfaces present intriguing phenomena critical to both natural processes and technological applications including anti-icing, thermal management, self-cleaning surfaces, and beyond. In this presentation, we first introduce mechanisms for rapid water droplet removal on both static and dynamic solid surfaces, as well as liquid interfaces, highlighting the enhanced detachment efficiency afforded by oblique pancake bouncing and rotational shedding dynamics. Further, we briefly discuss the magnetic-field-assisted self-assembly of ferrofluid droplets on superhydrophobic surfaces which advances our understanding of their dynamic reconfigurability under varying conditions. Lastly, this talk will introduce preliminary findings on droplet wetting behaviors on liquid metal interfaces, with implications for enhanced phase change heat transfer—an exciting frontier in thermal management. Collectively, these studies not only refine our understanding of fluid transport mechanisms but also open up versatile applications ranging from advanced cooling systems to enhanced fluidic devices.

BIOGRAPHY

Dr. Chonglei Hao is currently an associate professor at Harbin Institute of Technology, Shenzhen. He received his B.E. degree in electronic engineering from Shandong University. In 2011, he joined Prof. Zuankai Wang's group and received his Ph.D. degree in mechanical engineering from City University of Hong Kong. His research interesting include bio-inspired functional surfaces, micro/nano fabrication, interfacial fluid transport, and its applications in anti-icing, energy harvesting, and phase change heat transfer. He is a member of Chinese Mechanical Engineering Society (CMES), Materials Research Society (MRS) and International Society of Bionic Engineering (ISBE).

How a Salty Droplet Freezes and Sprouts Ice Crystals From Its Top

Fuqiang Chu[1], Yanhui Feng[1], Xiaomin Wu[2], Xiao Yan[3], and Nenad Miljkovic[4]
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[2]*Department of Energy and Power Engineering, Tsinghua University, Beijing 100084, China*
[3]*Institute of Engineering Thermophysics, Chongqing University, Chongqing 400030, China*
[4]*Department of Mechanical Science and Engineering, University of Illinois at Urbana–Champaign, Urbana, IL 61801, USA*

ABSTRACT

Icing of seawater droplets is capable of causing catastrophic damage to vessels, buildings, and human life, yet it also holds great potential for enhancing applications such as droplet-based freeze desalination and anti-icing of sea sprays. While large-scale sea ice growth has been investigated for decades, the icing features of small salty droplets remain poorly understood. Here, we demonstrate that salty droplet icing is governed by salt rejection-accompanied ice crystal growth, resulting in freezing dynamics different from pure water. Aided by the observation of brine films emerging on top of frozen salty droplets, we propose a universal definition of freezing duration to quantify the icing rate of droplets having varying salt concentrations. Furthermore, we show that the morphology of frozen salty droplets is governed by ice crystals that sprout from the bottom of the brine film. These crystals grow until they pierce the free interface, which we term ice sprouting. We reveal that ice sprouting is controlled by condensation at the brine film free interface, a mechanism validated through molecular dynamics simulations. Our findings shed light on the distinct physics that govern salty droplet icing, knowledge that is essential for the development of related technologies.

ABSTRACT FIGURE (OPTIONAL)

I want to be considered for a poster only.

Droplet impact regulation via liquid properties control and fin-stripe structure

Xing Han[1], Xin Tang[2], Jiaqian Li[3], Wei Li[4], Haibo Zhao[4], Ling Yang[4],and Liqiu Wang[5]

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[2] *Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology, Shenzhen, China*
[3] *School of Energy and Power Engineering, Shandong University, Jinan, China*
[4] *Department of Mechanical Engineering, The University of Hong Kong, Hong Kong, China*
[5] *Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hong Kong, China.*

Droplet impact is a ubiquitous phenomenon in nature, daily life, and industrial processes. It is thus crucial to tune the impact outcomes for various applications[1, 2]. In this seminar, I will introduce a liquid deposition method[3] via simply overlaying impacting droplets with a tiny amount of lubricant (less than 0.1 vol% of the droplet). Their interfacial properties are modified in such a way that damper-roller support is attached to the mass-spring system. The overlayers suppress the out-of-plane rebounds by slowing the departing droplets through viscous dissipation and sustain the droplets' in- plane mobility through self- lubrication, a preferential state for scenarios such as shedding of liquid in spray cooling and repositioning of droplets in printing. The footprint of the method can be made to be minimal, circumventing surface contamination and toxification.

Next, I will introduce the spatio-temporal maneuvering of impacting droplets[4]. Efforts have been made to solely spatially control the drop movement after the impact or solely temporally reduce liquid-solid contact by surface design. However, surfaces that can achieve these two aims at the same time are rare. We thus present a fin-stripe nonwetting surface that enables spatial offset maximization and temporal contact minimization simultaneously, just via structure design without the need for external energies. The normalized directional lateral movement distance on the fin-stripe nonwetting surface is an order of magnitude larger than the reported values in the literature. The contact time between the impacting drop and the surface is reduced by ~30%. The surface can be scaled up readily by fabricating the fin- stripe structure periodically on a nonwetting surface.

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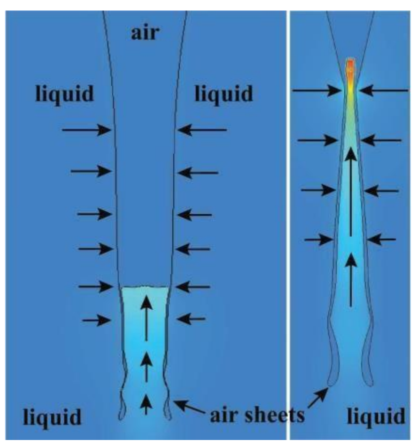
MECHANISM OF SINGULAR JETTING FROM DROP-IMPACT CRATERS

Yuansi Tian[1], Ziqiang Yang[2], Sigurdur T. Thoroddsen[2] and Erqiang Li[1]
[1]University of Science and Technology of China, China and
[2]King Abdullah University of Science and Technology, Saudi Arabia

ABSTRACT

Singular jets can emanate from the collapsing of drop-impact craters, or when a bubble bursts at the free surface. This jet is one of the sources of aerosols and condensation nuclei by raindrops hitting the ocean surface, which is of great importance to precipitation and the global water cycle. However, the dynamics of singular jets controlled by pure inertial or capillary-inertial force are still ambiguous. By using a high-speed imaging system, we find that the fastest singular jets are generated when a small dimple forms at the crater's bottom and contracts without pinching off a small bubble. The collapse of the dimple is controlled by pure inertial force. The most singular jets has a maximum velocity of 137±4 ms^{-1} and a diameter of 12 μm under reduced ambient pressures. A new mechanism for singular jet emergence is revealed by high-resolution numerical simulations, where a thin air sheet provides an effective slip at the outer boundary of the conically converging flow into the jet. This scenario bypasses any viscous cut-off of the jetting velocity and explains the extreme sensitivity of the critical impact condition for singular jets.

ABSTRACT FIGURE



SINGULAR JETS PRODUCED DURING THE IMPACT OF COMPOUND DROPLETS ON LYOPHILIC SURFACES

Jianwei Guo
School of Mechanics and Aerospace Engineering, Southwest Jiaotong University

ABSTRACT
An important phenomenon produced during the impingement of drops upon solid surfaces is the formation of singular jet, which is often followed by the pinch-off of satellite droplets. Great efforts have been made to investigate the jetting dynamics of low-viscosity single-phase drops impact upon sufficiently lyophobic surfaces. However, whether such singular jets can be produced during the impact of compound drops and how the liquid properties and surface wettabilities affect the dynamics have remained largely unexplored. Herein, we perform comparative and systematic experiments on the impact dynamics of single-phase water and silicon oil drops, as well as water-in-oil compound drops on lyophilic substrates. We show that singular jets only occur during the impact of compound drops. The critical values in terms of Weber number depend on both the viscosity of the silicon oil and the volume ratio of the two liquids composing the compound drops. We also show that the singular jets break up and throw out satellite droplets only when they are considerably fast and thin. Power-law correlations between the jet velocities and the jet radii, between the jet neck radius and time, and between the maximum jet height and the jetting time, are obtained. A linear correlation between the radii of the jet droplets and those of the singular jets are also found and analyzed.

BIOGRAPHY
Jianwei Guo is an associate professor working at Southwest Jiaotong University. She got her PhD degree from University of Toulouse, France. Her main research interest focuses on the impact dynamics of single-phase and compound droplets. She studies the maximum spreading, jetting and splashing phenomena combining both experimental and numerical methods. She published her woks in the leading journals such as Journal of Computational Physics, Physics of Fluids and Applied Physics Letters.

Dynamics of impinging droplets on superhydrophobic surfaces: rebound behaviors and singular jets

Longquan Chen

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ABSTRACT

The impact of liquid droplets on superhydrophobic surfaces frequently happen in nature and also in a number of industrial processes, given the wide application of superhydrophobic coatings. As a direct consequence, strenuous research efforts were devoted to exploring the underlying hydrodynamics of impinging droplets on superhydrophobic surfaces, and an abundant amount of new phenomena have been identified. In this talk, we introduce droplet impact dynamics on superhydrophobic surfaces from two perspectives: 1) the effects of the liquid-solid friction on droplet rebound behaviors; 2) jet dynamics in droplet impact and its applications.

BIOGRAPHY

Longquan Chen is currently a full professor in School of Physics at University of Electronic Science and Technology of China (UESTC). He received his BSc from Chongqing University (2007), MPhil from Hong Kong University of Science and Technology (2009), and Dr.-Ing. from the Technische Universität Darmstadt (2013). Prof. Chen is mainly engaged in research of soft matter physics, interfacial fluids, nanomechanics and functional interfacial materials and devices. He has published over 80 peer-reviewed articles in international journals including Physical Review Letters, Nano Letters, Advanced Science, and Physics of Fluids, with more than 4300 citations (H-index 29, google scholar).

Bioinspired multifunctional hydrogels for human-machine interactions

Ye Tian
Technical Institute of Physics and Chemistry, Chinese Academy of Sciences

Inspired by nature,we developed multifunctional hydrogels with tunable mechanical properties, good sensing properties and/or unique actuation. The hydrogels can not only monitor daily physiological activities, but also be used for complex activities underwater and message encryption/decryption. We also used them to create a complete finger joint rehabilitation system with an interactive interface that dynamically presents the user's health status, multi-gradient intelligent control and finger muscle condition evaluation, achieving real-time human- computer interaction (HCI). Our bioinspired multifunctional hydrogels will have a profound impact on the future of new rehabilitation medical, human– machine interaction, VR/AR and the metaverse fields.

Explore Wetting Dynamics at Micro and Nano Scales by Long-Needle AFM

Dongshi Guan[1,2] , Penger Tong[3]

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ABSTRACT

Contact line pinning and the corresponding contact angle hysteresis (CAH) are important interfacial phenomena that occur in nature and play a significant role in many industrial processes, such as surface coating, ink-jet printing, and immersion lithography. Traditional optical methods face limitations due to the optical diffraction limit, making it difficult to directly measure flow and interface phenomena at the micro- or nanoscale. However, atomic force microscopy (AFM) offers a solution by enabling precise manipulation and force measurements at micro and nano scales. The AFM-based microrheometer, which is assembled with a long-needle probe, can be used to study the dynamics of the gas-liquid-solid three-phase contact line and the micro- and nanoscale flow near the non-ideal fluid-solid interface. In this presentation, we will review the experimental principles and methods of long-needle AFM, along with its latest progress in the study of wetting dynamics at micro- and nanoscale [1-4]. This experimental method provides reliable data for testing various theoretical models and numerical simulations. The application of this technology in emerging fields may inspire us to explore the physical nature of complex phenomena at interfaces.

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BIOGRAPHY

Dr. Dongshi GUAN is a Professor of Institute of Mechanics at Chinese Academy of Sciences and a Professor of School of Engineering Science at University of Chinese Academy of Sciences. He received his PhD in Physics from Hong Kong University of Science and Technology (HKUST) in 2016. During 2014-2015, Guan was a Visiting Scholar at the Laboratoire Interdisciplinaire de Physique in Grenoble, France. After graduation, he served as a Postdoctoral Fellow in the Department of Physics at HKUST, and subsequently became a Research Assistant Professor and was honored with IAS Junior Fellow in 2017. After joining Institute of Mechanics in 2019, his research group has focused on experimental investigation of micro- and nano-scale liquids at interfaces in soft and living matter systems, such as dynamics of moving contact line, mechanism of phase-separatedprotein condensates, and mechanical properties and active behavior of living cells and tissues.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

COALESCENCE DYNAMICS OF MICRODROPLETS AND PARTIALLY FILLED MICROGROOVES

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[1] *Thermofluidics Research Laboratory, Department of Mechanical Engineering, Indian Institute of Technology, Ropar, Punjab, India*

Water vapor condensation on a hydrophobic surface with microgrooves, enhances the dropwise condensation efficiency through long-range coalescence when the ridge microdroplets of size (D) combine with the microgrooves (height (H) and width (W)) partially filled with condensate. We utilize an experimentally validated, three-dimensional, volume of fluid numerical modeling framework, combined with dynamic contact angle model, to study such a coalescence process. As the condensate wets the microgroove, it forms a liquid column with a meniscus pinned to the microgroove edges. The coalescence of ridge droplets with this pinned meniscus triggers capillary ripples propagating across the microgroove in both transverse and longitudinal directions, which can induce the depinning of the contact line from the opposing edge. The size of the coalescing droplet is non-dimensionalised as $(\frac{D}{W})$. The numerical results reveal that the contact line depins during the coalescence of droplets of size $(\frac{D}{W}) \geq 1$, at the instant of depinning, the local contact angle at the opposing edge reaches approximately ~180°, coinciding with the maximum conversion of available excess surface energy to kinetic energy. Fig.1. shows a time series of images illustrating the evolution of the coalescence process for a droplet $(\frac{D}{W}) = 1.5$. Furthermore, we observed that the overall coalescence process is significantly affected by the aspect ratio of the microgroove. For relatively shallower microgrooves imbibed with the same liquid volume as the deeper microgrooves, the meniscus is not pinned to the microgroove edges prior to coalescence due to which the overall coalescence process is similar to droplet coalescence over the planar surface.

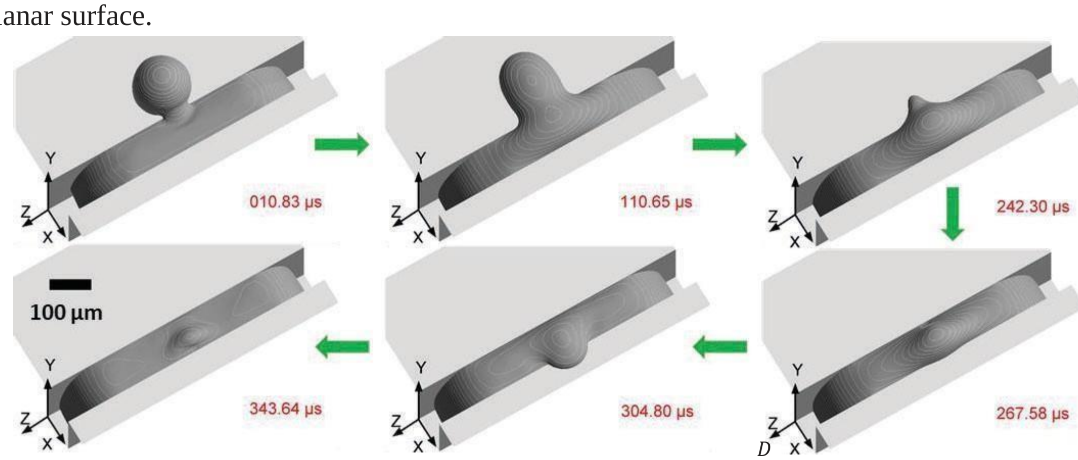

Figure 1. Evolution of liquid-vapor interface during coalescence of a $(\frac{D}{W}) = 1.5$ droplet and a partially filled hydrophobic microgroove (H = 200 μm, W = 100 μm). The coalescence sequence is indicated by the green arrow. It is evident that during coalescence the initially pinned meniscus at the edges of the microgroove remains pinned till ~ 242 μs. Subsequently, the meniscus gets depinned at the opposing edge, and the droplet fully coalesces with the microgroove at ~ 268 μs. The depinned meniscus advances over the ridge till ~ 305 μs, retracts, and ultimately gets repinned at the opposing edge at ~ 344 μs.

Nanotextures-mediated droplet splash on hot surfaces

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[2] *Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hong Kong 999077, China*

ABSTRACT

Upon contact with hot surfaces, the hydrodynamic behaviors of droplets can be substantially altered, thus giving rise to abundant fascinating phenomena. Despite extensive progress, droplet splash dynamics on hot surfaces, which underpin various industrial applications, has been less explored. Here we report the splashing patterns of ethanol droplets on hot surfaces with different roughness. We observe that splash can be greatly suppressed by increasing substrate temperature T on smooth surfaces; however, on rough surfaces, splash appears to be unaffected with changes in T. This temperature dependence divergence is attributed to different air drainage capacities, leading to distinct flow instabilities. We make theoretical predictions to describe the impact of temperature on splash dictated by surface morphologies, and propose a criterion to identify the surface roughness thresholds governing different temperature dependencies by comparing the timescales of air evacuation and flow instabilities.

BIOGRAPHY

Ran Tao received her B.S. degree from Chongqing University and earned her M.S. and Ph.D. from the Hong Kong University of Science and Technology under the supervision of Prof. Zhigang Li. Following her studies, she worked as a postdoctoral fellow at City University of Hong Kong and The Hong Kong Polytechnic University under the supervision of Prof. Zuankai Wang. Currently, she serves as an associate professor in School of Physics, the University of Electronic Science and Technology of China in Prof. Longquan Chen's group. Her research interests encompass micro-/nano-scale fluid dynamics, dropletdynamics, interfacial heat transfer, and transport phenomena.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

THE GLUGGING PHENOMENA OF A GLUGGLE JUG

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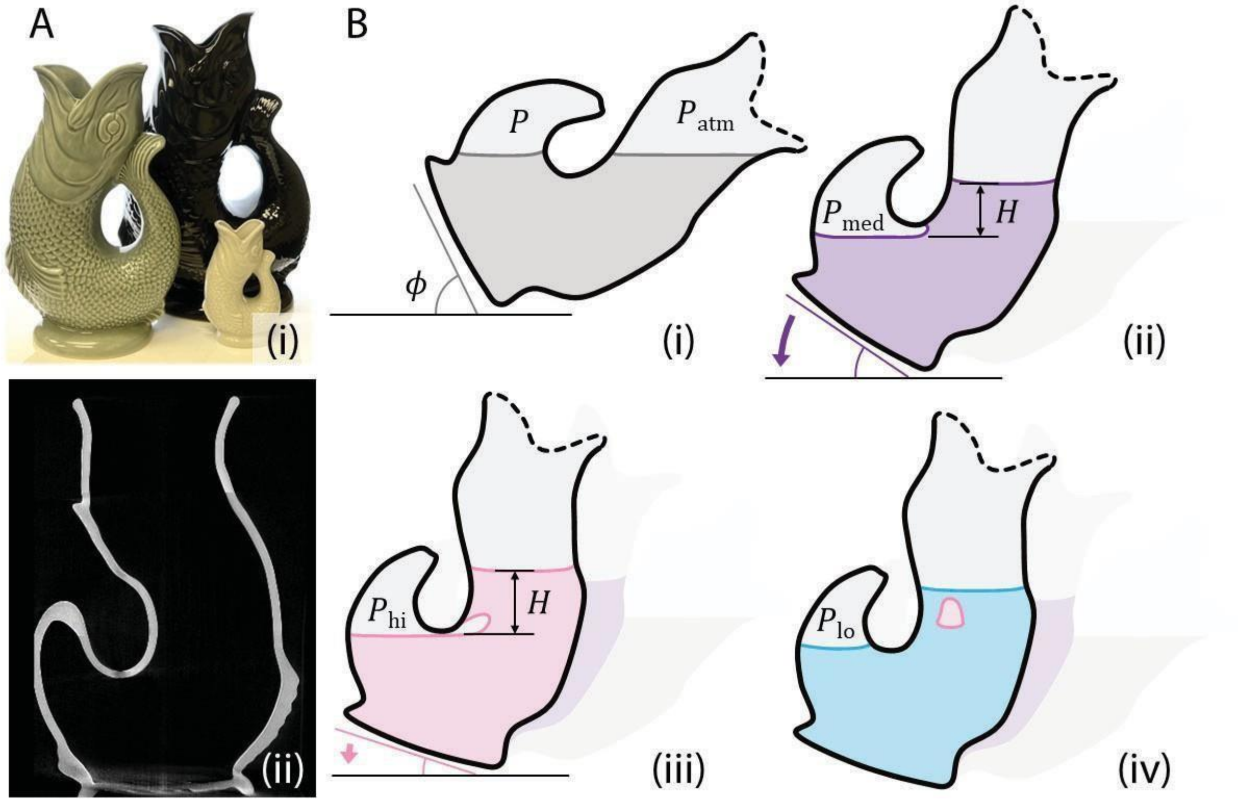
[1]Department of Mechanical Engineering, Rice University, Houston, TX, USA

ABSTRACT

The gluggle jug is a commercially available fish-shaped ceramic pitcher that, when tipped upright while holding liquid, will exert sounds resembling “glugs.” As the jug is tipped, pressure differences form between the closed air reservoir in the caudal fin and the open-to-atmosphere reservoir in the mouth of the jug. To balance the pressures, the closed reservoir’s liquid-air interface expands along the cusp that separates the reservoirs. Eventually the interface travels beyond the cusp far enough tohydrodynamically proceed and cause a sudden pinch-off, resulting in the interface snapping back to an equilibrated position with enough force to cause a glugging sound. We analyzed the profile of the interface as it travels around a given geometry, and we demonstrated that physically generalized gluggle jugs empirically match our theory. Across variously sized cusps, we observed distinct angles at which the gravitational potential reaches a local maximum and it becomes energetically favorable for the bubble to hydrodynamically proceed beyond the cusp. We found the rate with which glugs occur as it depends on geometry and other fluidic parameters, and we also determined the dependencies of the magnitude and pitch of the resulting gluggle sounds, which are also influenced by fluidic parameters as well as the height of the walls relative to the open reservoir’s interface. Arising from our understanding of the jug’s fluidic interactions, we created a full octave of notes that may be produced at variable rates, unlocking the full audio potential ofthe gluggle jug.

ABSTRACT FIGURE



Abstract Figure. (A) Images of the ceramic gluggle jugs with three commercially available sizes (i) and a computed tomographical (CT) scan of the medial plane (ii). (B) The tipping back, or righting, of the jug produces a positive differential pressure in the closed reservoir relative to the open reservoir (i-ii), as conducted in experiments. Eventually the pressure difference is large enough to force the bubble to proceed around the cusp to the pinch-off point (iii). At pinch-off, the closed reservoir's interface snap backs creating the glugging sound (iv).

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Experimental study on contact electrification near a three-phase contact line using Kelvin probe force microscopy

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ABSTRACT

The electrification caused by the contact of different phases is attracting increased attention because of its widespread relationship with a variety of fields. In recent, it has been revealed that electric charge near the three-phase contact line (TPCL) strongly affects dynamic wetting, which would be a new way to control fluids. However, the underlying physics of contact electrification remains elusive. Especially, the details of charging near TPCL are still poorly understood. In this study, we experimentally investigate contact electrification near the TPCL using Kelvin probe force microscopy (KPFM). Specifically, the surface potentials were measured at the same location before and after the TPCL was withdrawn. It was found that the potentials nanoscopically distribute only near the TPCL, and that the steepness of change in potential distribution varies with the type of liquids, suggesting its relationship with the Debye length. Our insights will shed light on the behavior of the electrons near the TPCL.

Research on double layer multiple liquid columns formation based on spatial electric field distribution

Shangru Zhou[1,2], Yan Ye[1,2], Kun Li[1], Chi Liu[1], Wanrong Wang[1], Hui Wang[1], Jiawang Wang[1], Gaofeng Zhang[1]*

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[2] *Hunan Engineering Research Center of Research and Development of Degradable Materials and Molding Technology, Changsha University, Changsha,410022, China*

ABSTRACT

This study utilized microfluidic technology to investigate the formation of polymer dielectric liquid columns and their directional flow phenomena, which holds significant practical value. By adjusting the spatial electric field, successful growth of liquid columns was achieved upwards, and by adjusting the spatial distribution of the electric field, multiple liquid columns were formed and manipulated in the vertical direction. The research involved constructing an adjustable electric field space using three parallel electrodes connected to a high-voltage DC power supply in a spatially perpendicular arrangement. By adjusting the shape of the upper electrode and the power supply parameters to alter the region's electric field distribution, the polymer liquid on the lower and middle electrodes was driven to form liquid columns at various positions. The results demonstrate that by dynamically controlling the spatial distribution of the electric field, the formation of dielectric liquid columns can be achieved. Furthermore, by adjusting the conductivity state of the conductive region, the movement of liquid columns can also be driven. This research outcome is expected to find applications in areas such as bipolar thermal switches, localized heating, and temperature control.

Keywords: Space electric field; Microfluidic technology; Dielectric fluid; Fluid movement

ABSTRACT FIGURE

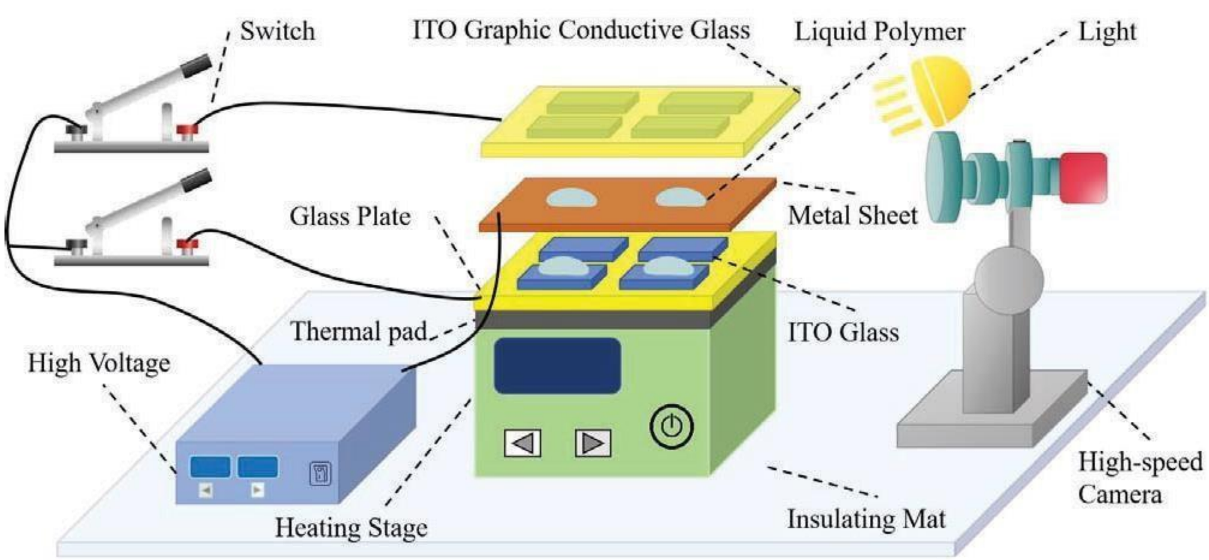

Fig. 1. Schematic diagram of experimental setup.

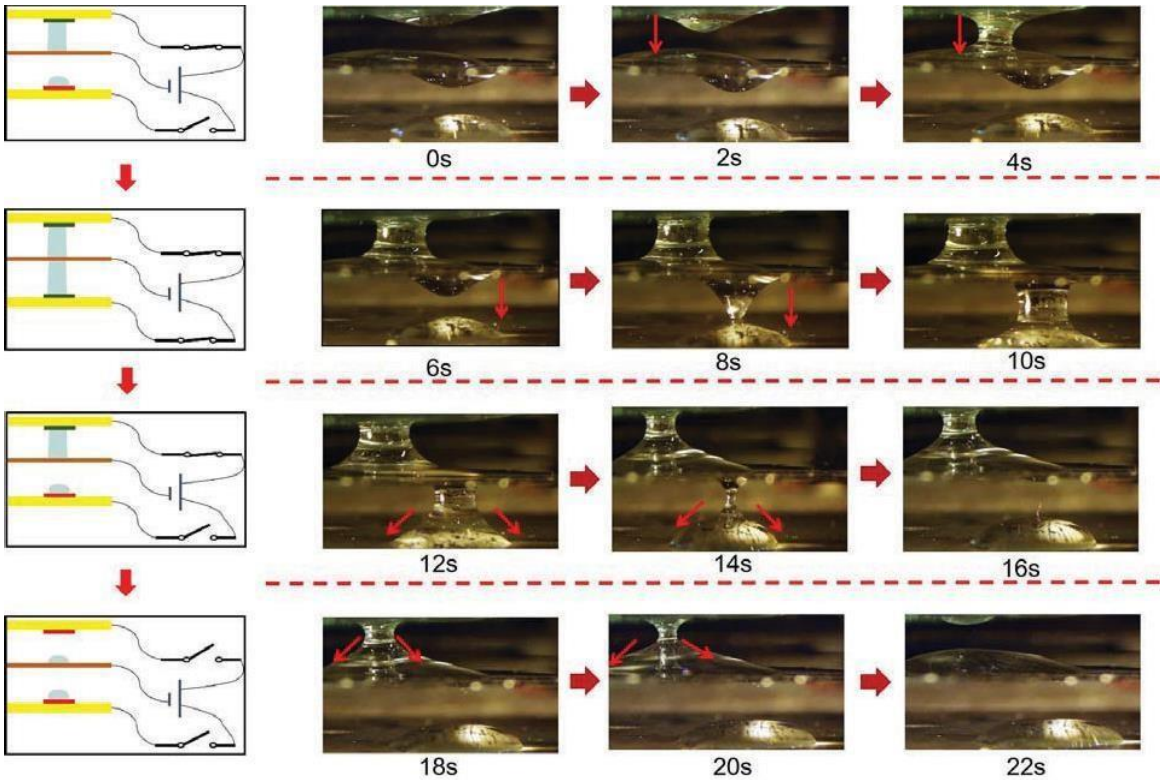

Fig. 2. Liquid column formation process driven by vertical double-layer electric field distribution

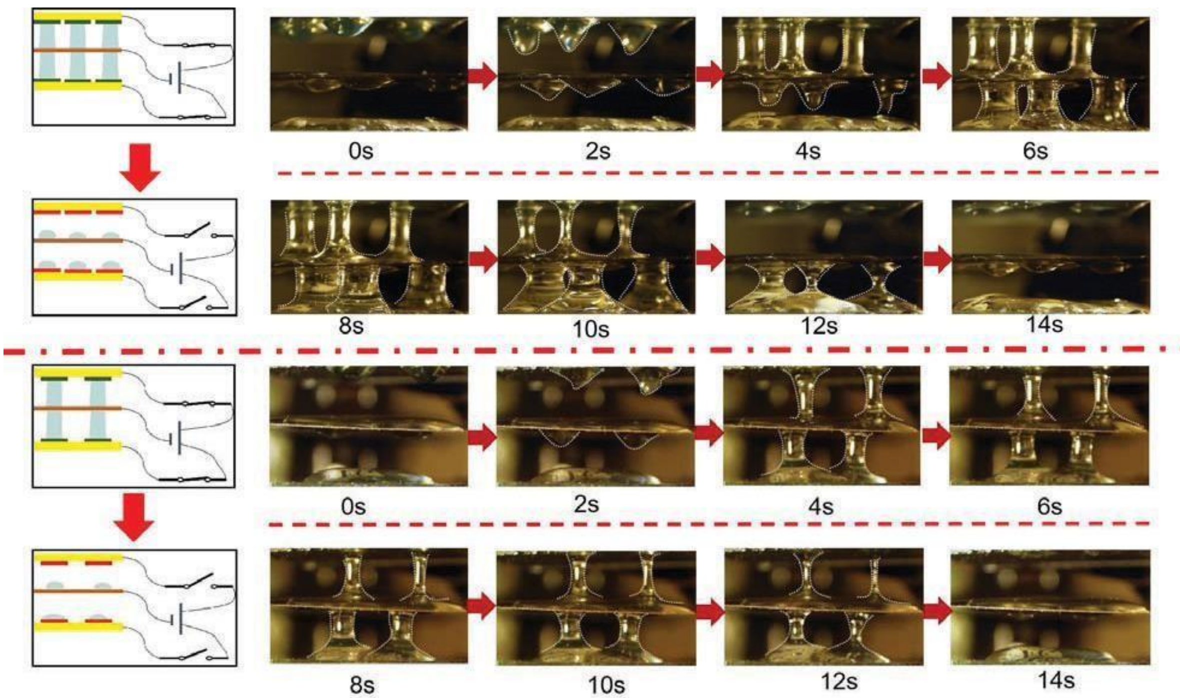

Fig. 3. The formation process of multiple liquid columns driven by vertical double-layer electric field distribution

Conclusion

1) The double layer space electric field can drive the dielectric liquid to form double layer liquid column.
2) By adjusting the conduction state of the conductive region, the movement of the liquid column can be driven.

EFFICIENT DROPLET TRANSPORT ON SUPERWETTING SURFACES

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ABSTRACT

Regulating droplet motion on structured surfaces is essential to various applications, ranging from thermal management to microfluidics and water harvesting. However, research in this fiend is still in the rough. For instance, there exists a theoretical contact time limit which is imposed by the classical hydrodynamics and the controllable droplet manipulation remains challenging in terms of response and functional adaptability. In this talk, I will briefly discuss our recent efforts to these puzzles[1-5]. Several droplet bouncing mechanisms were proposed to reduce the contact between impinging droplets and the underlying solid surfaces, and various droplet maneuvering approaches by leveraging external stimuli have been explored to realize the goals. We believe the research which can achieve enhanced droplet transportation will stimulate new applications.

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BIOGRAPHY

Dr. Yahua Liu is a Professor in the School of Mechanical Engineering at Dalian University of Technology. He received his Ph.D. degree in mechanical engineering from the City University of Hong Kong, China, in 2015. His research interests center on the interfaces between engineering and materials, with an emphasis on the rational design and development of novel materials and devices for multifunctional applications using a nature-inspired approach. He has published more than 50 articles in prestigious journals such as Science, Nature Physics, PRL, Science Advances and Nature Communications.

Title: Furcated Droplet Self-Propulsion on Crystalline Surfaces

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[2] *Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology*

The directed, long-range self-propulsion of fluids on solid surfaces is fundamental to biological/chemical analysis, thermal management, desalination, water harvest, and numerous other fields. Asymmetries such as chemical/charge inhomogeneity and topological anisotropy are conventionally pre-patterned on target surfaces to break the symmetry of contact lines, enabling transport of droplets along well-defined directions[1,2]. If no asymmetry or external force is provided, droplets propel isotropically, a situation observed for self-propulsion of small Leidenfrost droplets on hot and smooth surfaces (~200 ˚C)[3]. When we liberate a cold droplet (~7 ˚C) on a lubricated piezoelectric crystal (lithium niobate) at ambient temperature, the droplet instantaneously propels for a long distance (~50 times of droplet size). Unlike the Leidenfrost droplet which moves towards random direction, the motions of droplets on the crystal are furcated. Depending on the crystal plane that interfaces with the droplets, the self-propulsion can be unidirectional, bifurcated, and even trifurcated. In the absence of any macro-/micro-asymmetry, the intrinsically orientated liquid motion originates in the anisotropy of crystal structure that occurs at a scale seven orders of magnitude lower than the droplet size. This surprising furcated self-propulsion comes from a unique cross-scale multi- physical interaction, thermoelastic-piezoelectric coupling, enables an innovative way to delivery and transport liquids.

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BOUNCING WATER DROPLETS ON CURVED SOAP FILMS

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ABSTRACT

In this study, we report systematical investigation of drop impact dynamics on curved soap films using a high speed camera. The combined effect of substrate curvature and impact velocity on the impact behavior was explored. Three impact behavior regimes were observed: bouncing, passing and bubble bursting. The droplet bounced from the soap bubble at low impact velocity. At high impact velocities, we discovered two regimes by varying the curvature of the soap film. The water droplet passed through the soap film at low curvature while the soap film burst as the curvature was less than a critical value. For each regime, a theoretical model was proposed to predict the critical condition. In the bouncing regime, new bouncing mechanisms dependent on surface flexibility was found, which was different from the droplet bouncing on other substrates.

Dynamics of Successively Bouncing Droplets on Superhydrophobic Surfaces

Yile Wang[1], Yakang Jin[1], Longquan Chen*[1]
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ABSTRACT
The rebound behaviors of liquid droplets after impact on superhydrophobic surfaces are of significant importance in various research fields, and thus have been investigated for over 150 years; yet, the underlying dynamic mechanism isn't still fully understood. In this study, we experimentally investigate the rebound of impinging water droplets on flat superhydrophobic surfaces. It was found that water droplets undergo multiple rebounds before eventually coming to rest (Fig. 1a), when the kinetic energy is completely dissipated. To quantify the amount of energy lost in droplet impact, the restitution coefficient (ε) of bouncing droplets was examined. Our results demonstrate a nonmonotonic relationship between the restitution coefficient and the impact Weber number ($\mathrm{W}e$) (Fig. 1b). Whereas ε exhibits an increasing tend at $\mathrm{W}e < 0.2$, above which it begins to decrease. Based on scaling analyses of all dissipative energy terms involved in impact dynamics, we found that the bouncing behaviors at low Weber numbers are governed by the droplet-surface friction , while the viscous dissipation within the shearing boundary layer would become dominant at high Weber numbers. We propose a semi-empirical formula that not only describes the relationship between the restitution coefficient and the Weber number, but also can fairly predict the total number of droplet rebounds. These findings have broad implications for design superhydrophobic surfaces and manipulation of droplet dynamics on them.

ABSTRACT FIGURE (OPTIONAL)

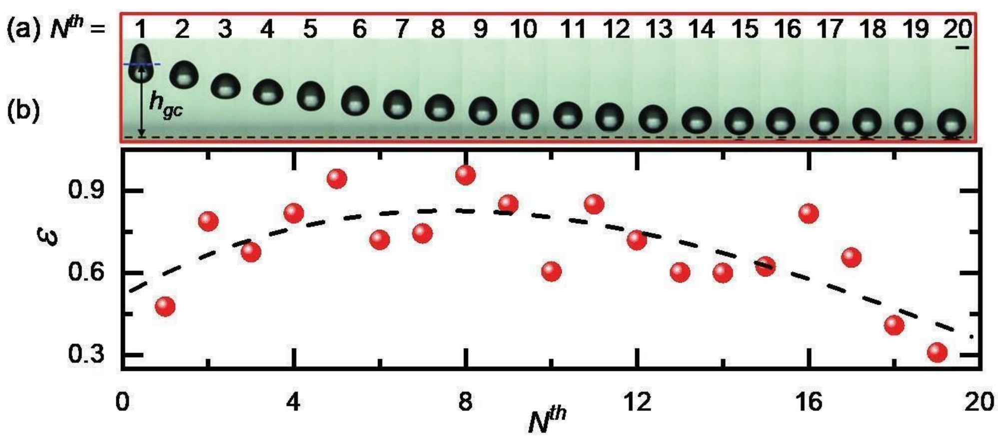

Figure 1. (a) Snapshots of an impinging water droplet with $R_0 \approx 1.0$ mm at $V_I \approx 0.41$ m/s and $\mathrm{W}e \approx 2.3$. The scale bar is 1.0 mm. (b) The restitution coefficient ε as a function of the N^{th} number of rebound for the bouncing droplet in (a). The black dashed line is guide to the eyes.

OBLIQUE DROPLET IMPACT ON SUPERHYDROPHOBIC SURFACES

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ABSTRACT

Over the past decades, superhydrophobic surfaces have gained considerable attention due to their promising applications, and so does the droplet impact dynamics occurring on them. In particular, strenuous efforts have been devoted to investigating the short-time impact (with a timescale of a few tens of milliseconds) of liquid droplets perpendicular to superhydrophobic surfaces, and exploring strategies to regulate their dynamic behaviors. In this work, we perform an experimental investigation on oblique droplet impacts on superhydrophobic surfaces at a timescale up to sub-seconds, which is frequently encountered in a plenty of application scenarios, but received much less attention so far. As illustrated in Fig. 1, after release the droplet would impact and rebound from the inclined superhydrophobic surface for many times, accompanying with the downward sliding (on the surface) and jumping (in the air) motions. We will characterize these impact characteristics and uncover the underlying dynamics.

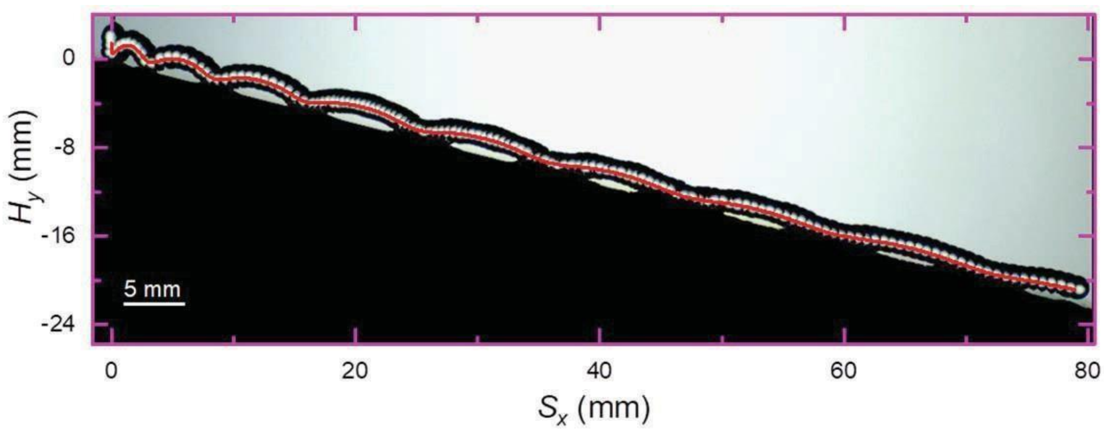


Fig. 1 A typical trajectory of an impinging water droplet on an inclined superhydrophobic surface.

PRECISION PROCESSING OF MICRO/NANO-LITER FLUIDS

Liqiu Wang
Department of Mechanical Engineering
The Hong Kong Polytechnic University

ABSTRACT

Precision manipulation of various liquids is essential in many fields, including DNA analysis, proteomics, cell assay and clinical diagnosis, chemical synthesis, and drug discovery. Their divisible, sticky, and sometime infectious features impose, however, great challenges on processing them, particularly when their volume is down to nano-/subnano-liter. A blood droplet from an Ebola patient can for example infect medical workers through the skin. For diagnosis, medial workers have to crash, filter, and purify a patient's blood sample to obtain the virus's genetic materials. This series of operations, very often in a fluidic medium, is highly infectious. Moreover, fluids stick to surfaces, which will contaminate containers and handling tools, causing potential dangers if the medical wastes are not properly managed. In this talk, Prof. Wang shall demonstrate how a simple light, fiber, thermal or magnetic touch functions as a "magic" wetting-proof hand to navigate, fuse, pinch, and cleave fluids on demand, being capable of reducing and even replacing the usage of disposable plastics in the biomedical and pharmaceutical industries.

BIOGRAPHY

Professor Liqiu Wang is the Chair Professor of Thermal-Fluid and Energy Engineering and the Otto Poon Charitable Foundation Endowed Professor in Smart and Sustainable Energy at the Department of Mechanical Engineering, the Hong Kong Polytechnic University. With a prolific career, Professor Wang has made significant contributions to the field. He has published over 550 papers in prestigious journals and conferences, also authored 11 scholarly monographs, books and five book chapters. A keynote speaker at over 80 plenary lectures at international conferences, Professor Wang's research has also been widely referenced by researchers worldwide. A proud holder of over 40 patents and copyrights, Professor Wang led a 100-strong international team in developing a cutting-edge thermal control system for the Alpha Magnetic Spectrometer (AMS) on the International Space Station. This system ensures precise temperature regulation for AMS and its sub-detectors, enabling optimal performance in extreme temperature variations from -40℃ to 60℃ at 90-minute intervals.

PRINTHEAD ON A CHIP: EMPOWERING DROPLET BIOPRINTING WITH MICROFLUIDICS

Pengfei Zhang
Beihang University, China

ABSTRACT

State-of-the-art bioprinters have successfully constructed artificial tissues and organs, yielding successful clinical and therapeutic outcomes in tissue translation and organ disease modeling. However, existing instruments are primitive in their ability to select and print single cells. Most print materials with cells randomly suspended in them, and thus provide minimal control over cell type and location in the final structure. The inability to precisely control cellular organization at the single-cell level is thus a major barrier to bioprint materials mimicking the form and function of real tissues. To enable the manufacturing of a new generation of biomaterials with properties mimicking the complexity of biological systems, bioprinting capable of precisely placing individual cells is required. Microfluidics is a powerful technology to manipulate cells and biomaterials at the micron scale. The convergence of droplet-based bioprinting and microfluidics provides an effective strategy to achieve new type of bioprinting technology. Combined with droplet microfluidics, we develop high-definition single cell printing, a novel droplet-based microfluidic bioprinter providing precise control over cell type and printing location. Our approach uses a novel cell-in-air microfluidic dielectrophoretic sorter to rapidly print specific cell types of interest to a substrate with ~10-micron resolution at hundreds of hertz. Through selectively printing single cells from mixed cell suspensions, our device can print cells into any desired pattern with a complexity and control that has never been demonstrated. Beyond on single cells, we also have developed a series of droplet-based printing techniques with microfluidics, which enable printing of droplets, emulsions, and multiple materials.

BIOGRAPHY

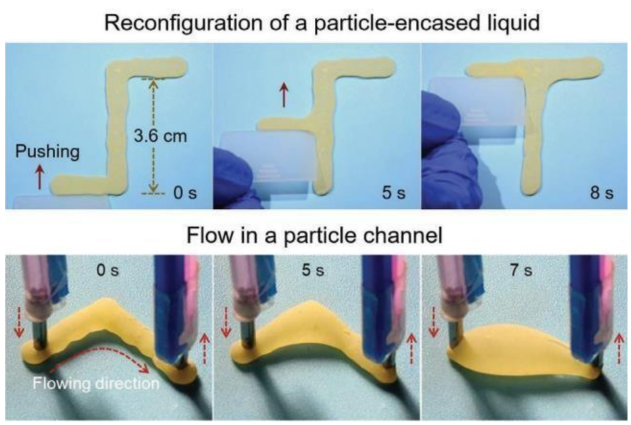
Pengfei Zhang is a Professor from School of Mechanical Engineering and Automation, Beihang University. He received both his B.S. and Ph.D. degree from the Beihang University in 2012 and 2017, respectively. He did his postdoctoral training in Abate Lab at UCSF from 2017 to 2022. His current research is mainly focused on microfluidics, single-cell printing, and intelligent (bio)printing technology, aiming to address key scientific and technological questions in the fields of precision biomanufacturing and precision in situ manufacturing. He has published papers in high-impact journals including Nature, Advanced Materials, Trends in Biotechnology, Biofabrication, and Lab on a Chip.

Open millifluidics based on liquid shaping

Xiaoguang Li
Northwestern Polytechnical University, China

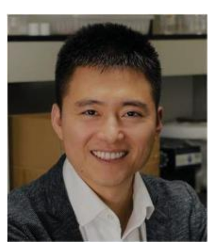
ABSTRACT

Containers/reactors are indispensable in various scientific experiments. Common containers, such as beakers and Petri dishes, are constructed with solid walls, which safely contain the liquids inside, though, are closed to the environment and thus limit the manipulation and design. Nonwetting droplets with spherical shapes can serve as self-supporting liquid containers, which are fully open to the environment but confronted with limitations from their simplex shapes. In this context, we have developed the liquid shaping technology and thereby realized open millifluidics, the manipulation of liquid flow in millimeter-sized channels with walls made of hydrophobic particles. The liquid shaping is realized by encasing a liquid in a particle shell and subjecting the interface to a jamming state. We have developed several strategies for achieving simple, precise and universal liquid shaping. In this report, I will focus on the liquid shaping strategies and how to produce open millifluidics. I will also report the flow performances in such a millifluidic device, the unique manipulation methods, and several proof-of-concept experiments for demonstrating the application potential.



BIOGRAPHY

Prof. Xiaoguang Li has focused on liquid manipulation since getting his PhD degree from Tongji University in 2013. His main interest lies in liquid shaping, an emerging topic in soft matter area. He is now one of the leaders of Shannxi Basic Discipline (Liquid Physics) Research Center. He is honored by International Association of Ad- vanced Materials (IAAM) for his academic achievements, having won the Advanced Materials Award and Young Scientist Medal.



Spontaneous and electrocapillary imbibition dynamics in nanoporous media

Bin Pan, *School of Civil and Resource Engineering, University of Science and Technology Beijing, China*

Abstract

Imbibition is important physics in nanoporous media, related to many energy and technology areas. The classic theory to describe the spontaneous imbibition dynamics is the Lucas-Washburn (L-W) equation, while the classic theory to describe the electrocapillary imbibition is the Lippmann equation and the Young – Lippmann (Y-L) equation. However, whether these classic theories are still valid at nanoscale have not been rigorously examined yet.

Therefore herein, we experimentally investigate the dynamics of spontaneous and electrocapillary imbibition in nanoporous media. For spontaneous imbibition in hydrophilic nanoporous media in the absence of evaporation, spontaneous imbibition height is linear with square root of time and a larger pore size causes a faster imbibition, which are consistent with the L-W equation; in contrast, for spontaneous imbibition in hydrophilic nanoporous media in the presence of evaporation, this linear relationship is deviated from linearity at early stages and a modified L-W theoretical model is derived to incorporate the evaporation effect. For electrocapillary imbibition in hydrophobic nanoporous media, counterintuitive voltage polarity dependence and electro-dewetting phenomena are observed, indicating that the Lippmann and the Y-L theory are invalid to describe the fundamentals of electrocapillary imbibition at nanoscale.

These insights will provide significant guidance on various applications relevant to energy storage and conversion.

Bio: Dr. Bin Pan is associate professor at University of Science and Technology Beijing, with expertise on fluids in nanoporous media and interfacial dynamics. Dr. Pan is editorial board member at InterPore Journal.

Droplets-from-Eye: A Digital Microfluidic Device for Intraocular Pressure Management

Glaucoma, the leading cause of global irreversible blindness, is closely linked to aqueous over-accumulation and elevated intraocular pressure (IOP). For refractory glaucoma, aqueous shunts with valves are commonly implanted for effective aqueous drainage control and IOP stabilization. However, existing valved glaucoma implants suffer from inconsistent valve opening/closing pressures and poor long-term durability due to their reliance on moving parts. Here, we propose a novel valving concept, the droplet Laplace valve (DLV), a 3D-printable moving-parts-free passive microvalve for the reliable aqueous shunting. The DLV employs a flow discretization unit comprising a droplet-forming nozzle and a separated reservoir to digitize continuous flow into quantifiable droplets. Unlike the classic one-time-use Laplace valves, the DLV's unique design allows for reusability. The opening pressure is adjustable by varying the nozzle size, like the classic Laplace valves (following the Young-Laplace equation), while the closing pressure can be modified by tuning the reservoir size and the separation distance. Various DLVs with opening pressures from 5 to 11 mmHg have been demonstrated, with differences of opening/closing pressures suppressed down to < 0.15 mmHg. Thanks to its moving-parts-free nature and digitized flow properties, the DLV exhibits a highly repeatable valving performance (< 2.0%) and a predictable linear flowrate-pressure correlation ($R^2 > 0.99$). Using an enucleated porcine eye, the DLV has been preliminarily validated *ex vivo* for efficient aqueous shunting and prompt IOP stabilization. With its simple architecture and dependable valving performance, the DLV technology holds great promise in glaucoma implants for aqueous shunting and in various microsystems for flow control.

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4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Colloidal Dynamics and Assembly in Combined Poiseuille and Electroosmotic Flow

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ABSTRACT

The dynamics of dielectric microparticles suspended in a microchannel flow are of interest in microfluidics applications. We observe a novel lift force with adjustable direction on such particles in combined Poiseuille and electroosmotic flow. Dilute (< 0.4 vol%) suspensions of fluorescent radius a = 250 nm polystyrene particles were visualized within 1 μm of the channel wall using total internal reflection fluorescence (TIRF) microscopy at flow Reynolds numbers *Re* □1 in ~30 μm depth channels. When the negatively charged particles lag the flow due to electrophoresis, the particles, driven by this lift force, migrate towards the channel centerline and the region of low flow shear.

When the particles lead the flow, they migrate instead towards, and accumulate near, the negatively charged wall. These particles become concentrated more than 100-fold, then assemble into elongated stable streamwise structures—“bands”, which have diameters of a few μm, lengths of a few cm, and fairly consistent cross-stream spacing. The streamwise velocities of the near-wall particles during accumulation and within the bands appear to be greater in magnitude than the sum of the flow and the particle electrophoretic velocities. The particle velocity distributions scale linearly with changes in electric field magnitude, however, suggesting that nonlinear electrokinetic phenomena are negligible. These largely unexplained observations illustrate significant gaps in our understanding of colloidal and interfacial dynamics, with unexpected nonlinear phenomena even in low *Re* flows.

PLASMONIC MICROBUBBLES AND THEIR APPLICATIONS IN MICRO/NANOFLUIDICS

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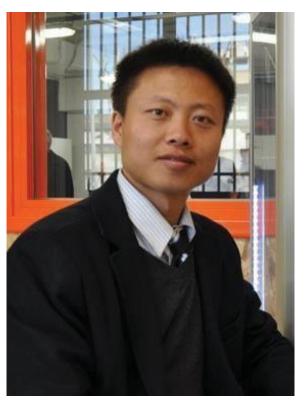
ABSTRACT
When illuminated by a resonant laser, noble metal nanoparticles immersed in liquid can efficiently produce a huge amount of heat, triggering the nucleation of microsized bubbles, which are referred to as plasmonic microbubbles. Plasmonic microbubbles can be divided into initial plasmonic microbubbles (IPMBs) [1] and ordinary plasmonic bubbles (OPMBs)[2,3]. The two types of plasmonic microbubbles exhibit distinct nucleation and growth dynamics. Due to their unique properties and excellent controllability, plasmonic microbubbles have been gaining increasing attentions and emerged in numerous applications such as microfabrication, micromanipulation, robot propulsion, and clinical therapies.

In this report, we are going to summarize the state of the art of plasmonic microbubble study. We will first talk about the nucleation mechanisms of IPMBs. From the nucleation mechanism, the counter-intuitive dependence of bubble volumes on laser power and gas concentration will be reported. After that, the growth dynamics of OPMBs will be presented. It turns out the growth of OPMBs is governed by the competition between water vaporization and gas diffusion. As a result, the physicochemical properties of liquids have a strong influence on the growth dynamics of plasmonic bubbles. Next, the underlying mechanisms of optomechanical energy conversion will be reviewed. We will show that the IPMBs exhibit extremely high optomechanical energy conversion efficiency. This is the reason of the distinct growth dynamics of IPMBs from OPMBs. At last, the approaches of optomechanical energy conversion[4] along with growing plasmonic bubbles will be summarized, followed by the applications of plasmonic bubbles, spanning from micro/nanomanipulation to microfabrication[5].

BIOGRAPHY



Yuliang Wang is a professor in Robotics Institute at Beihang University. He received his B.S. (2004), M.S. (2006), and Ph.D. (2009) in Mechanical Engineering from Harbin Institute of Technology and worked as a postdoctoral fellow in the department of Mechanical Engineering at the Ohio State University. Since 2012, he joined Beihang University as an associate professor and later as a full professor from 2019. His research interests include micro/nanorobotics, micro/nanomanipulation, microfluidics, and ultra-high precision measurement and control.

Dynamics of three-phase contact line when crossing micro-patterns

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[1]School of Mechanical Engineering, Tongji University, Shanghai 201804, P. R. China and
[2]Department of Mechanical Engineering, The University of Tokyo, Bunkyo-ku, Tokyo 113-8656, Japan

ABSTRACT

Within the Couette flow computational system, the slip behavior of the three-phase contact line as it crosses a micro-pattern was numerically analyzed using a modified interFoam solver shipped with OpenFoam. Micro-patterns are rectangular hydrophilic, hydrophobic, pillar, and hole areas, which are located on a surface with intrinsic contact angle at 60 ° . The calculation results show that on the hydrophilic area decorated surface, the three-phase contact line is slowed down, and then a shooting behavior is seen when it leaves the pattern. An inverse crossing behavior is obtained on hydrophobic area masked surface. On the surfaces with a micro- pillar or hole, the breaking of the liquid tail enhances the sliding of contact line. The findings in this work will be help for designing functional slippery surfaces.

CROSS-SECTIONAL EFFECTS ON NANOROD DIFFUSION IN POLYMER MELTS

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ABSTRACT

Low dimensional materials, like carbon nanotube and graphene, serve as great candidates for thermal management due to their superior thermal properties, which are however anisotropic. Embedding these nanomaterials within polymer matrices randomly will show an increased thermal conductivity compared to pristine polymer materials undoubtedly, but a further enhancement of the thermal conductivity value is always desired. An important route towards this end is by achieving the orientation control of these non-spherical nanoparticles and preferably aligning them towards one direction by the application of some external fields. The prerequisite to this control is understanding the rotational dynamics of these non-spherical nanoparticles at equilibrium in polymer matrices.

In this study, we modeled the translational and rotational diffusion of a rod-shaped nanoparticle in linear polymer melts by coarse-grained molecular dynamics simulations. Three-dimensional cross-sectional effect of the nanorod were added by increasing its diameter and the rotational dynamics around the axial direction was calculated for the first time. Crossing from the unentangled to entangled regime, the nanoparticle is coupled or confined to polymer matrices to various degrees, resulting in distinct quantitative scaling laws of the diffusion coefficients based on its diameter. Monitoring the diffusion of rod-shaped nanoparticles not only provides insights into the behavior of the nanoparticles themselves but also offers valuable information about the surrounding macromolecular environments. This concept is reminiscent of microrheology, a technique used to study the rheological properties of complex fluids at the microscale.

BIOGRAPHY

Dr. Ruoyu Dong is a professor and doctoral supervisor in the School of Astronautics at Beihang University. He has received the Wu Zhonghua Outstanding Graduate Student Award from the Chinese Society of Engineering Thermophysics and has been selected for the National Excellent Young Overseas Program. He also serves as a member of the Youth Committee of the Heat Transfer and Mass Transfer Branch of the Chinese Society of Engineering Thermophysics. His research focuses on fundamental scientific problems in heat and mass transfer and fluid flow in soft matter and multiphase fluid systems, as well as their applications in space thermal control and propulsion. He has published papers in Nature, Science, Nature communications, ACS Nano et al.

Acoustofluidics -sound waves meet fluid interfaces

Ashis Sen
IIT Madras

Fluid interfaces exposed to high-frequency sound waves can lead to unique and interesting phenomena. In constrained geometries, acoustic waves can provide acoustic radiation force and streaming flow that can be utilized to handle and manipulate fluid interfaces, cells, droplets, and particles. The talk would focus on some of the recent fundamental and applied research carried out by our group in this area.

dCas9-mediated PCR-free Detection of Oncogenic Mutation by Non-equilibrium Nanoelectrokinetic SelectivePreconcentration

Sung Jae Kim

Department of Electrical and Computer Engineering, Seoul National University, Republic of Korea

ABSTRACT

Nanoelectrokinetic selective preconcentration has been employed in various diagnostics such as bio-, chemical- and environmental- field. Cutting-edge nanoelectrokinetic technology in this presentation provides a breakthrough for the present clinical demands of molecular diagnosis to detect a trace amount of oncogenic mutation of DNA in a short time without an erroneous PCR procedure. We combined the sequence-specific labeling scheme of CRISPR/dCas9 and ion concentration polarization (ICP) mechanism to separately preconcentrate target DNA molecules for rapid detection. Using the mobility shift caused by dCas9's specific binding to the mutant, the mutated DNA and normal DNA were distinguished in the microchip. Based on this technique, we successfully demonstrated the dCas9-mediated 1-min detection of single base substitution (SBS) in EGFR DNA, a carcinogenesis indicator. Moreover, the presence/absence of target DNA was identified at a glance like a commercial pregnancy test kit (two lines for positive and one line for negative) by the distinct preconcentration mechanisms of ICP as shown in Figure, even at the 0.1% concentration of the target mutant.

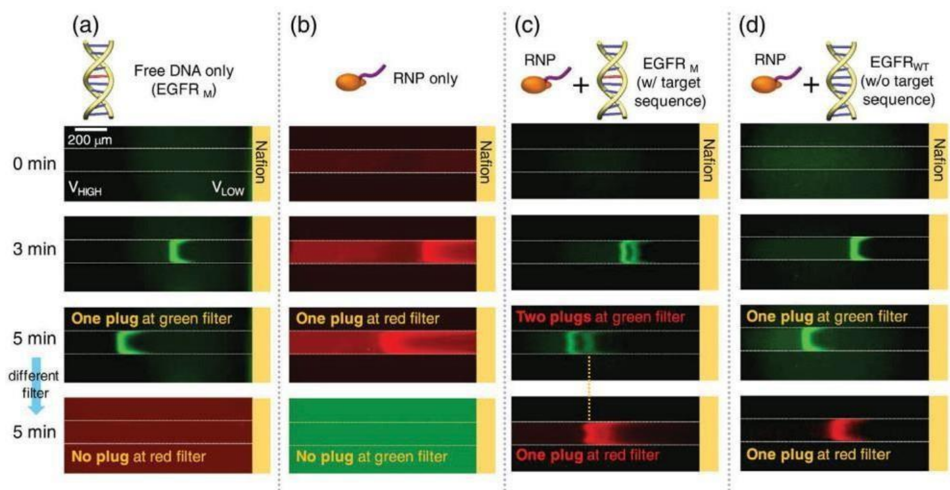

Figure. Fluorescence images of (a) free DNA, (b) RNP,(c) RNP with $EGFR_M$, and (d) RNP with $EGFR_{WT}$ using a selective concentration of nanoelectrokinetics selective preconcentration. It was confirmed that RNP could be combined only with $EGFR_M$ to detect SBS in the micro/nanofluidic platform.

BIOGRAPHY

Professor Sung Jae Kim completed his Ph. D. from Chemical Engineering at POSTECH, Korea. Following his doctoral studies at MIT (2005-2012), he joined the faculty of Seoul National University in the Department of Electrical and Computer Engineering 2012, where he was later promoted to a tenured professorship in 2021. Professor Kim's current research program centers on the investigation of fundamental nanoscale electrokinetics, with a particular focus on the ion concentration polarization phenomenon and its potential applications in the fields of energy, environment, and biotechnology. As a result of seminal works in electrokinetics, he has received various awards, such as Sinyang research award from Seoul National University and Next Generation Scientist Award from S-oil. Also, he co-founded ProvaLabs in 2020, striving to industrialize his research efforts. Currently, he is in charge of Director of Inter-university Semiconductor Research Center, which is the largest institute in Seoul National University.

STEP-BY-STEP DNA ANALYSIS ON DIGITAL MICROFLUIDICS

Ren Shen[1,2], Wenhao Hui[1], A'man Lv[1], Pui-In Mak[1], Rui P. Martins[1], Xuming Zhang[2], Yanwei Jia[1]
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[2]*The Hong Kong Polytechnic University, Hong Kong SAR, China*

ABSTRACT

In response to the need to economically perform large-scale gene variant profiling, we proposed an innovative method to detect DNA mutations with no-label probes based on a digital microfluidic (DMF) platform. Conventional all-in-one reactions were decomposed into step-by-step reactions, as shown in Fig. 1. Firstly an exponential dsDNA amplification was performed with limited and the same concentration of primers. Then a linear ssDNA amplification step took place after on-chip pipetting of a certain amount of one primer. Unlabeled oligo-nucleotide probes were added to the reaction mixture only after amplification. We showcased the principles and performance of this approach through analysis of a disease-related allele of the human HEXA gene. The method's resolution in identifying single-nucleotide polymorphisms was also demonstrated. With its cost- effectiveness, operation robustness, and high resolution in mutation discrimination, the proposed platform would promote gene mutation screening in the human population, especially in resource-limited regions.

ABSTRACT FIGURE

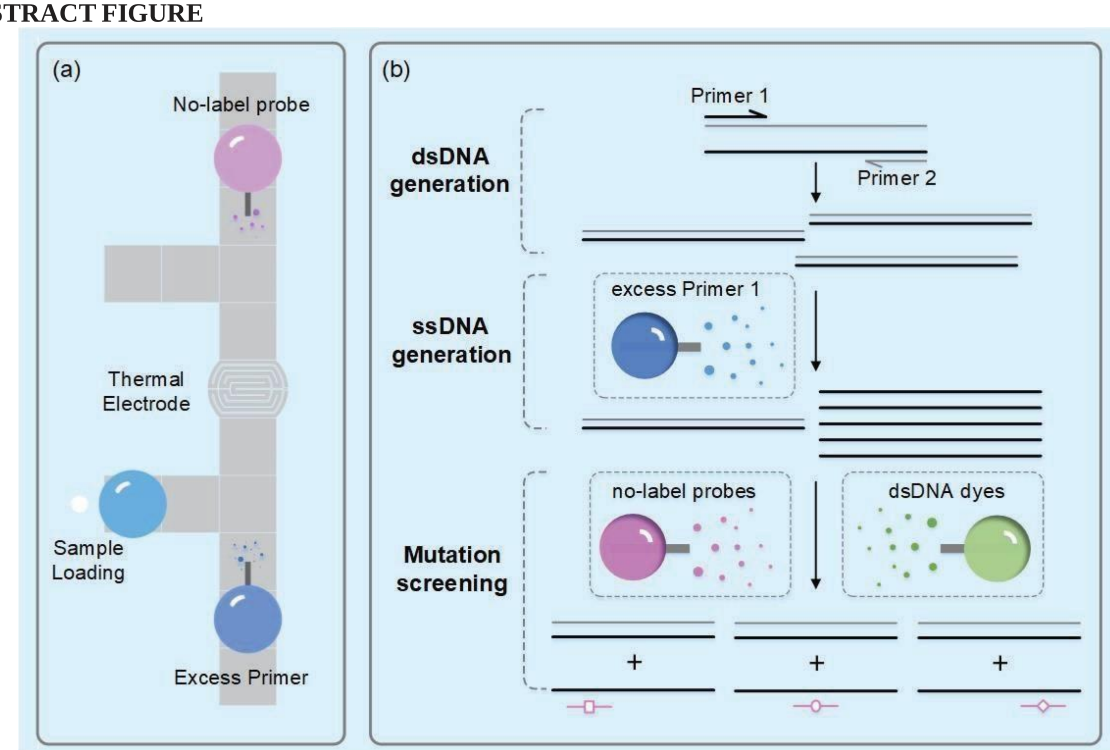

Fig. 1. Schematic of step-by-step reactions on a digital microfluidic chip for DNA mutation detection. (a) Arrangement of the electrode array. (b) Workflow of the step-by-step reactions.

HIGH-THROUGHPUT AND LOW-COST ORTHOGONAL ELECTRODE MATRIX DIGITAL MICROFLUDICS CHIP

Yufan Wang[1], Chi Chung Tsoi[2], Xiaodong Lin[3], Ren Shen[1], Xuming Zhang[2]* and Yanwei Jia[1]*
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[3]Macau Zhuhai UM Science & Technology Research Institute, Hengqin, China

ABSTRACT

This paper proposed a low-cost and high-throughput approaches to control droplets on DMF devices made from ITO glasses. We cut the ITO conductive layer of two conductive glasses into strip electrodes, put the ITO conductive layer of the upper and lower plates face-to-face. The strip electrodes on the top plate are in X direction while the electrodes on the bottom plate are in Y direction. The top electrodes and the bottom electrodes were connected a voltage of V with 180^o phase difference. By this way, the position at the cross point of a charged X electrode and a charged Y electrode would have a voltage of 2V,shown in Fig 1. The V is adjusted to make 2V right above the threshold for droplet transportation, so that the droplet next to the cross point would move to the cross point while other droplets next to X or Y electrode stay for not receiving high enough driving voltage.

This high-throughput microfluidic chip has broad application prospects. For example, the elevated content of miRNA-21 in human tissues is a risk indicator for various cancers, so miRNA quantitative detection can be used as a marker for cancer screening. When the corresponding molecular beacon is combined with the target miRNA, the fluorescence intensity is proportional to the content of miRNA. In quantitative gene detection, the content of miRNA in the target can be determined quantitatively by the fluorescence intensity under the microscope.

ABSTRACT FIGURE

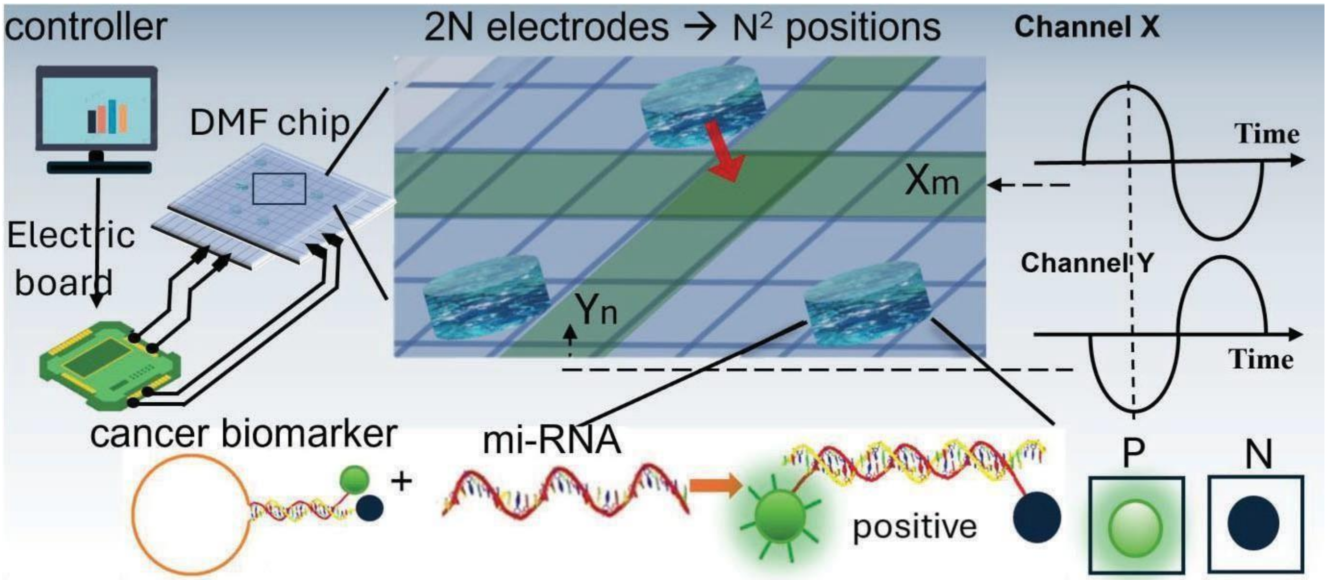

Figure 1: Whole system flow. The computer send command to electrode board via Bluetooth, and the DMF chip receive two roads sin signal with 180 phase difference. The top plate channel Xm and the bottom plate channel Yn are connected at a voltage V with a phase difference of 180°, respectively. Therefore, the voltage at the intersection (Xm,Yn) is 2V, and when 2V is just above the droplet movement threshold, the neighboring droplet moves towards the point (Xm,Yn) (as indicated by the arrow), and other droplets do not move. The chip could realize the cancer causative gene detect. MB with fluorophores is combined with the corresponding miRNA, and through quantitative detection of fluorescence intensity, it can preliminarily determine whether there is a cancer risk indication.

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SHAPE OPTIMIZATION OF DENSITY-LENGTH MATCHING NANOCHANNELS FOR REALISTIC OSMOTIC ENERGY CONVERSION ENHANCEMENT

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ABSTRACT

Osmotic power density enhancement of nanochannels is the vital target to promote the osmotic energy conversion for salt-gradient energy harnessing. Previous studies have shown that due to the competitive mechanism between ion selectivity and permeability, the power density of nanochannels is limited. However, there exists no research focusing on the channel density and length matching for higher power density. Moreover, previous studies did not involve the weakening effect of interfacial ion adsorption on effective surface charge density and ion transport, resulting in an overestimation of the osmotic power in numerical research. Herein, this study developed a model with ion-specific adsorption to describe the realistic osmotic energy conversion process of silica nanochannels. A density-length matching design method is then proposed and found that combining high density with long nanochannels is more conducive to power density with alleviated concentration polarization effect. The modified calculation formula for energy conversion efficiency was also derived based on the current-voltage test, and the reasons for the low efficiency are also discussed. According to the above analysis, a target optimization function was further proposed to optimize the shape of nanochannels. It was found that the vase-shaped nanochannel with an enlarged channel size on the high concentration side as an outward convex body, and a reduced size on the low concentration side as an inward concave mouth, can further promote the realistic power density. This research fills the theoretical gap in the geometrical regulation of nanochannels and guides the design of ion-selective membranes.

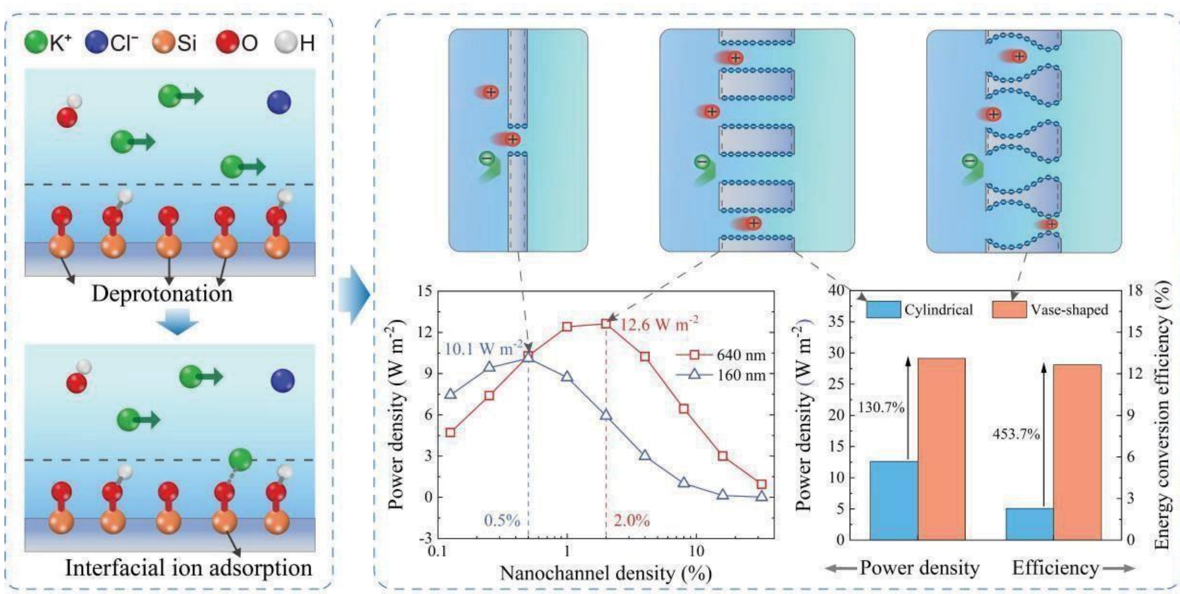

Figure 1. Shape optimization of density-length matching nanochannels for osmotic energy conversion improvement considering interfacial ion adsorption

Size analysis of single DNA molecules using nanoslit channels and evaluation of its resolution

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[1] Nagoya University, Japan and
[2] JST PRESTO, Japan

ABSTRACT

The global spread of infections caused by antibiotic-resistant bacteria has significantly affected public health. However, conventional methods for identifying DNA types of bacteria, such as pulsed-field capillary electrophoresis, are time consuming and labor intensive. Therefore, we propose a new method for high-resolution and high-speed analysis through relaxation time measurements using a nanoslit channel. Our study investigated the impact of the number of DNA molecules analyzed and the depth of the nanoslit on the analysis resolution.

The relaxation time signifies the duration for which the molecules transition from a stretchedstate to a coiled state. Previous studies have examined the correlation between the relaxation time of DNA molecules and their molecular weight[1,2], allowing for DNA size determination. In our study, we employed advanced nanofabrication techniques to create nanoslits of varying depths to stretch DNA molecules. DNA molecules were introduced into the nanoslit, stretched by electrophoresis, and underwent a relaxation process when the voltage was turned off, enabling the collection of a large amount of data on the relaxation process (Fig. 1a). We successfully performed DNA size analysis using relaxation time histograms (Fig. 1b). Furthermore, we confirmed that nanoslit depth was the primary factor influencing the resolution of size determination. Decreasing the nanoslit depth improves the resolution, whereas the number of DNA molecules analyzed does not affect the resolution once a critical amount of data is reached.

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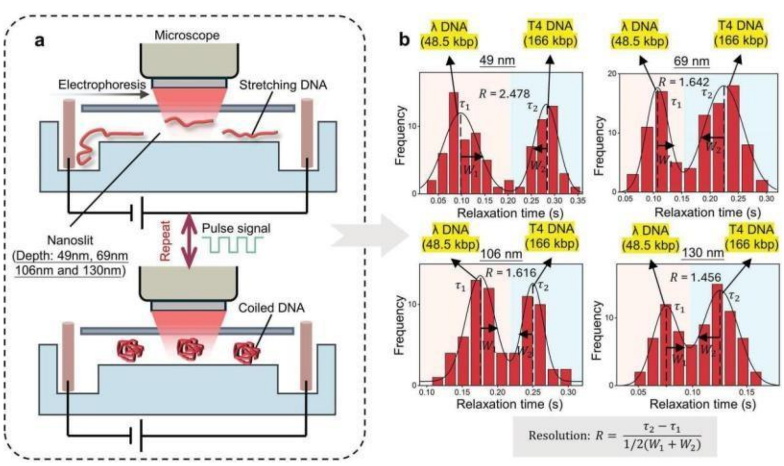
(2) Perkins, T. T. et al. *Science* 1994, *264* (5160), 822–826.



ABSTRACT FIGURE

Fig. 1 Schematic depiction of a method for analyzing the size of single DNA molecules through relaxation time measurements using nanoslit channels. (a) Overview of the process for capturing relaxation phenomenon. (b) Histogram of the relaxation time of DNA molecules of different size (48.5 kbp and 166 kbp) at different nanoslit channel depths (49, 69, 106, and 130 nm).

Intelligent Magnetic Soft Millirobots for Droplet Manipulation

Yi Zhang
University of Electronic Science and Technology of China

ABSTRACT

3D printing via vat photopolymerization (VP) is a highly promising approach for fabricating magnetic soft millirobots (MSMRs) with accurate miniature 3D structures; however, magnetic filler materials added to resin either strongly interfere with the photon energy source or sediment too fast, resulting in the nonuniformity of the filler distribution or failed prints, which limits the application of VP. To this end, a circulating vat photopolymerization (CVP) platform that can print MSMRs with high uniformity, high particle loading and strong magnetic responseis presented in this study. After extensive characterization of materials and 3D printed parts, it is found that SrFe12O19 is an ideal magnetic filler for CVP and can be printed with 30% particle loading and high uniformity. By using CVP, various tethered and untethered MSMRs are 3D printed monolithically and demonstrate the capability of reversible 3D-to-3D transformation and liquid droplet manipulation in 3D, an important task for in vitro diagnostics that have not been shown with conventional MSMRs. An AI-enabled and fully automated liquid droplet handling platform that manipulates droplets with MSMR is presented for detecting carbapenem antibiotic resistance in hazardous biosamples as a proof of concept, and the results agree with the benchmark

BIOGRAPHY

Yi Zhang is currently a Professor at the University of Electronic Science and Technology of China. Previously he served as an assistant professor at the School of Mechanical and Aerospace Engineering at Nanyang Technological University, Singapore. He received his Ph.D in Biomedical Engineering from Johns Hopkins University School of Medicine, USA, in 2013 and B.Eng in Bioengineering from Nanyang Technological University, Singapore, in 2007. He received his postdoc training in the Institute of Bioengineering and Nanotechnology, the Agency of Science Technology and Research (A*STAR), Singapore from 2013−2015, and subsequently worked there as a Research Scientist from 2015−2016. His research aims to develop micro and nano systems to bridge the gap between engineering advancement and current medicine practice. His achievement is recognized by a series of awards including Nanyang Young Alumni Award, Outstanding Self-Financed Student Overseas, Hodson Fellowship, Siebel Scholar, and various Young Scientist Awards, Best Conference Awards and Art in Science Awards.

Light manipulation of levitated/suspended droplet/bubble via localized photothermal effect

Rong Chen

School of Energy and Power Engineering, Chongqing University, Chongqing China

ABSTRACT: Droplets and bubbles are extensively utilized in various fields, including agriculture, industry, medicine, biology, energy, etc. Levitated/suspended droplets/bubbles have no contact with solid wall surfaces, which can effectively avoid contamination and decrease the motion resistance, making them particularly promising. However, efficient, simple and flexible manipulation of levitated/suspended droplets/bubbles against gravity/buoyant forces still remains a challenge. Light method based on the photothermal effect has been demonstrated to be able to precisely manipulate droplets/bubbles in microfluidics, offering the merits of remote and non-contact control, high sensitivity and fast response. Herein, we employ the localized photothermal effect of a focus laser beam to manipulate the droplets/bubbles. Amazingly, precise and flexible manipulation of the droplets/bubbles against gravity/buoyant forces can be realized using this approach. The underlying mechanisms leading to these fascinating functions are revealed. It is believed that this light method based on the localized photothermal effect for manipulating levitated/suspended droplets/bubbles shows promising potentials in biochemistry, analytical chemistry, drug delivery, diagnostics, etc.

BIOGRAPHY: Professor Rong Chen is a full professor at Chongqing University of China. He obtained his bachelor's and master's degrees from School of Energy and Power Engineering at Chongqing University in 2000 and 2003 respectively. He got his Ph.D degree in Mechanical Engineering from the Hong Kong University of Science and Technology in 2007. He continued his postdoctoral research at the same department. In 2010, he joined School of Energy and Power Engineering at Chongqing University, where he was promoted to full professor in 2014. His research interests include optofluidics, microscale transport and interfacial phenomena, solar energy utilization by photochemistry, new energy conversion technologies.

Exploring Unconventional Nanofluidics: from Nanoparticle-Blocked Nanopores to Confinement-Dependent Wet Etching in Nanochannels

Chuanhua Duan
Department of Mechanical Engineering, Boston University

ABSTRACT

Nanofluidics, exploring mass transport in nanostructures like nanopores, nanotubes, and nanochannels, has attracted great attention over the past three decades for its bio- and energy-related potentials. Yet, current research primarily focuses on certain traditional directions. Specifically, nanopore studies emphasize translocation-based sensing and analysis, while nanochannel/nanotube research leverages nanoconfinement and nanoscale interactions to achieve unique transport phenomena and/or novel applications. Other nanoconfinement-related research topics remain overlooked despite their potential implications. In this talk, I will discuss my group's recent efforts in exploring nonconventional nanofluidics. First, I will present our work on studying nanoparticle-blocked nanopore systems. Such systems have been considered as experimental failures for conventional nanopore research, but our studies showed that the blockage state actually includes trapping and contact blockage modes, both of which can respond to various electrical or mechanical stimuli and can lead to new applications for nanoparticle characterization, nanopore gating as well as bio-sensing. Secondly, I will introduce our latest work on nanoconfinement-dependent wet etching, a long-standing issue for the semiconductor industry since the advent of 3-D semiconductor manufacturing. Through systematically investigating basic KOH-Si etching and acidic HF-SiO2 etching using 2-D nanochannels, we found that both the electrostatic interactions and water structuring inside the nanoconfinements contribute to the confinement-dependent etching rates. We further discovered that these nanoscale effects can be mitigated using active/passive methods to achieve uniform etching rates. Our studies expand the scope of nanofluidics, offering new insights and promising advancements across various fields.

BIOGRAPHY

Dr. Chuanhua Duan earned his B.S. and M.S. in Engineering Thermophysics from Tsinghua University in 2002 and 2004, respectively. He completed his Ph.D. in Mechanical Engineering at the University of California, Berkeley, in 2009 under Prof. Arun Majumdar's supervision. After two years as a post-doctoral researcher at Lawrence Berkeley National Laboratory, he joined Boston University's Mechanical Engineering Department as an assistant professor in 2012, now serving as an associate professor. Leading the Nanoscale Energy-Fluids Transport Laboratory, he has received honors such as the Defense Advanced Research Project Agency Young Faculty Award (2018), the National Science Foundation Early Faculty Career Development Award (2017), and the American Chemistry Society Petroleum Research Fund Doctoral New Investigator Award (2013). His research focuses on the study of micro- and nanofluidic transport phenomena and the development of new fluidic devices/approaches for applications in healthcare, energy systems, and thermal management.

Nanoscale thermal-driven flows and potential inspirations

Yakang Jin
University of Electronic Science and Technology of China

ABSTRACT

Nanoscale flows are of great importance in a variety of areas, including energy conversion, water desalination, and DNA sequencing. In this talk, we center on the transport of aqueous solutions inside nanochannels driven by thermal gradients. Extensive molecular dynamics simulations reveal that such transport is highly sensitive to the channel height, and is modulated by the excess enthalpy of nanoconfined solution. Thanks to remarkable fluid slip and mean excess enthalpy density of the solution in strong nanoconfinements, the nanofluidic system of specific size can achieve high-efficiency conversion of thermal energy into electricity, which can serve as a potential device for harvesting low-grade waste heat. The size-sensitive transport is further utilized to design a thermal pump using a hetero-junction strategy. We explicitly demonstrate that water flows in a carbon nanotube hetero-junction of different diameters can be modulated by symmetric temperature gradients, which can also be a promising candidate for chip-level cooling.

BIOGRAPHY

Dr. Yakang Jin was awarded his Ph.D. degree in Mechanical Engineering from Department of Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology (HKUST) in 2021, and then joined School of Physics, University of Electronic Science and Technology of China (UESTC) as an assistant professor via an International Postdoctoral Exchange Fellowship Program. Dr. Jin's main research interest lies in Micro/Nano-Mechanics, Nanofluidics and their applications in the field of energy and environmental science, etc. Currently, his study centers on exploring both statics and dynamics of nanodrops, nanobubbles and nanoblisters, by experimental (AFM, high-speed camera, etc) and multi-scale simulation methods (MD, DSMC and LBM, etc), with the support of the National Natural Science Foundation of China (NSFC), the Natural Science Foundation of SiChuan Province (NSFSC), to name a few.

Nanoconfined structural design and transport modulation in graphene nanopores

Luda Wang
Peking University, Beijing

ABSTRACT

Confined fluidic transport down to nano and angstrom level exhibits numerous intriguing phenomena distinct from macro scale. Owing to its atomic thickness, mechanical and chemical stability, and scalability, graphene has emerged as an ideal platform for investigating transport mechanisms and exploring potential applications in diverse fields, ranging from DNA sequencing to water-energy-environment nexus. As pristine graphene serves as a perfect barrier, impermeable to almost all molecules, the controlled design of nanopores in graphene becomes a prerequisite for realizing investigation and applications.

Here, we will give a systematic overview of our recent work on tunable nanopore designin graphene lattice. We start with the etching dynamics of graphene nanopores by a decoupling method to fine-control pore size distribution and pore density. Then, we focus on designing functional groups, which provide a new degree of freedom for the confined space of nanofluids. Specifically, we propose a covalently functionalization method and a preanchoring enabled directional modification method to tune functional groups in graphene nanopores and related transport properties. Besides, considering the inevitable defects during growth and transfer process, we propose a COF-anchored design of nanoporous graphene membranes to achieve high permeance and selectivity simultaneously. Finally, we also bridged the gap between lab-scale demo and commercialization to utilize graphene membranes in specific applications, with a focus on membrane-based precision instrument and membrane module. Our research has the potential to advance nanopore fabrication and sheds light on transport mechanisms in graphene and other 2D materials, as well as explores their applications in membrane-based technologies.

Prof. Luda Wang works in the National Key Laboratory of Advanced Micro and Nano Manufacture Technology, and the Academy for Advanced Interdisciplinary Studies of Peking University. He received his Ph.D in University of Colorado boulder in 2014 (with Prof. J. Scott Bunch), and then joined the group of Prof. Rohit Karnik as a postdoctoral researcher in Massachusetts Institute of Technology. His research interests cover the areas of fluid transport at the molecular level, micro and nano sensors, membrane separations for clean energy, water treatment and high-end applications. More than 40 articles have been published, including Nature Nanotechnology, Advanced Materials, Nano Letters, Science Advances, Nature Communications etc.

THREE-DIMENSIONAL STRUCTURES AND DYNAMICS OF MULTIPHASE FLUIDS CONFINED IN NANOTUBES

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[2]International Institute for Carbon Neutral Energy Research, Kyushu University, Japan

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ABSTRACT

Fluid confined in nanopores is ubiquitous across natural and artificial systems. However, gaining a comprehensive understanding of nanoconfined multiphase fluid has been hindered by experimental challenges. Here, we elucidate the three-dimensional multiphase structures and phase dynamics of various fluids confined within carbon nanotubes with transmission electron microscopy (TEM). First, we reconstructed the three- dimensional details of nanoscale multiphase structures within nanotubes with a large number of 2D-projection TEM images from various viewing angles. We observed complex deformation of nanobubbles due to intermolecular interactions between nanoscale solid, liquid, and gas phases. Multiple nanobubbles within a distance of less than 2 nm were significantly distorted with high asymmetry. We quantitatively determined the distribution of Laplace pressure and disjoining pressure at each liquid-gas interface from the 3D distribution of curvature radii, revealing ultrahigh pressure inside the nanobubbles. Second, I will demonstrate in-situ TEM studies of the dynamics of nanoscale multiphase structures under strong electron beam irradiation and temperature changes. We quantitatively analyzed the coalescence of multiple nanobubbles and nanoscale bubble oscillation, revealing insights into surface energy release with ultrahigh resolutions. Furthermore, we elucidated nanoscale liquid-gas phase change phenomena of pure water and crystallization processes within the electrolyte. These experimental methods and findings, based on in-situ TEM, contribute significantly to our understanding of nanofluidics and can provide valuable guidance for designing various applications involving nanoconfined fluids.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
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COMBINED PRESSURE-DRIVEN AND ELECTROOSMOTIC FLOW FOR ION TRANSPORT IN NANOFLUIDIC DEVICES

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ABSTRACT

Electrokinetic ion transport and fluid flow have great potential in biomedical and industrial applications such as drug delivery, water purification, fuel cell, and catalysis. Harvesting energy with nanofluidic devices from natural or daily mechanical movements is an economic and environment-friendly approach, however, the progress is far from satisfactory due to poor device performance. Conceptual experiments show the promising potential of giant power density, but it is difficult to translate the estimated high-power density into practical high power in membrane-scale applications due to mechanical difficulties in new materials. Herein, a customized nanofluidic chip consisting of nanochannel arrays was fabricated to generate electric energy using pressure gradients. Parallelly stacked three-dimensional (3D) micro-nanofluidic devices are successfully achieved. The measured streaming current increase is proportional to the external pressure gradient. We also explore the combined effects of pressure and external electric field on ion transport in confined structures. The numerical results systematically discussed the effects of external pressure force and solution concentration on the streaming current output, which is crucial to improving the nanofluidic energy conversion efficiency. This pressure-driven nanofluidic device enables improvement of the practical mechanical energy harvesting by readily controlling the ionic screening effect of nanochannel and could facilitate mass spectrometer and fluid sensors to an ultrahigh detection limit.

HIGH-THROUGHPUT MANIPULATION OF NANOPARTICLES BY CONTROLLING FLUIDIC ELECTRO-ELASTICITY AND JOULE HEATING IN MICROCHANNELS

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ABSTRACT

Microfluidic manipulation of particles often depends on their cross-flow migration, which becomes less efficient for nano-sized particles due to reduced cross-flow forces. We present an innovative method that enhances the focusing of nanoparticles in a viscoelastic polyethylene oxide (PEO) solution by positive or negative electrophoresis. This technique has efficiently manipulated nanoparticles as small as 100 nm in a high-throughput manner by combining different electric fields with pressure-driven flow. Our results show that in the electro-hydrodynamic flow of the PEO solution, leading and lagging particles migrate toward the centerline and walls of a rectangular microchannel, respectively. In addition, we use dry ice to counteract the temperature rise caused by Joule heating, allowing the application of much higher electric fields to focus nanoparticles down to 20 nm. A theoretical framework has also been developed to explain these phenomena.

BIOGRAPHY

Dr. Guoqing Hu, a Qiushi Chair Professor at Zhejiang University, specializes in microfluidics and nanofluidics, lab-on-a-chip technologies, and nanotoxicology. He has led several major projects, including the Key Project of the National Natural Science Foundation of China, the National Key Research and Development Program of China, and the Key Research Program of Frontier Sciences of the Chinese Academy of Sciences. He has published more than 100 SCI papers in journals such as Nature Communications, Journal of the American Chemical Society, ACS Nano, Nano Letters, Journal of Fluid Mechanics, Lab-on-a-chip, and Analytical Chemistry. In addition, he contributes as an editor for several academic journals.

When two-phase flows emerge from porous media…

Sungyon Lee
University of Minnesota

ABSTRACT

With the advances in microfluidics, two-phase flows in porous media have been studied extensively in the last few decades, motivated by various applications including oil recovery, soil remediation, and fuel cell technology. However, the current state of the art almost exclusively focuses on resolving the displacement pattern inside porous media but not the resultant output flow emerging from the media. To address this gap in knowledge, we use the microfluidic platform to simultaneously visualize the invasion pattern inside a fibrous porous network and the resultant outflow, when we systematically co-inject water (dispersed phase) and immersion oil (continuous phase) into the media. Our experimental results suggest a strong coupling between the ratio of water to oil flow rates and the size of resultant water droplets, which we aim to rationalize with a mathematical model. In addition, we visualize the water pathway inside the filter media with a fluorescent dye and establish a connection to the outgoing water droplets.

BIOGRAPHY

Sungyon Lee is currently an Associate Professor of Mechanical Engineering at the University of Minnesota. She completed her Ph.D. and M.S. in Mechanical Engineering at Massachusetts Institute of Technology, and B.S. in Mechanical Engineering at University of California, Berkeley. Following a post-doc at Ecole Polytechnique and an adjunct faculty position in Applied Mathematics at University of California, Los Angeles, she was an assistant professor in Mechanical Engineering at Texas A&M University from 2013-2017. Dr. Lee's fluid mechanics research group specializes in reducing complex physical phenomena into tractable problems that can be visualized with table-top experiments and solved with mathematical modeling. The physical systems of interest range from drops and bubbles, particle-laden flows and interfaces, to two-phase flows through porous media.

Label-free Microfluidics Technologies for Extracellular Vesicles Isolation

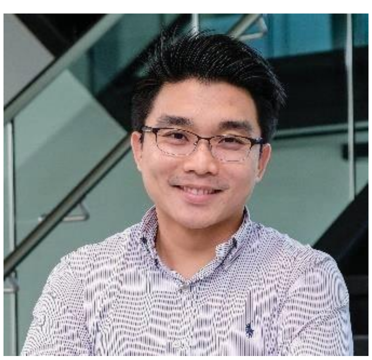
Associate Professor Han Wei Hou, PhD
School of Mechanical and Aerospace Engineering
Lee Kong Chian School of Medicine
Nanyang Technological University Singapore

ABSTRACT

Emerging biomarkers including extracellular vesicles (EVs) and microRNAs have shown great potential in blood- based diagnostics. However their detection is often confounded by delayed blood processing and cellular contam- ination due to non-standardized centrifugation practices which may cause large variations in plasma quality. Con- ventional EV isolation methods using ultracentrifugation, size-exclusion chromatography (SEC) and tangential flow filtration (TFF) are manual, time-consuming and require plasma as input sample. In this talk, I will highlight the development of several label-free microfluidic tools from our lab for EV sample preparation. We will first present a high throughput (~10 mins/per mL of whole blood) and gentle microfluidic sorting technology (ExoArc) for single- step plasma extraction from whole blood. With a size cut-off of 500 nm based on particle inertial focusing effects, ExoArc-isolated plasma is completely cell-free, platelet-free and highly enriched in EVs. When coupled with SEC, this centrifugation-free workflow (< 1 hr) greatly improves EV yield while reducing formation of EVaggregation and platelet-derived EVs as compared to ultracentrifugation. To address the bottleneck of protein contamination, we also developed a microfluidic SEC device (μSEC) integrated with an on-chip nanoliter sample plug injection to separate EVs from plasma proteins under continuous flow. We envision that μSEC system can be readily automated and integrated with ExoArc and downstream EV detection or assays for real time monitoring tool in EVs manufac- turing or EV-based clinical applications.

BIOGRAPHY

Dr. Han Wei Hou is an Associate Professor and currently serves as the Assistant Chair (Students) at the School of Mechanical and Aerospace Engineering (MAE), Nanyang Technological University Singapore (NTU). Dr. Hou re- ceived his BEng (First Class Hons) and PhD degree in Biomedical Engineering at the National Universityof Singa- pore in 2008 and 2012, respectively. He did his postdoctoral training at Massachusetts Institute of Technology (USA) (2012-2013) and LKCMedicine (2014-2017). He started his research group (BioMicroSystems Laboratory) in 2018 and has authored over 55 peer-reviewed journal publications and filed 12 patents/patent applications. His recent research awards and accolades include World's Top 2% Scientists (By Stanford University) (2023), International Academy of Medical and Biological Engineering (IAMBE) Early Career Award (2022), NTU College of Engineering Research – Young Faculty Special Mention (2022), IFMBE Asia-Pacific Research Networking (APRN) Fellowship (2022) and International Society for Advancement of Cytometry (ISAC) Innovators (2021).



SINGLE-CELL ELECTRIC IMPEDANCE SENSOR BASED ON INTEGRATED CIRCUIT CHIP

Wenhao Hui[1,2], Ren Shen[1,2], Pui-In Mak[1,2], Rui P. Martins[1,2,4], Ka-Meng Lei[1,2*], and Yanwei Jia[1,2,3*]

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ABSTRACT

Drug screening with in-vitro primary tumor cells provides a direct means of assessing drug sensitivity. It is widely employed in personalized cancer diagnosis and precision medicine. Nevertheless, current tumor drug screening methods face a common challenge: the presence of normal cells within tumor samples from patients, which hinders the accurate evaluation of drug effects on cancer cells alone. Herein, we present a real-time impedance sensing method based on the integrated circuit (IC) chip to distinguish cancer from normal cells at a single-cell level, and individually analyze their sensitivity to the drug. It innovatively integrated the impedance calculation circuits directly beneath the array of 22×16=352 single-cell-sized sensing electrodes, effectively reducing the high background noise hindering ultra-weak signal detection. We validated this method in various cancers, demonstrating its ability of impedance-based classifying and conducting drug sensitivity tests on the IC chips. The response of cancer cell lines to the chemotherapy drug cisplatin on the chip is in accord with those obtained from traditional 96-well plate screening. Additionally, we directly obtained clinical samples of liver cancer and cholangiocarcinoma from patients for impedance analysis. The classification results were consistent with the hospital's pathological findings. To the best of our knowledge, this is the first time that a cell electrical impedance sensing circuit is integrated into an IC chip to distinguish single cells. It revealed the potential of this real-time, non- invasive, and label-free single-cell distinguishing method for precision medicine, paving the way to design ultra- microbiological signal sensors and actualize the lab on IC.

ABSTRACT FIGURE

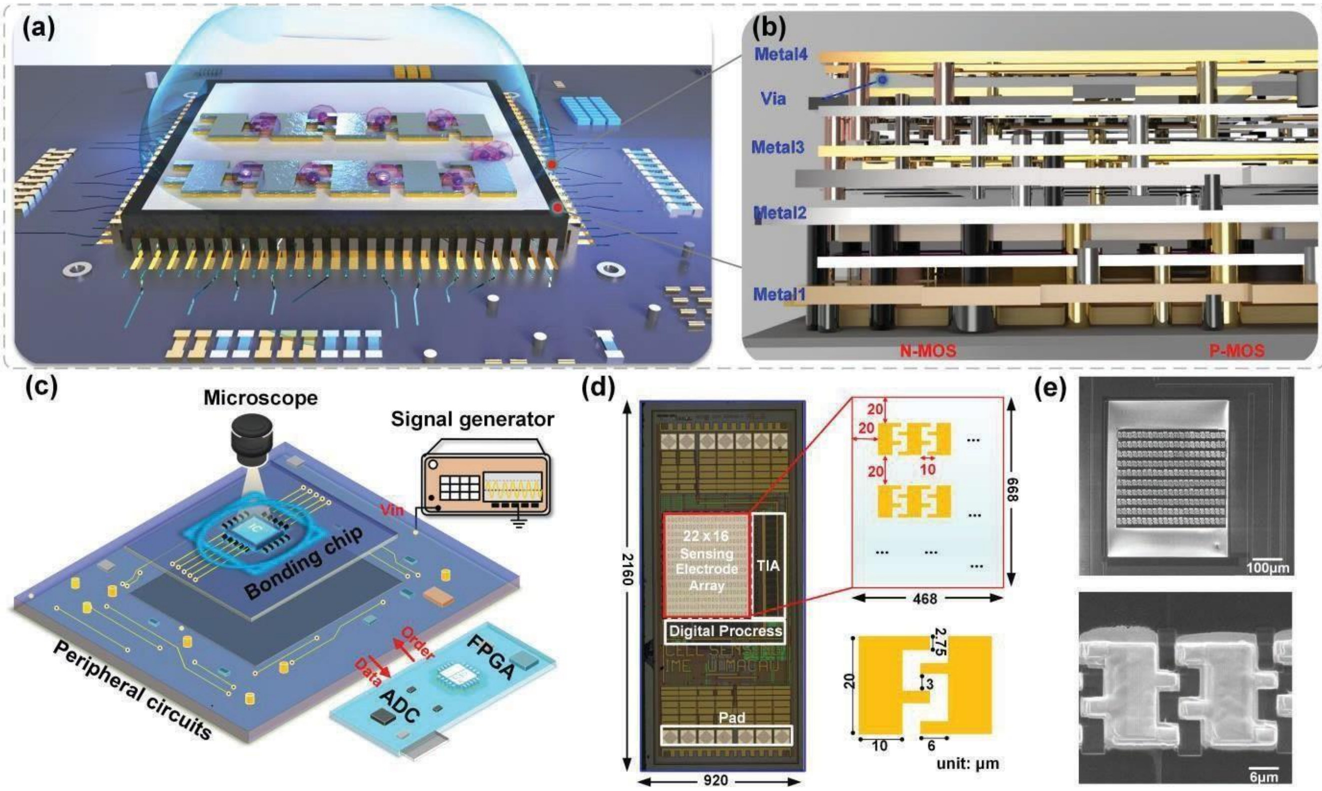

Figure 1: (a) Schematic of single-cell electric impedance sensor based on IC chip. (b) The internal structure of the IC chip. (c) Impedance monitoring and measurement platform. (d) Photograph of the IC chip and functional module. (e) SEM photo of the electrode pattern.

The liquid ring sealed air bearing

Jun Wen
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ABSTRACT

With the rapid development of micro-electro-mechanical systems (MEMS), micro-turbines, micro-motors, and micro-generators are becoming increasingly important due to their indispensable functions in a system. However, friction and wear are severe at the micro scale due to the high surface-to-volume ratio. Air bearings can largely reduce the friction and wear by replacing the solid/solid contact with air/solid contact which is promising in MEMS systems. The air cushions of conventional air bearings are normally maintained by continuous air supply. Therefore, extra energy input and complex control systems are indispensable for these air bearings. Herein, a method of holding an air cushion between the rotor and stator of a thrust air bearing (see Fig. 1) without extra energy input was developed using surface wettability modification. Alternate superhydrophobic and hydrophilic patterns have the ability to form surface free energy barriers on a solid surface. Such surface free energy barrier can strongly pin the air/water/solid three-phase contact line there. By applying such annular patterns on the lower (upper) surface of the upper rotor (lower stator) of a thrust bearing, water rings were formed and confined on the annular hydrophilic strips between the rotor and stator with an air cushion sealed inside. When being compressed, the Laplace pressure in the air cushion builds up and supports the load. The performance of the water ring sealed air bearing has been studied both experimentally and numerically and the results were used to optimize the bearing.

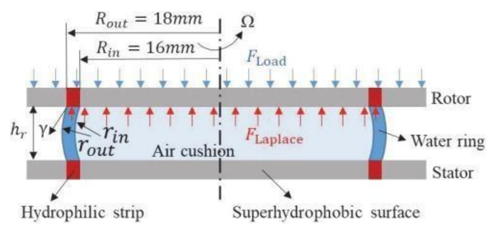

Figure 1. Cross-section view of the water ring sealed air bearing.

BIOGRAPHY

Dr. Jun Wen holds a post as a Professor in Fluid Mechanics. Prior to joining Northwestern Polytechnical University in 2021, Dr. Wen studied for a D.Phil. in the Department of Mechanical Engineering at Imperial College London (2017). Dr. Wen is an Editorial board member of the Journal of Hydrodynamics. His research focuses on surface & interface flow, frictional drag reduction and surface wettability. His work is founded by the National Natural Science Foundation of China.

Label-Free Targeted Single-Cell Feedback-Controlled High Efficiency Electroporation Using Focused Electric Fields in a Microsystem

Aniruddh Sarkar
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ABSTRACT

Cell therapies have radically transformed the treatment of cancer. This has created a pressing need for efficient, safe, and scalable intracellular delivery systems. While viral vectors are commonly used, significant unresolved concerns remain with them especially for larger cargos (e.g. CRISPR-Cas9). Electroporation presents a payload- size agnostic, safer and more cost-effective solution. Conventional bulk electroporation however uses high voltages (~kV) which can result in low cell viability especially for heterogenous patient-derived cells. In this work, we present a new microscale technique for continuous flow, label-free, single-cell characterization and tandem real- time feedback-controlled low-voltage electroporation of selected single cells. Single cells are first detected and characterized in flow in a label-free manner, using multi-frequency impedance cytometry, as they arrive in a focused microscale electrical sensing zone in a biconical micro-aperture. Coupled to machine-learning based analytics, this enables label-free cell discrimination. This is then used to selectively trigger a low-voltage electroporation pulse. Due to the shape of the aperture, this creates a focused high electric field electroporation zone around the target single cell and results in selective in-flow single-cell electroporation from large heterogenous cell populations. The focused electric field zone and the low voltage used result in simultaneous high post-electroporation cell viability (~90%) and delivery efficiency (~85%) across cell types and delivery cargos. Overall, this novel microscale label- free single-cell selective electroporation method can improve cell therapy manufacturing workflows. It can reduce the need for costly cell isolation steps and the time required for post-delivery cell expansion thus reducing overall vein-to-vein time and cost.

BIOGRAPHY

Dr. Aniruddh Sarkar is an Assistant Professor in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University. He received his B.Tech. and M.Tech. in Electrical Engineering from IIT Bombay and his Ph.D. in Electrical Engineering and Computer Science from MIT. Dr. Sarkar joined the faculty at Georgia Tech in 2019 after completing postdoctoral training at Harvard Medical School. His research program exploits microscale and nanoscale physical phenomena to develop technology for precision biology and medicine, with a specific focus on addressing healthcare disparities. Most recently, this has resulted in the discovery of a novel class of diagnostic and prognostic biomarkers for infectious diseases (e.g. Tuberculosis, COVID-19) and methods for their inexpensive point-of-care detection. His work has been published in leading journals such as Cell and Nature Communications. Dr. Sarkar is recipient of the Bernie Marcus Early Career Professorship in Therapeutic Cell Characterization and Manufacturing.

3.5D Organoid Engineering strategy

Prof. Hanry Yu

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ABSTRACT

An organoid is a self-organized microtissue typically derived from stem cells which mimic the complexity and functionality of real tissues *in vitro*. Despite demonstrating substantial potential as versatile platforms for drug development, personalized therapy and regenerative medicine, a major challenge is to rationally design and control their shape and morphology during differentiation and self-assembly, reducing variability and improving robustness in applications. We propose that an ideal organoid model useful for application would be a flatter multilayer tissue construct anchored on 2D substrate with well-organized internal structures. To achieve this, we form a confluent cell sheet and investigate to control the cell self-assembly process to form the multilayer tissue construct (3.5D organoid). We dissected the dynamics of organoid formation process and found that topological defects on a confluent layer of progenitor cells by mechanochemical cues, can trigger tissue morphogenesis events including collective cell migration, cell sheet folding, differentiation and formation of complex 3D structures like tubes. These events can be controlled partially by the spatial and temporal administration of mechanochemical cues. We envision that µFIP technologies can provide control of these cues, via precise modulation of soluble environment, cell-cell and cell-matrix interaction. Application of these technologies to generate flatter organoids with precision controlled internal structures would address the variability issues inherent in organoid engineering.

BIOGRAPHY

Dr. Hanry Yu is a trained cell biologist turned technology innovator. He ventured into multiple fields, including µFIP from application angle. His lab has established a number of pioneering cell based models and concepts in microfluidics. Recently, he has been integrating mechanobiology into applications. He wishes to stimulate µFIP community to explore new applications of the µFIP technologies in controlling organoid engineering. Dr. Yu is a professor at the National University of Singapore Medical School and NUS College. He is a PI at the Mechanobiology Institute, and co-leads a cell therapy manufacturing program at a MIT research entity in Singapore. He advises companies, institutions and organizations. He has published >220 papers in leading journals, delivered >250 invited talks and commercialized multiple technologies. Dr. Yu is proud of his many students and staff who went on to successful career in academia and industry worldwide.

Droplet trapping, oscillating, and releasing in viscoelastic fluids

Chiyu Xie
Beihang University

ABSTRACT

This talk summarizes our recent findings on droplet trapping, oscillating, and releasing in viscoelastic fluids, which is a new observation of viscoelastic instability in the multiphase flow state. The viscoelastic oscillation causes trapping of droplets in contraction-expansion micro-channels regardless of the injection rate. Based on the force balance analysis on the viscous, capillary and elastic forces, the oscillation amplitude is found to linearly increase with viscoelasticity, and the trapped droplet size is determined by the elasto-capillary number. The oscillation also helps to extract droplets from their originally trapped positions such as dead-ends once a critical Deborah number is reached. These results successfully explain the phenomenon that the alternative injection of viscoelastic and inelastic fluids continually produces additional oil, indicating that the viscoelastic oscillation is a new important mechanism of viscoelastic fluid for enhanced oil recovery. It also provides new possibilities for the manipulation of droplets.

BIOGRAPHY

Dr. Chiyu Xie is a professor at Beihang University. He gained his doctoral degree from Tsinghua University in 2018, and worked as a postdoc at The University of Texas at Austin during 2018-2021. He was also a technical consultant for Total E&P USA, Inc. He has been working on fundamental problems of multiphase flow that are related to energy and the environment. He has developed a series of LB models for the multiphase flow of non-Newtonian fluids in porous media, successfully enriched the mechanical understanding towards the mechanisms of chemical EOR. He has published over 50 journal papers, including PRL, JFM, WRR, etc. He won the Best Young Researcher Presentation Award in the CMWR 2020 Conference. His current research interests include non-Newtonian fluid mechanics, interfacial dynamics, multiphase flow in porous media, pore-scale modeling, and microfluidics.

Light-Responsive Surfactants for Droplet Manipulation

Megan Yi-Ping Ho
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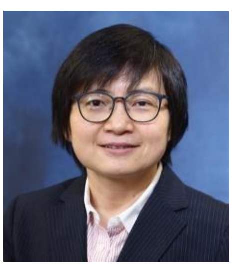
ABSTRACT

Droplet microfluidics has gathered significant interest for biomedical applications. Currently, fluorocarbon oil is the most commonly used continuous phase in droplet microfluidics. Kinetic stabilization of water-in-fluorocarbon oil droplets requires the surfactants being partially fluorophilic and hydrophilic, such as the perfluoropolyether-polyethylene glycol block copolymer. Additionally, particulate stabilizers, such as fluorinated silica nanoparticles (NPs), are recently introduced as surfactants for droplets, termed fluorinated Pickering emulsions. Upon stable production of droplets, droplet manipulation, such as droplet moving and merging, would allow for large-scale complex biological and chemical assays. Although active droplet manipulation by light may provide benefits such as three-dimensional addressing and dynamic reconfiguration, optical based techniques have received relatively scant attention due to the inefficient energy harvest from light. Inspired by the development on thermoplasmonics, where heat may be effectively generated in plasmonic metal NPs under light illumination, we present a novel surfactant based on fluorinated plasmonic NPs, rendering a previously unavailable feature of photo-responsiveness in droplets produced by microfluidics. The demonstration by fluorinated gold-silica core-shell NPs (f-Au@SiO_2) has shown effective in stabilizing the water-in-fluorocarbon oil droplets and promising for light-driven droplet manipulation enabled by the plasmonic photothermal effect. The intense photothermal response inherited from the f-Au@SiO_2 has also enabled on-demand selective release of trapped droplets. The release event may also be triggered by fluorescence signal, the most commonly used staining in biochemical reactions. Among the reported release methods by for example the light-induced bubble, the presented release platform based on fluorinated plasmonic NPs demonstrates the salient features of simple chip fabrication, low laser power, short response time, facile scale-up ability, and reusability of the microfluidic traps. These efforts are expected to fuel the droplet-based large-scale screening applications, where fast and precise retrieval of targeting droplets after extended incubation and observation are in critical need.

BIOGRAPHY



Yi-Ping (Megan) Ho is currently an Associate Professor and the Vice Chairman (Research) in the Department of Biomedical Engineering at the Chinese University of Hong Kong. She received her B.S. and M.S. in Power Mechanical Engineering from National Tsing-Hua University, Taiwan. She received her Ph.D. in Mechanical Engineering from the Johns Hopkins University. After her postdoctoral training with Duke University, she received the Young Elite Researcher Award from the Danish Research Council and started her independent career at Aarhus University in Denmark. She has published 83 peer-reviewed journal articles, 7 book chapters, 83 conference papers, edited 1 book and holds 4 granted patents. The results that she presented have been recognized internationally by the American Society of Gene Therapy and Controlled Release Society. Her research is focused on developing nanosensors and microfluidics as diagnostic tools that may potentially expand the capacity of disease detection and treatment evaluation.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Deep Droplet Digital LAMP (dddLAMP) by Omni-directional Ejection on Digital Microfluidics

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ABSTRACT

Digital microfluidics (DMF) holds immense promise in the precise manipulation of individual droplets for biomedical research, disease diagnosis, and forensic analysis. However, the restricted number of electrodes on DMF poses a fundamental obstacle to realizing high throughput applications on DMF, including digital nucleic acid amplification and analysis. In this study, we introduce a novel approach termed Deep Droplet Digital LAMP (dddLAMP) for absolute nucleic acid quantification using digital microfluidics. We have developed an omni-directional droplet ejection platform to generate tens of thousands of non-uniform droplets in seconds with a simple and robust setup. The non-uniformity and a huge number of those sub-droplets at various volume scales from femtoliter to picoliter provide a way to analyze a large dynamic range of the original sample. Additionally, we used photocurable polyurethane as the continuous oil phase to achieve the rapid in situ photoimmobilization of droplets for digital LAMP. This circumvents possible fusion/fission of surface tension-controlled droplets due to drastic temperature changes during LAMP thermal cycling. Absolute quantification of λDNA is achieved by counting the number of positive dots after on-chip incubation, demonstrating the strong potential for rapid, low- cost, reliable, and quantitative nucleic acid analysis with high accuracy.

ABSTRACT FIGURE

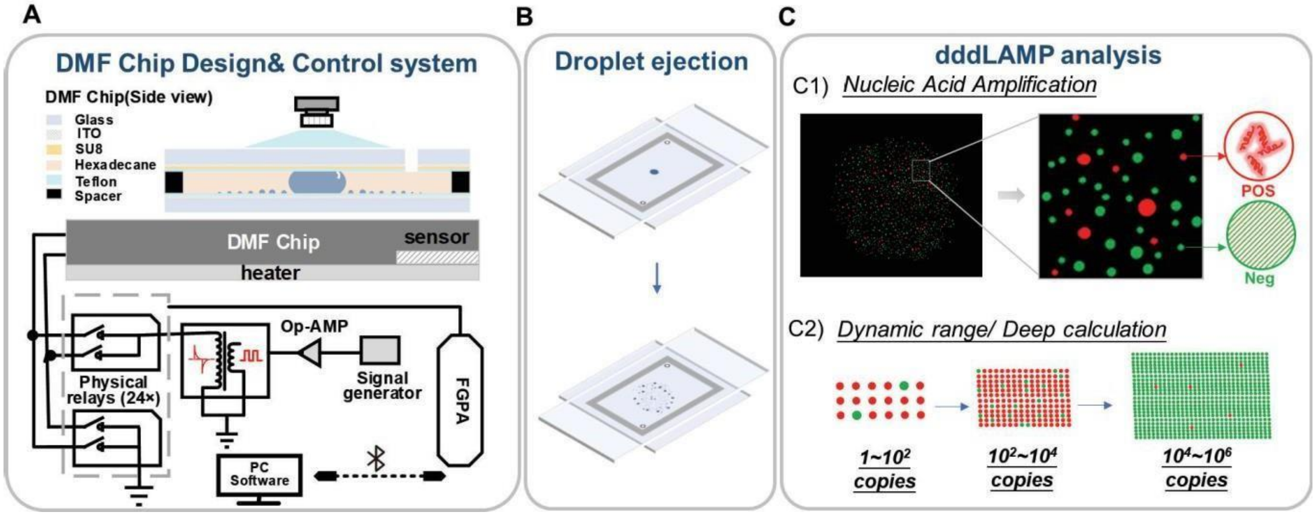

Figure Schematic system setup of deep droplet digital LAMP (dddLAMP) by Omni-directional ejection on digital microfluidics. (a) DMF chip design and DMF control system. (b) Droplet ejection. (c) dddLAMP analysis.

Living Metasurface Biosensors for Immune Functional Profiling

Chia-Hung Chen
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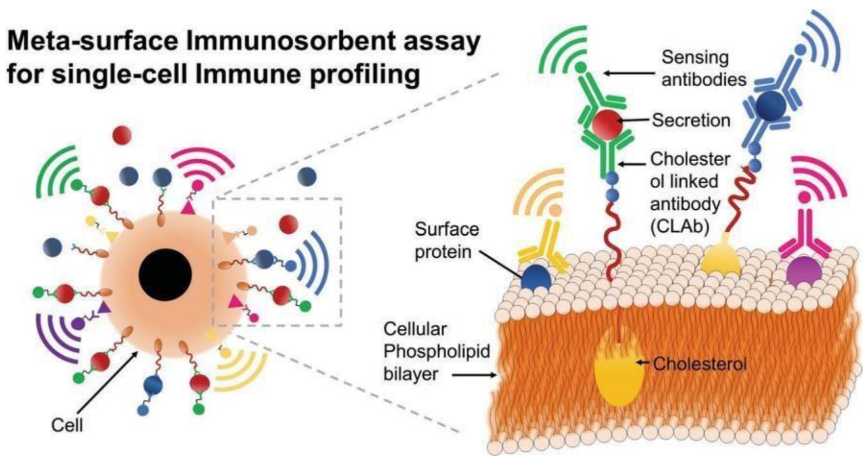
ABSTRACT
Multiplexed single-cell analysis is revolutionizing biomarker discovery for disease monitoring, thus advancing precision medicine. However, traditional immunosorbent assays often lack efficiency, while droplet microfluidics require custom assays for each biomarker, posing significant challenges. To overcome these limitations, we have developed a high-throughput cell membrane immunosorbent assay utilizing cholesterol-linked antibodies (CLAbs). This innovative method seamlessly integrates the specificity of immunosorbent assays with the scalability of microfluidics, allowing for concurrent analysis of cell surface proteins and secretions. With our technique, we can rapidly screen cells at a rate of approximately 1,000 per second, enabling the differentiation between healthy and diseased states, such as in nasopharyngeal carcinoma. By identifying unique immune cell clusters, our approach holds promise for guiding precision therapy in various diseases.



BIOGRAPHY

Chia-Hung Chen is focused on exploiting microfluidic devices, soft systems and single cell micro/nanotechnologies for comprehensive analysis of cellular heterogeneity in human health and disease. The goal is to innovate advanced tools to revolutionize diagnosis, and therapeutical strategies of complex human diseases including cancer, infectious and autoimmune diseases to enable precision medicine.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Explore Surface Thermodynamics using a Smart Droplet Technique

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ABSTRACT

Surface thermodynamics deals with the study of thermodynamic properties and processes that occur at material interfaces or surfaces. It serves as a two-dimensional counterpart to the classical thermodynamics. Langmuir monolayer self-assembled at the air-water surface represents an excellent model for studying surface thermodynamics involving phase transitions and lipid polymorphism. Compared with numerous studies of phospholipid phase transitions induced by isothermal compression, there are very scarce reports on two-dimensional phase transitions induced by isobaric or isoareal heating/cooling. This is mainly due to technical difficulties of continuously regulating temperature variations while maintaining a constant surface pressure or a constant molecular area in a classical Langmuir-type film balance. Here, with technological advances in constrained drop surfactometry (CDS), we have studied the isobaric and isoareal phase transitions in the dipalmitoylphosphatidylcholine (DPPC) monolayer. It was found that temperature, surface pressure, and molecular area are three equally important intensive properties that jointly determine the phase behavior of the phospholipid monolayer. For the first time, we have determined the critical point for the DPPC monolayer with a unique combination of temperature, surface pressure and molecular area. Beyond this critical point, no phase transition can exist in the DPPC monolayer, either by isothermal compression or by isobaric heating. Our study provides novel insights into the understanding of two-dimensional surface thermodynamics. Fundamental knowledge derived from this study may findapplications in biomembranes and pulmonary surfactants.

Short Bio

Prof. Zuo earned his PhD from the University of Toronto. Currently, he holds the position of Professor in the Department of Mechanical Engineering at the University of Hawaii at Manoa, and serves as an Adjunct Professor in the Department of Pediatrics at the John A. Burns School of Medicine. Additionally, he serves as an editor for 'Colloids and Surfaces A: Physicochemical and Engineering Aspects.' Prof. Zuo's research focuses on biomedical engineering, particularly in lung surfactant-related therapies, as well as development of droplet/bubble technology, environmental science and technology concerning nanoparticle and aerosol inhalation. He has received the NSF CAREER Award and Faculty Research Awards.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

REGULATION OFBIOMOLECULAR PHASE SEPARATION BY MICROFLUIDICS

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ABSTRACT

Biomolecular phase separation is crucial in organizing cytoplasmic and nuclear biomolecules into membrane-less condensates and organelles, allowing various biological functions to take place. The formation of these bio-molecular condensates involves complex interactions between different molecules and interfaces, the kinetics of phase nucleation and growth, and other intriguing phenomena that occur on a micro and nanoscale in biological environments. However, our understanding of the underlying mechanisms and precise control of biomolecular phase separation remains limited. To address these issues, this study designed a microfluidic channel capable of precisely controlling the experimental conditions, including concentration and flow rates, and can systematically observe nucleation and growth dynamics associated with phase separation. Furthermore, manipulating salt concen- tration and interactions among proteins and solid surfaces was employed to control the growth dynamics of phase- separated droplets. In summary, we provide an in vitro system that allows for the systematic observation of the phase separation dynamic process. This gives the foundation for understanding the formation of biomolecular con-densates and their regulations in complex environments.

NANOFLUIDIC CONTROL BY ELECTROSTATIC GATING

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ABSTRACT

Electrocapillary techniques exhibit great advantages in nonmechanical electrofluidic manipulation, e.g., flow actuation in micro-/nano- channels. we show for aqueous electrolyte imbibition in nanoporous gold that the fluid flow can be reversibly switched on and off through electric potential control of the solid–liquid interfacial tension. By shrinking the pore size down to an atomic scale, we show that an atomic-scale ion transistor can be constructed by graphene channels of 3 angstrom size under electrostatic gating to mimic biological ion channels acting as life's transistors, which can gate simultaneously fast and selective ion transport through atomic-scale filters to maintain vital life functions. The atomic-scale ion transistor exhibits simultaneously ultrafast and highly selective ion transport with the ion diffusion coefficient reaching two orders of magnitude higher than that in bulk water. We observe the atomic-scale ion transport has a threshold behavior due to the critical energy barrier for hydrated ion insertion, similar to that in biological channels. Our in situ optical measurements suggest ultrafast ion transport likely originates from highly dense packing of ions and their concerted movement inside the graphene channels. This mechanism is analogous with that of "Newton's cradle". This discovery opens a door to both fundamental understanding of ion transport and applications such as water desalination, mineral ion extraction, and medical dialysis.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
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INVESTIGATION OF WAVE-SOLID-FLUID INTERACTION IN RECONFIGURABLE ACOUSTOFLUIDIC SYSTEM

Jeongeun Park[1], Beomseok Cha[1], Furkan Ginaz Almus[2], Mehmet Akif Sahin[2], Ghulam Destgeer[2], and Jinsoo Park[1]

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ABSTRACT

Acoustofluidics has emerged as a promising technology that leverages acoustic waves for micro/nano-scale flow control with a non-contact, label-free approach. Acoustofluidic systems consist of an acoustic wave generating device and a polydimethylsiloxane (PDMS) microchannel. The PDMS microchannel is required to be permanently bonded to the wave-generating device to prevent leakage of the fluid sample. To prevent sample cross-contamination, reconfigurable acoustofluidic systems utilize a PDMS film to facilitate reversible bonding between a device and a microchannel. In reconfigurable acoustofluidic systems, the acoustic waves transmitted through a PDMS film to the fluid in the microchannel experience wave attenuation due to the viscoelasticity of PDMS. Heating induced by wave attenuation leads to thermal damage in biological samples and local boiling of liquid samples. However, there has been no guideline for the PDMS film thickness. The PDMS film thickness determines the length scale of wave attenuation. In this study, we quantitatively investigated the PDMS thickness effects on wave-solid-fluid interaction analysis and proposed a design rule for reconfigurable acoustofluidic systems. Polymer microparticle trapping experiments were performed using various PDMS thicknesses to indirectly quantify wave attenuation. Particle image velocimetry was used to analyze the acoustic flow field based on the PDMS thickness. It was revealed that the propagating waves completely attenuated when they traveled eight times their wavelength. Our findings suggest that the PDMS thickness relative to the acoustic wavelength plays a crucial role in wave attenuation in PDMS and the working mechanism of reconfiguration acoustofluidic systems.

ABSTRACT FIGURE

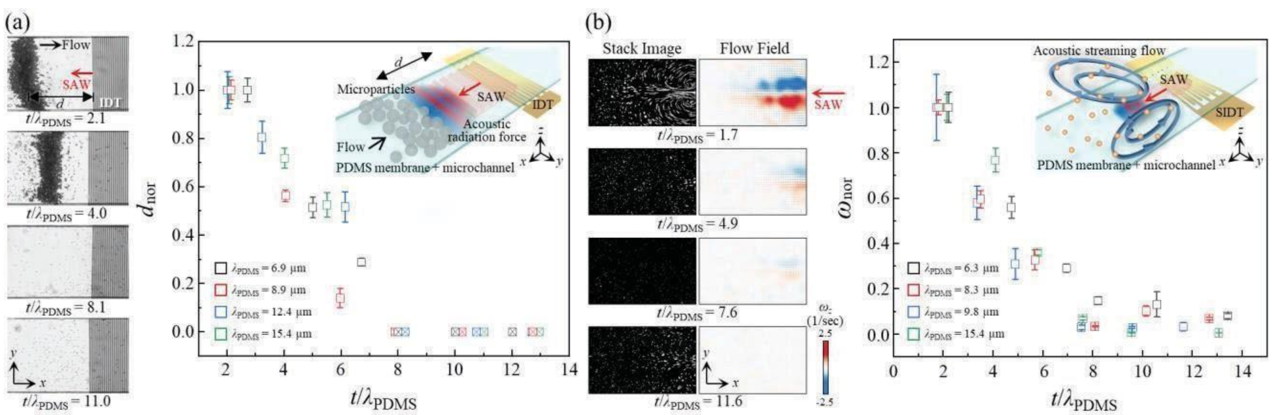

Figure 1 Experimental images and normalized graphs as a function of PDMS thickness divided by acoustic wavelength in PDMS. (a) Particle trapping distance with varying frequency. (b) Wave-induced vorticity with varying frequency.

ACKNOWLEDGMENT

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Visualizing the Miscibility Interface: Experimental Determination of MMP for CO_2 and Shale Oil in Nanoporous

Haowei Lu, Peixue Jiang, Ruina Xu*

Key Laboratory for CO_2 Utilization and Reduction Technology of Beijing, Key Laboratory for Thermal Science and Power Engineering of Ministry of Education, Department of Energy and Power Engineering, Tsinghua University, Beijing 100084, China

ABSTRACT

As a promising unconventional resource, shale oil is naturally generated and stored within nanoporous. The enhancing recovery of shale oil through miscible CO_2 injection relies critically on the minimum miscibility pressure (MMP), which signifies the threshold at which the CO_2-oil interface vanishes. However, due to the minute fluid volumes and the vanishing interface in nanoconfined spaces, accurately delineating the miscible interface and determining the MMP is challenging. Debate persists regarding potential deviations of the MMP at the nanoscale from macroscale.

To address these challenges, we have developed a visualization method for nanoporous experimental samples using photolithography-etching-bonding technology, which typically faces limitations in pressure handling and exhibits weak fluid signals. Our method enables direct visualization of fluid interfaces at 15 MPa within 25 nm deep one-dimensional nanoporous by enhancing the contrast signal at the multiphase fluid interface through silica layer oxidation on the nanoporous surface.

In our study, we explore the MMP of CO_2 and oil within nanoporous structures using a novel approach that diverges from the conventional "interface disappearance method." We utilize the pressure corresponding to the abrupt change in CO_2-oil interface thickness as the experimental criterion for MMP determination. As the pressure increases, the phase distribution shifts towards the oil phase, enabling us to quantify MMP values for nanoporous structures with different depths. Our experimental findings indicate that the MMP of CO_2-n-dodecane in 25 nm deep nanoporous aligns with macroscale, thereby resolving the controversy surrounding the consistency of MMP in sub-100 nm pores in comparison to macroscale.

All-aqueous interfacial phenomena

Anderson Ho Cheung SHUM
The University of Hong Kong

ABSTRACT

In this talk, I will share our works investigating microflows and interfacial phenomena along aqueous liquid-liquid interfaces. These interfaces arise as a result of aqueous phase separation based on the interactions of the constituent molecules in water. The unique properties of these interfaces, such as adjustable interfacial tensions, preferential affinity to different water-soluble compounds, and concentration dependence, lead to different flow and interfacial behaviors. In addition, the bio- and cyto-compatibility, ability to enrich and concentrate molecules, as well as their versatility to enable interfacial assembly and reaction make them suitable as templates for biomaterials and biomedical applications.

BIOGRAPHY

Ir Prof. Anderson Ho Cheung SHUM received his B.S.E. degree, summa cum laude, in Chemical Engineering from Princeton University, S.M. and Ph.D. in Applied Physics from Harvard University. He is currently a Professor (Tenured) in the Department of Mechanical Engineering and Associate Vice-President (Research and Innovation) at the University of Hong Kong (HKU). He also serves as the Founding Director of the Advanced Biomedical Instrumentation Centre (since 2021). His research interests include aqueous two-phase systems, emulsions, biomicrofluidics, biomedical engineering, and soft matter. Prof. Shum was selected as Fellows of the International Association of Advanced Materials (FIAAM, 2023), Hong Kong Institution of Engineers (FHKIE, 2023), Croucher Senior Research (2020), Royal Society of Chemistry (FRSC, 2017), and as President (since 2021) and Founding Member (since 2018) of Hong Kong Young Academy of Sciences. He currently serves as Editorial Board Member for Microsystems and Nanoengineering (Springer Nature), Scientific Reports (Springer Nature), and Colloids and Interfaces by MDPI AG, as well as Editorial Advisory Board Member for Lab-on-a-Chip (RSC) and Associate Editor for Biomicrofluidics (American Institute of Physics).

Microfluidic manipulation of multiphasic liquid-liquid phase-separated (LLPS) systems for in vitro models

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ABSTRACT

Nature has demonstrated the power to synthesize chemicals, achieve diverse functions and construct complicated materials through aqueous compartmentalization. In living cells, biological condensates, phase-separated membrane-less compartments, are crucial in regulating biochemical reactions and orchestrating cellular functions. Inspired by these natural systems, synthetic condensates exploit the principles of liquid-liquid phase separation (LLPS) to selectively concentrate or exclude various biomolecules, such as peptides, proteins, nucleic acids, and even bacteria. By integrating LLPS with microfluidics technology, which allows precise control of flow and distinct interfaces, we create detailed and functional in vitro models. We combine segregative and associative LLPS methods to generate hierarchically compartmentalized structures and control fluid dynamics to form "stagnation rings" that maintain core-shell compartments for biochemical reactions, including protein and nucleic acid segregation, enrichment, and amplification. We engineer coacervates that enhance biomolecule concentration, improving detection sensitivity, with DNA amplification in coacervate droplets showing a strong correlation between DNA copy number and fluorescent droplet count, thus reducing detection limits. Inspired by the hanging drop method, we use microfluidics to assemble GUV-based protocells into arrays connected by lipid bilayers, facilitating cell-cell and cell-environment communication and enabling the creation of hybrid cell/protocell spheroids for new biomaterials and in vitro models. Additionally, we exploit interfaces of multiphase LLPS to enable freeform three-dimensional printing of liquid-liquid architectures compatible with viable cells. The synergy between multiple LLPS and microfluidics has the potential to create more detailed and functional in vitro models, significantly enhancing our ability to study and replicate complex biological processes.

BIOGRAPHY

Prof. Tiantian Kong is currently a professor in the Department of Biomedical Engineering at Shenzhen University China. As the first or corresponding author, she has contributed to more than 90 papers published in high-impact journals, including Nature Communications, Proceedings of the National Academy of Sciences (PNAS), Advanced Materials, Angewandte Chemie, and others. She has served as Editorial broad Member/Guest Editor for high-impact journal Microengineering and Nanosystems (MINE), Green Energy Environment (GEE) and Small. In 2020, she was granted the "Young Scientist Award" at the Microsystem and Nanoengineering Summit. Further, in 2022, she was named an "Emerging Investigator" by Soft Matter (RSC). Later that year, she also received the Second Prize of the Science and Technology Award from the Chemical Industry and Engineering Society of China (CIESC). In 2023, she received a competitive recognition of the “Excellent Young Scholar” of National Natural Science Foundation of China (NSFC).

Rapid and Selective Cell Lysis Achieved with a Chemical-Free Piezoelectric Actuator Preserving Cytoplasmic Integrity

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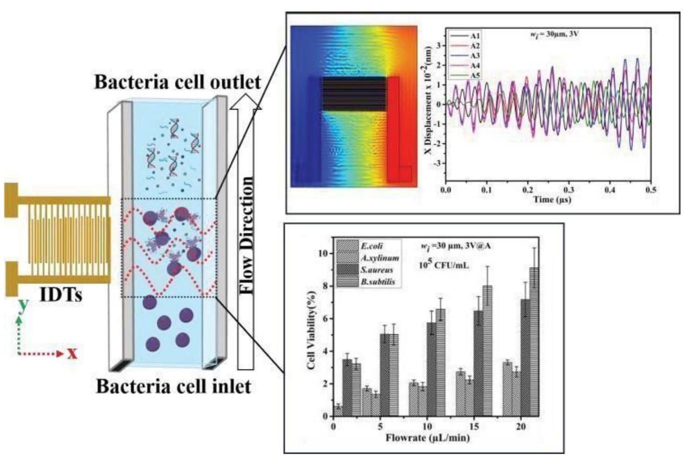
ABSTRACT

Molecular methods for disease diagnosis rely on extracting DNA/RNA and other markers from within the cell membrane of the pathogen. However, the presence of a complex cell wall in these infectious organisms provides a protective barrier, making it difficult for diagnostic and therapeutic efforts to be effective. This necessitates the use of specialized techniques, known as cell lysis, to disrupt the cell wall without altering the molecular composition of the cellular contents. We present a cutting-edge microfluidic technique utilizing travelling surface acoustic waves (TSAW) for cell lysis. This method allows for the lysis of any biological entity, eliminating the requirement for additional additives. The cells in the sample solution flowing through a PDMS microchannel are able to be lysed due to their interaction with TSAW that is propagated from gold interdigitated transducers (IDT) that are patterned onto a $LiNbO_3$ piezoelectric substrate, which is bonded to the microchannel. Numerical simulations was performed to analyze the wave propagation intensities under different parameters such as IDT design, supply voltage, and channel distance from the IDT. Experiments were conducted to validate the simulations and determine the optimal lysis parameters for achieving a high NA/protein extraction efficiency of over 95% in just a few seconds. Our method outperforms traditional chemical, physical, and thermal methods as well as current microfluidic methods for lysis. It is an effective strategy that can replace current protocols for the lysis of any pathogen, cell, and tissue at low voltage (3 V) and frequency (33 MHz) without requiring any modifications.

ABSTRACT FIGURE



Marangoni-Flow-Assisted Assembly of Single-Walled Carbon Nanotube Films for Sensors

Yuguang Chen[1], Yitan Li[2], Zilong Qiu[1], and Yan Li[1]

[1] *College of Chemistry and Molecular Engineering, Peking University, Beijing 100871, P. R. China*
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ABSTRACT

Single-walled carbon nanotubes (SWCNTs) exhibit superb electronic and mechanical characteristics that are sought after in wearable and flexible devices. The first step in creating a variety of devices involves producing SWCNT films. We develop a scalable and feasible method to assemble SWCNT thin films on water surfaces based on the Marangoni flow. When the dispersion of SWCNTs in water-soluble organic solvents is injected onto a water surface, a Marangoni flow is induced by the surface tension gradient between water and the organic dispersant, and the SWCNTs are transported outbound then they assemble into thin films from the margin of the water surface. The films possess a large area of 40 cm × 30 cm (extensible), a tunable thickness of 15–150 nm, a high transparency of up to 96%, and a decent conductivity. The films can be directly transferred to various substrates, including flexible ones. Flexible strain sensors were fabricated with the films on flexible substrates and they worked with high sensitivity and repeatability. By realizing multi-functional human motion sensing, including responding to voices, monitoring artery pulses, and detecting knuckle and muscle actions, the assembled SWCNT films demonstrate the potential for application in smart devices.

REFERENCE

Chen, Y.; Li, Y.; Han, L. et al. Marangoni-flow-assisted assembly of single-walled carbon nanotube films for human motion sensing, *Fundam. Res.* **2022**. https://doi.org/10.1016/j.fmre.2022.05.010.

Stage divisions of droplet generation regimes in a T-junctionmicrochannel

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ABSTRACT

T-junction is one of the most commendable tools to generate droplets in many applications including bioengineering, chemical industry, and the field of thermodynamics. Understanding the mechanism of droplet generation is the key to controlling droplets effectively. The generation process of droplets from a T-junction microchannel is numerically analyzed using the level-set method. Linear theory is introduced to verify the accuracy of the simulation. Four regimes are observed in this paper, including the squeezing, dripping, jetting and parallel flow. We emphasize the roles of pressure change and droplet morphology in stage divisions of droplet generation regimes. As the dimensionless capillary number increases, the effect of the pressure resistance gets weaker, and the viscous shear force plays a dominant role in the generation process, resulting in the differences between regime divisions. Finally, the influences of the flow rate, the surface tension and the contact angle on the dynamic process of droplet generation are comprehensively discussed. The simulation results and theoretical analysis hold a good agreement with the experimental results.

Membrane-Anchored Immunosorbent Assay Based on Cholesterol-linked Antibody Technology for High Throughput Single Cell Multiplexed Analysis

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ABSTRACT

Single cells have an exquisite mechanism capable of responding to the physiological environment by change of expression levels for both surface receptors and secretions. Simultaneously detections of cell types via surface proteins and functions of secretions are of much significance in disease diagnosis and therapeutic monitoring. Immunosorbent assays are promising for assessing multiple cellular compounds but have limited throughput, whereas droplet microfluidics is high-throughput but requires a custom assay for each target. It is therefore needed to develop a high throughput platform for multiplexed single-cell analysis of cell surface biomarkers and secreted proteomic signatures. Here, a cholesterol-linked antibody (CLAb) technology was developed to integrate with flow cytometry (FACS) for high throughput analysis of surface biomarkers and multiple cytokines (Figure 1). The capture antibodies were linked to cholesterol tails via click chemistry to stably anchor to the cell surface due to the hydrophobic interaction between the cholesterol and the lipid of the cell membrane. Single cells grafted with CLAbs were encapsulated within the droplets to capture their secreted proteins on the cell surfaces. After that, the single cells with captured proteins were extracted from the droplets and then labeled by detection antibodies with fluorescence tags and then screened through flow cytometry with a throughput of ~103 cells per second for multiplexed profiling. To show the case, this device was applied to analyze surface biomarkers (CD13) and secreted cytokines (IFN-γ, TNF-α) of M0, M1 macrophages (M0, M1) and dendritic cells (DCs) derived from THP-1 cells to display cell differential efficiency.

ABSTRACT FIGURE

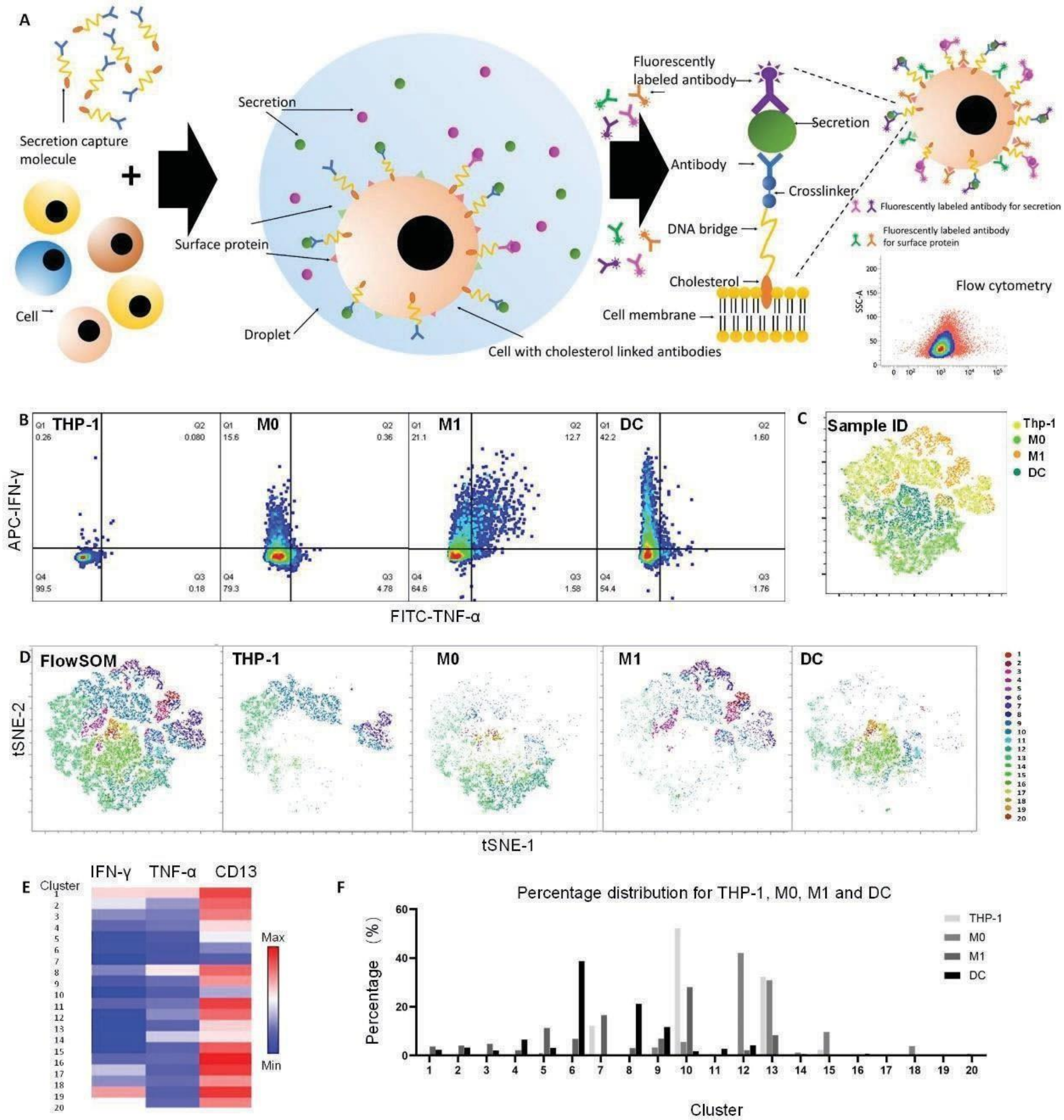

Figure A Schematic of CLAb for single-cell multiplexed analysis. B. Flow cytometry analysis of IFN-γ and TNF-α for Thp-1, M0, M1 and DCs. C. The position of each kind of cell in tSNE map. D. 20 clusters generated by FlowSOM in t-SNE map. E. The scaled total median fluorescence intensity of each marker (IFN-γ, TNF-α, and CD13) was displayed in the heatmap. F. The cluster frequency was depicted in bar graphs.

Biomimetic Emulsion-Templated Surface Engineering for Active microdroplet Harvesting

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ABSTRACT

Drawing inspiration from nature, our research endeavors to enhance microdroplet harvesting efficiency, focusing on biomimetic surface engineering for fog/dew harvesting. Despite the potential of natural superwettable surfaces like beetle backs in capturing water, scalability of bioinspired water-harvest surfaces remains a challenge due to the trade-off between water deposition and transport. Herein, we present a novel approach using structured Pickering emulsions to create a superhydrophobic surface with adjustable hydrophilicity. Preferential exposure of cellulose nanocrystal's outer surface and wax microspheres accelerates droplet deposition allowing for the manipulation of droplet mobility. Appropriate tuning of the wetting characteristics of the surfaces, optimizing the hydrophobicity and density of the water affinity nanodomains enhance the water deposition rate without the sacrifice of water transport rate, achieving a high and long-term water harvesting flux of 5.02 $L/m^2/h$ for a porous substrate. The emulsion-templated surface engineering described here not only offers a facial and scalable approach allows tailored adjustment of droplet pinning-detachment forces applied on droplets for enhanced capture and release, but also offers predictive insights into droplet dynamics during harvesting. This study offers a sustainable strategy for the water-stressed community to ease the growing shortage of clean water, while also providing scalable manufacturing techniques to tailor the surface topology with patterned structures and heterogeneous wettability.

Acoustofluidic Separation of Bacteria from Platelets using Acoustic Radiation Force

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ABSTRACT

Sepsis and endocarditis are conditions that result from bacterial infections in the bloodstream. Sepsis causes one out of five deaths worldwide and claims the lives of one million people annually. The World Health Organization (WHO) passed a resolution aimed at strengthening the prevention, diagnosis, and treatment of sepsis in 2017. The separation of microscale entities, such as cells and bacteria, is a crucial preparatory procedure in various microflu- idic applications within the fields of microbiology, chemistry, biology, and biomedicine. Platelets, due to their size distribution similarity to bacteria, present a technical challenge in the separation, unlike red and white blood cells. Existing microfluidic separations rely on size as a differentiating factor, which limits their effectiveness when separating samples of the similar sizes. In this study, we propose an acoustofluidic approach utilizing a tilted-angle standing surface acoustic wave (taSSAW) for the label-free separation of microscale entities of comparable sizes based on their compressibility. Through experimental analysis involving polymethylmethacrylate, polystyrene, and polycaprolactone microparticles of identical sizes, it was observed that less compressible entities migrated further when subjected to the taSSAW field generated within a microchannel. The research findings indicate that *Escherichia coli (E. coli*) can be effectively separated from platelets using this method. The acoustic radiation force induced by taSSAW on the relatively less compressible *E. coli* was greater than that exerted on the platelets. Various analytical techniques, including fluorescence microscopy, scanning electron microscopy, hemocytometry, sodium dodecyl sulfate polyacrylamide gel electrophoresis, and polymerase chain reaction.

ABSTRACT FIGURE

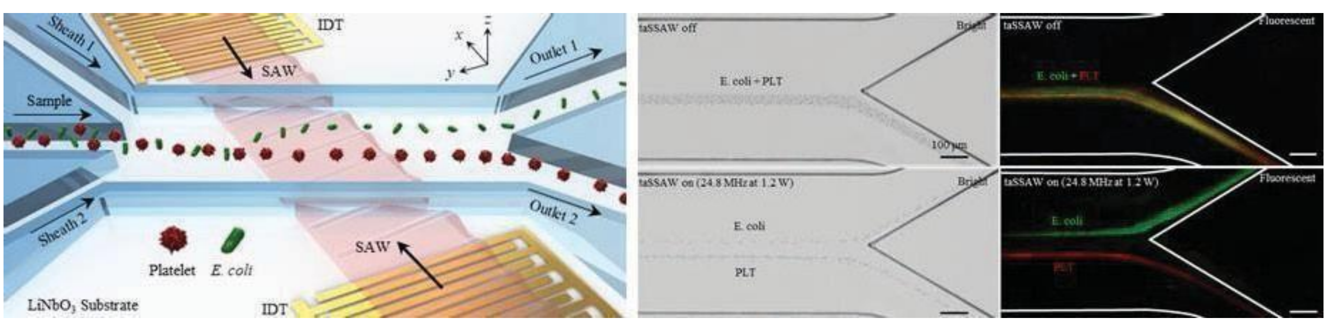

Figure 1. Schematic of acoustofluidics separation of bacteria from platelets

ACKNOWLEDGMENT
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MOLECULAR TRANSPORT THROUGH ANGSTROPOROUS 2D CRYSTALS

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ABSTRACT

It is widely believed that, despite being one-atom thick, graphene and other 2D crystals is completely impermeable to all gases and liquids. In this talk, I will present my recent research[1-4] on the topic "Molecular transport through angstroporous 2D crystals."

Using monocrystalline container made from atomically flat graphite, which is tightly sealed with graphene, we have achieved measurements that put the permeation limit through 2D materials at 8–9 orders of magnitude lower than previously, such that we would discern (but did not observe) just a few helium atoms per hour crossing micrometer-size membranes. This detection limit is also valid for all other gases tested, except for hydrogen. Hydrogen shows noticeable permeation, even though its molecule is larger than helium. The mechanism of this anomalous observation is proposed and later corroborated by experiments. To make the generally "impermeable" graphene not only "permeable" but also highly "selective", we have developed a perforation technique which involves a short-time exposure of the graphene membrane to low-energy electrons. Using the same monocrystalline containers, we are able to study gas transport through the created individual graphene pores with an effective size of about one missing carbon ring. Helium and hydrogen permeate easily through these pores whereas larger molecules such as xenon and methane are blocked. Permeating gases experience activation barriers that increase quadratically with the kinetic diameter, and the transport process crucially involves surface adsorption.

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2. **P. Z. Sun, et al. *Nat. Commun.* 2021, 12, 7170.**
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FORMS AND FUNCTIONS OF SLIPPERY LIQUID-INFUSED SURFACES

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ABSTRACT

The insect trapping capability of the *Nepenthes* pitcher plant, facilitated by its slippery liquid-infused peristome, has inspired the development of a new class of liquid-repellent surfaces since 2011. The advancement of these slippery liquid-infused surfaces has become a pivotal cornerstone in liquid-repellent surface technologies since the introduction of lotus-leaf-inspired superhydrophobic surfaces in the 1990s. In this talk, I will discuss the biological function of the slippery peristome found in the *Nepenthes* pitcher plant and the subsequent development of synthetic bio-inspired slippery liquid-infused surfaces. Specifically, I will explore three distinct forms of slippery surfaces: slippery liquid-infused porous surfaces (SLIPS), slippery rough surfaces (SRS), and liquid entrenched smooth surfaces (LESS). I will elaborate on how these various forms of slippery surfaces influence their functions and applications, and will also provide insights into their recent progress in commercialization and development.

BIOGRAPHY

Dr. Tak-Sing Wong is a Professor of Mechanical Engineering and Biomedical Engineering at Penn State. His research spans surface and interfacial engineering, micro- and nanomanufacturing, and bio-inspired materials design. Dr. Wong is a pioneer in the development of a new class of slippery surfaces, including slippery liquid-infused porous surfaces (SLIPS) and liquid-entrenched smooth surface (LESS). Dr. Wong holds over 60 issued and pending patents, 46 of which are licensed, and co-founded spotLESS Materials Inc., where he currently serves as CTO and director. His accolades include the Presidential Early Career Award for Scientists and Engineers (PECASE), the Innovators Under 35 (Global) by MIT Technology Review, the Distinguished Alumni Award from the Faculty of Engineering of the Chinese University of Hong Kong, and the Faculty Scholar Medal for Outstanding Achievement from Penn State. He is an elected Fellow of the American Society of Mechanical Engineers and the Royal Society of Chemistry.

Control of water slipperiness using heterogeneous self-assembled monolayer surface

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[2]*Fundamental Technology Unit, Nippon Paint Surf Chemicals Co., Ltd., Tokyo, Japan*

ABSTRACT

Wetting behavior of water on a solid surface is present in everyday life and important phenomenon in nature and industry. As a fundamental feature of wetting, contact angle hysteresis, which describes the multiple stability of a droplet on an actual solid surface, is widespread and is directly related to important applications such as heat transfer, self-cleaning, defrosting, droplet transport and microfluidics. Chemical and topological heterogeneity is widely acknowledged to be the origin of contact angle hysteresis. However, the effect of surface heterogeneity on wetting hysteresis in molecular scale is complex and unknown. Here we report that heterogeneous monolayers composed of hydrophilic and hydrophobic polymer molecules exhibit hydrophilic but slippery behavior instead of producing high hysteresis. Systematic investigation of different mixing ratios and molecular lengths reveals that surfaces composed of long hydrophilic and short hydrophobic polymer molecules can even produce reduced hysteresis than uniform monolayer surfaces. X-ray photoelectron spectroscopy and atomic force microscopy are used to characterize the composition and smoothness of the heterogeneous monolayer surfaces. We further found that the small wetting hysteresis of the heterogeneous monolayers can be further reduced by increasing the surface temperature, indicating that the reduced hysteresis is caused by enhanced mobility of the constituent molecules. This study not only paves the way to control hydrophilic but slippery surfaces, but also provides key insights into the molecular nature on dynamic wetting phenomenon.

HIERARCHICAL NANOPOROUS SELF-ASSEMBLED SURFACES WITH ENHANCED DURABILITY OF INFUSED LUBRICANT

Joowon Lim[1], Geonho Lee[1], Beomsu Kim[1], Junho Oh[1], and Won Chul Lee[1]
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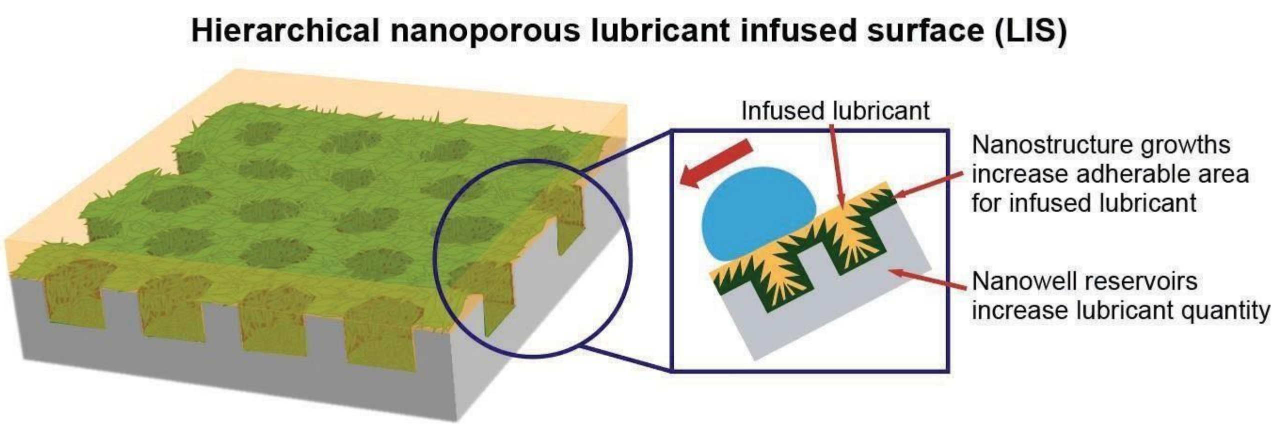
ABSTRACT
This work presents a method for creating lubricant infused surfaces (LIS) using a hierarchical nanoporous surface composed of nanowell reservoirs and nanostructure coating. The nanostructure coating strengthens lubricant retention by greatly increasing adhering area, while increased lubricant quantity from the reservoirs facilitates slower overall depletion. A silicon nanowell array, fabricated using self-assembled semiconductor methods, has copper (Cu) coated onto it, and caustic wet oxidation modifies the surface to form numerous nanostructure growths. Varying oxidation time created different nanostructure morphologies on the nanowell reservoir's top and interior walls. Application of low surface energy material (HTMS, heptadecahexafluorotrimethoxysilane) caused surfaces to exhibit high hydrophobicity, appropriate for fabricating water-repelling LISs. Lubricant (silicone oil) was infused into the surfaces, and the resulting sample's ability to retain infused lubricant was tested over several durability experiments. The infused lubricant's resistance to drainage was tested by exposure to a continuous stream of water droplets. Analysis of contact angle hysteresis (CAH) showed longer lubricant retention duration (+ 20 m) in samples with nanostructure coating on nanowell reservoirs compared to control samples (~10 m). Additionally, the fabricated samples exhibited lubricant recovery in depleted areas after time passed, showing attributes associable with LIS not observed in control samples. Finally, the infused lubricant showed strong resistance to shear when exposed to high spin speeds on a spin coater, while maintaining the fabricated surface's original constitution. The obtained results offer insight on understanding differing surface structure's performance when used for LISs, while further optimization promoting fabrication of LISs with enhanced lubricant retention.

ABSTRACT FIGURE



Asymmetric deposition on high-speed moving superhydrophobic surfaces

Meng Wang, Shun Wang and Meirong Song*[a]

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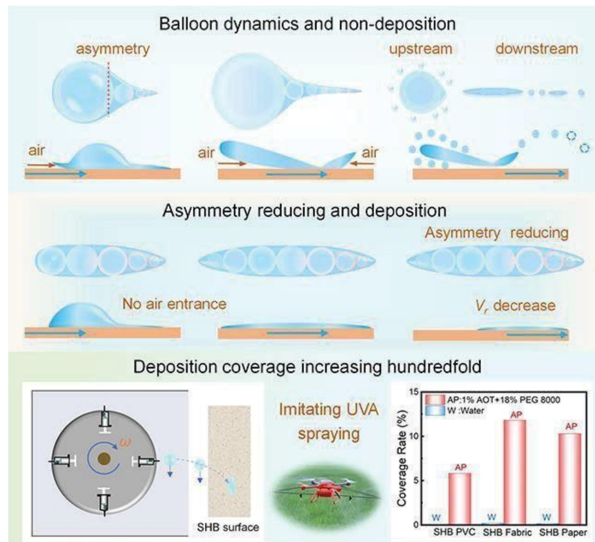
ABSTRACT

Droplet deposition on high-speed moving superhydrophobic (HM-SHB) surfaces is important for industrial and agricultural purposes. However, current deposition additives for static SHB surfaces don't work well on HM-SHB surfaces. This is because the highly asymmetric balloon-string impact dynamics and prompt air entrainment reduce the contact time for aqueous droplets by more than 63%, making deposition difficult. To solve this problem, the asymmetry between the upstream and downstream parts hasbeen reduced to a spindle deposition shape. This was done by adding a large quantity of molecular polymer and small amounts of surfactant to increase viscosity and decrease surface tension,



thereby reducing relative lateral solid–liquid velocity and consequently inhibiting air entrainment. Additionally, the relationship between dynamic capillary number and contact angle is disclosed to be linear, taking into account viscosity, surface tension, and solid-liquid relative motion speed. This novel deposition strategy is effective in imitating drone spraying with a significant hundredfold increase in deposition coverage. This work improves our understanding of the complicated impact dynamics on HM-SHB, enhances liquid deposition and provides a solution in related applications.

BIOGRAPHY

Meirong Song is currently a professor in college of science at Henan Agricultural University. She received his B.S. degree from Nanjing University of Technology and Science in 1998, M.S. degree from Henan University in 2004 and Ph. D. degree from Chinese Academy of Sciences in 2007. Her research interest focuses on the phenomena of droplet-solid impacting like directional droplet bouncing and enhancing deposition on superhydrophobic leaves and so on.

LIQUID DROPLETS ON LIQUIDLIKE SURFACES

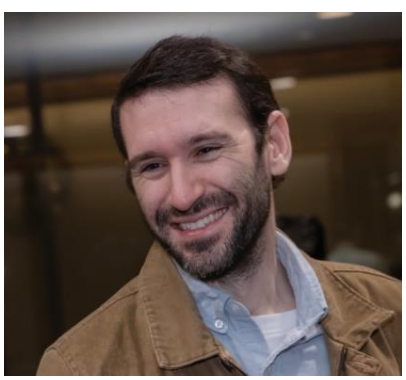
Professor Kevin Golovin
Department of Mechanical & Industrial Engineering, University of Toronto

ABSTRACT

Surface-grafted polymer chains can be tuned to retain many of the fluidic properties of the polymer in the liquid phase. Such 'liquidlike' surfaces have unique surface properties, particularly when in contact with liquid droplets or solid fouling substances. In this talk I will overview some of the most interesting surface phenomenon that occur on liquidlike surfaces in terms of wettability, adhesion, and droplet mechanics. Applications include the development of non-fluorinated omniphobic surfaces, anti-fouling surfaces and coatings, ultra-small volume liquid viscometry, the lossless, self-transportation of low surface tension liquids, including against gravity, and also surfaces with low adhesion to highly adhesive substances, such as ice and glues. Throughout the talk I will attempt to emphasize what aspects of the liquidlike properties are most beneficial in terms of engineering surface design, as well as highlight the unanswered questions that remain in the field today. Further, the extremely important and often overlooked role of chain termination will be discussed, especially in relation to contact line friction and solid adhesion. Strategies for altering the chain termination will be investigated, which lead to exciting surface properties unachievable when only considering the polymer backbone and side chains.

BIOGRAPHY

Kevin Golovin is an Assistant Professor at the University of Toronto in the Department of Mechanical & Industrial Engineering. Golovin holds degrees in material science and engineering from Cornell University and the University of Michigan. His research group investigates interfacial mechanics, coatings, surface modification, andsustainable methods for achieving solid and liquid repellency. His current research interests include reducing microplastics release, sustainable chemistry, textiles, and smart materials, coatings, and surfaces. He has published 100+ research articles, mostly in the fields of materials science, fluid mechanics, polymer chemistry, and wettability. Prof. Golovin is an inventor on 11 patents, two of which are actively licensed. He has received various accolades, including the Eco Innovation Case Competition Grand Prize from Patagonia, and was named an Emerging Leader in Chemical Engineering by the Canadian Society of Chemistry in 2020. In 2023, Golovin received the SGS Early Career Supervision Award from the University of Toronto.



BIOINSPIRED TWO DIMENSIONAL CARBON-BASED NANOCOMPOSITES

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ABSTRACT

High performance nanocomposites can potentially solve the bottleneck problems of miniaturization and lightweight in the field of aerospace. Although two-dimensional carbon-based nanosheets, such as graphene, MXene, show excellent mechanical and electrical properties, the properties of carbon-based nanocomposites are much lower than expectation. It was found that the void is an essential factor to decrease the properties of carbon- based nanocomposites, but usually neglected in the past decades. Herein, we applied both focused ion beam and scanning electron microscopy tomography (FIB/SEMT) and nanoscale x-ray computed tomography (nano-CT) to reconstruct the void microstructure of carbon-based nanocomposites. These results overturned the conventional densely stacked structure model of carbon-based nanocomposites. We further developed a simple and effective densification strategy to cure the voids using a sequential bridging process with different interfacial interactions. The resultant sequentially bridged carbon-based nanocomposites[1-5] achieved dramatical improvement in mechanical properties, resistance to cyclic mechanical deformation, oxidation, and stress relaxation etc.

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BIOGRAPHY

Dr. Cheng is now a full professor and the deputy dean of the School of Chemistry. He has published 110 papers, including Science, Nature Materials, Nature Communications, and PNAS. He has received grants from the National Science Fund for Distinguished Young Scholars, the Newton Advanced Fellowship, etc. He was awarded the Beijing Distinguished Young Zhongguancun Award, Mao Yi-sheng Science and Technology Award-Beijing Youth Science and Technology Award,China Young Scientist Award of Composites Society, the Chinese Chemical Society Award for Outstanding Young Chemist, and the Cheung Kong Scholar Award for Young Scholars.

PREPARATION AND APPLICATION OF POROUS COMPOSITE MATERIALS WITH SPECIAL SURFACE WETTABILITY

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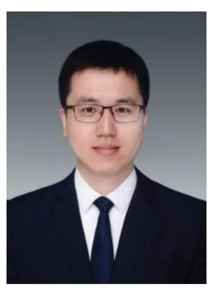
[2] *International Center of Future Science, Jilin University, Changchun 130012, P. R. China*

ABSTRACT

The interaction of all things starts from the surface, and the integration of surface properties and bulk porous structure endows composite materials with new functions. Focusing on the interdisciplinary field of surface/interface science and porous materials, we have designed and constructed thermally insulating and highly polarized porous materials with special surface wettability by adjusting the surface properties and bulk-phase porous structure of the material, and developed their applications in the fields of heat transfer and liquid phase separation, respectively. The main innovations include: (1) Proposed strategy for the superwetting of liquid on the surface of 1150 degree Celsius using thermally insulating inorganic porous membranes, overturning the classical physical effect of liquid suspension on high-temperature surfaces (Leidenfrost effect), solving the thermal problems that have plagued the scientific research and industrial circles for 266 years, and a structured thermal armor is developed for efficient liquid cooling in an extremely high temperature environment; (2) Proposed a new universal separation principle and strategy by using the difference in polar interaction between inorganic porous membranes and different liquids, providing from the principle achieving the efficient separation of arbitrary immiscible liquids for the first time.

BIOGRAPHY



Yang Wang is a professor at College of Chemistry, Jilin University. From 2008 to 2017, he received a bachelor's degree and a doctorate degree from College of Chemistry, Jilin University, under the tutelage of academician Jihong Yu and academician Lei Jiang. From 2018 to 2022, he is engaged in postdoctoral research at the City University of Hong Kong. In 2023, he is returned to Jilin University to teach. The main research direction is porous materials and surface/interface science. By adjusting the surface properties and bulk-phase porous structure of the material, a variety of porous materials with special surface wettability have been prepared, which has broadened and opened up the application of porous membrane materials in the field of liquid separation, atmospheric water harvesting and heat transfer. He has published 13 SCI papers in international journals such as Nature, Nature Communications, Matter, Advanced Functional Materials, Chemical Science.

Overcoming the Adhesion Paradox and Switchability Conflict on Rough Surfaces with Shape Memory Polymers

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Maintaining adhesion on rough surfaces is a long-standing challenge in engineering due to the adhesion paradox [1,2] (rapid decrease in adhesion strength with increasing surface roughness) and the switchability conflict (trade-off between strong adhesion strength and easy detachment). Here, we show [3-5] that, utilizing the rubber-glass transition of shape memory polymers (SMPs), both challenges are overcome. Making contact between an SMP adhesive and a rough surface in the rubbery state followed by shape-locking in the glassy state results in orders of magnitude enhancement in adhesion strength. On the other hand, detaching the SMP adhesive upon transitioning back to rubbery-state results in weak adhesion and on-demand detachment. We further demonstrate that, employing our method, rougher surfaces enable stronger adhesion and easier detachment. The working principle and the mechanics model of R2G adhesion provide guidelines for developing stronger and more switchable adhesives adaptable to rough surfaces, thereby enhancing the capabilities of smart adhesives, and impacting various fields such as adhesive grippers and climbing robots.

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BIOGRAPHY

Changhong LINGHU is currently a Postdoctoral Research Fellow in the School of Mechanical and Aerospace Engineering at Nanyang Technological University, Singapore collaborating with Prof. Huajian Gao and Prof. K Jimmy Hsia. He received his Ph.D. degree in Mechanical & Aerospace Engineering from Nanyang Technological University, Singapore in 2023, and his M.S. and B.E. in Solid Mechanics and Engineering Mechanics from Zhejiang University, China in 2020 and 2017, respectively.

He is dedicated to exploring the Mechanics and Applications of Adaptable Interfacial Adhesion Systems Across Multiple Domains, and works in the interdisciplinary frontiers of mechanics, materials, and engineering. He has published 21 peer-reviewed papers (with 950 citations, H-index =14), including **3 ESI highly cited papers (Top 1‰)** in journals such as ***Nature Communications***, ***Science Advances***, ***PNAS***, ***npj Flexible Electronics***, ***Soft Matter***, ***Journal of the Mechanics and Physics of Solids***, ***Extreme Mechanics Letters***, ***International Journal of Solids and Structures***, and one chapter in an Elsevier book. He has also served as a reviewer for SCI journals including ***Extreme Mechanics Letters, Theoretical and Applied Mechanics Letters,*** and ***Chemical Engineering Journal***.

He has filed **18 Chinese and 2 International Patents** with over ten of them being successfully commercialized. Moreover, he has impact by implementing his research findings. His accomplishments have been recognized by approximately 50 innovation and entrepreneurship awards.

To date, he has mentored 8 postgraduates and 53 undergraduates (32 of them pursuing postgraduate studies at prestigious universities such as Stanford University, Massachusetts Institute of Technology).

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
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Hierarchical Cu Foam-Enabled High Performance Interfacial Evaporation for Future Water Sustainability

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ABSTRACT

Efficient solar water evaporation for seawater desalination has been considered as a key to address the global water shortage. However, the challenge remains on sustaining an efficient evaporation rate at a high concentration of brine, where the salt accumulated on the surface of ? hinders the light absorption and steam escape. An effective water management supposed to be a counterpart solution, with a well-balanced evaporation and water absorption rate. Here, we develop a facile anodizing strategy to achieve highly ordered, vertically aligned nanowire arrays covering the microchannels in the Cu foam. Such hierarchical fluffy structure contributes a unprecedent interfacial evaporation with a record high rate of 2.7 kg m^{-2} h^{-1} (~ 91.2% energy efficiency) to stand out among the inorganic materials. Notably, under natural light irradiation conditions with a solar flux less than 1kW m^{-2}, the solar water evaporator can produce 12.07 liters of fresh water from 3.5% brine water per square meter in a day.

BIOGRAPHY

Ben Bin Xu

Ben is a Chair professor in materials and mechanics with a multi-disciplinary research interest covering smart surface, functional materials, applied mechanics and micro-engineering. Ben holds the title of visiting professorship in over 10 universities, including UCLA (US), TAMU (US), University of Alberta (US), University of Sydney (AU), Amity University (UAE), Manipal University (India), etc. He chairs the Materials Characterisation & Properties Group in the Institute of Materials, Mining and Minerals (IoM^3). He has published over 230 peer reviewed journal articles (h = 50), 10 books (incl. chapters), 6 patents, given 90+ invited talks and won multiple awards (*2016 Young investigator award* from *the International Polymer Networks Group*, *2023 Excellence in Research- mid-career award from AICHE*, etc.). Ben is an associate editor for *Advanced Composites and Hybrid Materials* (*SpringerNature, IF=20*) and EcoMat (Wiley, IF= 14.6). Ben is an elected Fellow of the Royal Society of Chemistry (FRSC), Fellow of the Institute of Materials, Mining and Minerals (FIMMM), Fellow of the Royal Society for the Encouragement of Arts, Manufactures and Commerce (FRSA). He has been an elected member in the Advisory Council in IoM^3 from 2019, an elected member in the RSC Materials Chemistry Division Council from 2020, an elected member in the RSC Materials Chemistry Division Council (2020-2023).

Bioinspired Optical Metamaterials

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ABSTRACT

Controlling the interaction between light and matter through optical structures has laid the foundations for a broad spectrum of applications, ranging from colors, lasers, and optoelectronics, to quantum information processing. Optical metamaterials, 2D or 3D structures comprising subwavelength metallic or dielectric pixels, are a new class of material that enable precision tailoring of light–matter interactions. Inspired by the natural hierarchical optical structures, we developed a series of optical metamaterials with a low spatial footprint and enhanced light-matter interaction. Deep-strong coupling of different optical structures, such as Fabry-Pérot interferometers, distributed Bragg reflectors, photonic crystals and grating structures, unlocks a large variety of novel phenomena spanning traditionally distant research areas. Moreover, we emerge compound optical structure materials with surface-functionalization, chemical regulation, and optoelectronic device which open prospects for diverse applications, including anti-counterfeiting, encryption, sensing, displays, photovoltaics and imaging.

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BIOGRAPHY

Prof. Dr. Mingzhu Li, Key laboratory of Bionic Materials and Interface Science, Technical Institute of Physics and Chemistry. She has published more than 90 peer-reviewed SCI journal articles, including Science, Science Advances, Nature Communications, Angew. Chem. Int. Ed., J. Am. Chem. Soc., Adv. Mater. and so on. Her articles have been cited more than 5300 times and her H index is 42. She has received several awards including the National Science Fund for Distinguished Young Scholars, the first prize of Beijing Science and Technology Award, and the outstanding member of the Youth Innovation Promotion Association of Chinese Academy of Sciences. She has joined the Editorial Boards of Journal of Materials Chemistry C and Materials Advances as an Associate Editor since April, 2023.

Mechanism and engineering application of fluid-electromagnetic coupling suspension micropump without grooves

Xiaobing Luo
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ABSTRACT

In order to solve the bearing wear failure problem of micropump, the heart of the liquid cooling system, a new hydraulic and electromagnetic coupling suspension principle was proposed, and the first fluid-electromagnetic coupling suspension micropump was invented. Aiming at the design of suspension bearings, a transient model of thin liquid film flow and motor electromagnetic field inside the micropump is established, which realizes the multi-condition dynamic balance of hydraulic force, time-varying electromagnetic force, gravity and unbalanced load on the micropump rotor in a narrow gap, so that the rotor can be suspended at a high rotation speed with full freedom. The developed suspension micropump can reach speeds exceeding 20,000 rpm, with an output performance 37 times greater than similar products and a lifespan exceeding 10 years. This innovation finds broad applications in the AI server, new energy electric vehicle, charging pile and other markets, and has achieved transformation and sales.

BIOGRAPHY

Xiaobing Luo is a professor at Huazhong University of Science and Technology. He is the recipient of the National Outstanding Youth Fund, IEEE Fellow and ASME Fellow, as well as a National 10,000 plan scientific and technological innovation leader. He has published 180 peer-reviewed international journal papers as the first author or the corresponding author, and authorized 59 Chinese invention patents and 5 US patents as the first inventor, published 2 monographs each in Chinese and English. The developed ultra-thin micropump and suspension micropump technologies were transferred to Huawei and other companies with 15 million yuan in cash. An efficient thermal management system integrating heat insulation, heat storage and heat conduction has been successfully developed, and has been operated in the South China Sea and East China Sea on a large scale after being purchased in mass by CNOOC.

Bionic manipulation of droplet&bubble to address bottleneck issues of trans-media vehicles

Zhang Chengchun, Wei Zhenjiang, Xin Zhentao, Zheng Yihua

The process of water-exit and diving of the trans-media vehicle involves complex problems such as droplet disengagement from the body, droplet fragmentation in duct and cavitation corrosion of impeller. The report focuses on how to effectively reduce the water load attached to the trans-media aircraft, how to improve the propulsion efficiency of the amphibious propulsion system by breaking the droplets in duct, and how to avoid cavitation erosion of the impeller, to introduce the basic ways of bionic control of droplets and bubbles to addressing these bottleneck issues. In order to reduce the drag of water-exit of trans-media vehicle, the superhydrophobic surface with grooves inspired by kingfisher feathers makes the droplets efficiently disengage from the trans-media vehicles through vibration, elasticity, surface curvature. In order to improve the propulsion efficiency and the thrust of the ducted fan, a surface with multi- scale ridged structures was prepared inspired by the excellent droplet crushing ability of barnyard grass leaves. The Multi-scale ridged structures can induce the anisotropic spreading and retraction of the liquid film to form a very liquid column with stability, which can accelerate the droplet breakage, and reduce the impact of large droplets on the rotating blades. In order to solve the cavitation erosion on the propeller in the underwater diving mode of the trans-media aircraft, the underwater super-aerophilic surface was designed inspired by the adhesion of underwater bubbles by insects such as water spiders, which can produce It can automatically replenish air to form stable bubbles on the bionic surface. These bubbles can control the collapse direction of cavitation bubbles, forming a jet away from the wall surface and reducing cavitation erosion of the impeller.

A BIONIC DECOUPLED SPONTANEOUS TRANSPORT SURFACE RESISTANT TO TEMPERATURE GRADIENT

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ABSTRACT

With the rapid development of electronic integration technology, the working environment and stability of heat dissipation equipment are more and more demanding. The gas-liquid two-phase heat transfer system has received wide attention as a passive heat dissipation method with high stability, long life and high efficiency. This paper combines the wetting gradient and the shape gradient, and proposes a gradient wettability multi-wedge patterned surface, which allows the liquid droplets to realize long-distance and high-velocity transport. This multi-wedge patterned surface effectively address the limitation of liquid transport performance caused by the temperature gradient in the heat transfer process. This paper focuses on the temperature gradient resistance of gradient-wetting multi-wedge patterned surfaces. Place a 5 μL droplet on a surface where the temperature gradient is in the opposite direction of droplet movement. Comparing the drop transfer characteristics of a gradient wettability multi-wedge patterned surfaces with different temperature gradients, it is found that the maximum distance of the droplet transport is reduced with the increase of the temperature gradient. Comparative experiments were also carried out on gradient-wetting and uniformly wettable multi-wedge patterned surfaces. The results showed that the droplets could still be transported at an average velocity of ~38 mm at a temperature gradient of T / x = 0.59 °C/mm with an average velocity of ~158 mm/s, which is a 26.7% increase in the maximum transport distance compared to the uniformly wettable surfaces. Finally, the theoretical analysis provides a mechanistic elaboration of the temperature gradient resistance of the surface.

DROPLET MANIPULATION: FROM DESIGN TO APPLICATION

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ABSTRACT

Manipulation of droplet on surfaces with special wettability shows enormous application prospects in numerous scenarios, such as desalination, evaporative cooling, emergency medical diagnosis system, fog collection and so on. Regarding the theme of controlling droplets, we designed three types of surfaces with different wettabilities: (1) bio-inspired super spreading surfaces. Taking inspiration from the superspreading performance of water droplet on a plant leaf, we fabricated the artificial surface that outperforming its natural counterpart, achieving a spreading index of ~0.28 and a final spreading area per volume of 560mm2/μL. The as prepared surface show great promise in evaporative cooling of electronics.; (2) designed a photo-thermal lubricant surface. The surface show ultra-low adhesion to the salt crystals precipitated on it through controlling the crystallization process. This design supplies a strategy to cope the unfriendly discharge of concentrated brine water from the origin of anti-scaling; (3) one-dimensional conical surface with helical arranged micro-grooves. Inspired by the helical microgrooves on the natural cactus spine, we studied the function of the helical grooves on the directional liquid transport, and proved that the helix was able to accelerate transformation of droplet configuration from clam-shell to barrel state, thus facilitate the rapid motion of droplet at a smaller volume.

BIOGRAPHY

Jie Ju received her B.S. degree from Jilin University and Ph.D. degree from Institute of Chemistry, Chinese Academy of Sciences, under the supervision of Prof. Lei Jiang. She finished her postdoctoral training in Brigham and Women's Hospital, Harvard Medical School with Prof. Ali Khademhosseini and Tufts University with Prof. Brian P. Timko. She is currently a full professor at School of Material, Henan University, China. Her research focus are materials for water-energy nexus, including zero energy-input fog harvest, solar desalination, liquid super-spreading enabled heat dissipation as well as electric-energy harvest through manipulating interaction between liquid and surfaces with special wettability.

Liquid manipulation using heterogeneous wettability surfaces

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ABSTRACT

The control and utilization of liquid behavior are pivotal in various processes, including solution-based material preparation and patterning, analysis and detection, and high-throughput screening. By designing the wettability of the solid surface, we can adjust the dynamic behavior of the liquids, which offers a straightforward and energy-efficient liquid control method. Heterogeneous wetting surfaces integrate the properties of both hydrophilic and hydrophobic regions and can be tailored according to specific requirements. Our research primarily focuses on the modulating solid-liquid interaction [1-6] and solution-based material processing[7,8] using heterogeneous wettability surfaces. Diverse intriguing and innovative liquid behaviors, such as droplet self-splitting and gyrating, have been realized on symmetry-designed heterogeneous surfaces. Additionally, area-selective electrochemical deposition, spatially-controllable self-assembly, and highly-precise patterning, are achieved by taking advantage of the heterogeneous wettability systems. The research results have been highlighted by journals and media such as *Science*, *Nature Asia*, *New York Times*, *NHK*, and *CGTN*.

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Short BIOGRAPHY

Huizeng Li is an Associate Professor at the Institute of Chemistry Chinese Academy of Sciences (ICCAS). He obtained his Ph.D. from the University of Chinese Academy of Sciences, then worked as a postdoc at ICCAS, where he joined as an assistance professor since 2021. His research interests include heterogeneous surface wettability design, liquid manipulation, and functional materials patterning. He has published more than 50 peer-reviewed papers including *Nat. Commun.*, *PNAS*, *Sci. Adv.*, *Angew. Chem.*, and granted 6 patents. Several research results have been transferred to enterprises.

Oil-on-water Droplets Sculpted by Vortex Halos

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[1] National Engineering Research Center for Colloidal Materials, School of Chemistry and Chemical Engineering, Shandong University, Jinan, Shandong 250100, P. R. China

ABSTRACT

Oil droplets on water test the principle of surface free energy minimization when volatility or dissolution produce ffow-induced viscous shear stresses that take the system out of equilibrium. We find that on macroscales, single droplets adopt polyhedral shapes in shallow water, droplet pairs pulsate in their spacing and shape, multiple oil droplet arrays display active motion, and these droplets are protected from coalescence. On microscales, the oil droplets of single component adopts either spike-shaped or branched treelike structures while the oil droplets of multiple components evolve to show microjets. Combined experiments, scaling arguments, and linear stability analysis trace these effects to rapid Marangoni flow ("vortex halos") that shears individual droplets. The analogy that active emulsion droplets are like an iceberg with submerged halos formed by high-Reynolds number flow thus presents an approach to control and manipulate this common system [1-2].

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Light-induced charged surfaces for droplet manipulation

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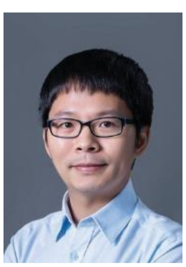
ABSTRACT

Manipulating droplets plays vital roles in fundamental research and practical applications from chemical reactions to bio-analysis. As an intriguing and active format, photocontrol of droplets, typically induced by photochemical, photomechanical, light-induced Marangoni effects, or light-induced electric fields, enable remote and contactless control with remarkable spatial and temporal accuracy. However, current photocontrol of droplets suffers from poor performances and limited reliability. Herein, we develop a new smart material that integrates dual merits of both light and electric field by rationally preparing liquid metal particles/poly(vinylidene fluoride-trifluoroethylene) (LMPs/P(VDF-TrFE)) polymer composites with light-induced charge generation capability in real time, enabling photocontrol of droplets on the basis of light-induced dielectrophoretic force. First, we demonstrate that light-induced charged superamphiphobic surface imparts a new paradigm for controllable droplet motion, including high average velocity, unlimited distance, multimode motions, and single-to-multiple droplet manipulation with high spatiotemporal resolution. Second, we further develop a new slippery material by infusing a lubricant layer into the above surface, and demonstrate that this light-induced charged slippery surface (LICS) eliminates the unwanted screening effect caused by the presence of lubricant, imparting photocontrol of droplets with fast speed, long distance, anti-gravity motion, and directionally collective motion. More importantly, we further extend the LICS to biomedical domains, ranging from specific morphological hydrogel-beads formation in an open environment to biological diagnosis and analysis in closed-channel microfluidics. The simple design, portable operation, and unique features of these light-induced charged polymer surfaces would open new avenues for the next-generation interfacial materials and microfluidics, bringing wide possibilities for chemical and biomedical applications.

BIOGRAPHY



Xuemin Du is a full professor at Shenzhen Institute of Advanced Technology (SIAT), Chinese Academy of Sciences (CAS), where he is also the Director of Center for Intelligent Biomedical Materials and Devices (IBMD). His research interests cover mainly intelligent polymers, bio-adaptive interfaces, and smart wearable and implantable devices (*e.g.*, soft sensors & actuators, tissue engineering scaffolds, bioelectronics). He has published high impact articles in *Science Advances*, *Matter*, *Advanced Materials*, *ACS Nano*, *Advanced Functional Materials*, and *National Science Review*, etc. He was awarded the National Science Foundation of China's Excellent Young Scientists in 2020, the RSC Nanoscale Emerging Investigator in 2021, and Nano Research Young Innovators (NR45 Awards) in 2023. Currently, he is the deputy Editor of *Research*, and also serves on the editorial boards of numerous esteemed international journals, including *The Innovation*, *National Science Open*, and *Research*.

Bioinspired Multi-Scale Pore/Channel

Xu Hou[1,2,3*]

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ABSTRACT

"Pore" and "Channel" are everywhere, e.g., from small biological ion channels to large oil pipelines. The difference between pore and channel is the relationship between its diameter and its depth. If the diameter is greater than its depth, it is referred to as Pore, otherwise, Channel. Both “Pore” and “Channel” have a wide range of significant applications on different scales. For example, pipelines which are commonly used in the chemical industry, food industry, agriculture, and energy-petroleum transportation, can be treated as macro-scale channels. The problems with such channels center on energy-saving, anti-fouling, anti-corrosion, and anti-block. Another example of micro-scale pores is “ liquid gating technology”, which has a great impact in the areas of chemical synthesis, biological analysis, optics and information technology, etc. It utilizes the capillary-stabilized functional liquid as a pressure-driven, reversible, and reconfigurable gate to fill and seal the pores in the closed state and create completely liquid-lined pores in the open state under pressure changes. Recently, it has already become a reality by design of various smart materials by responsive design of the porous solid phase and dynamic liquid phase, which expand the basic scientific issues of the traditional membrane materials from the solid-liquid/gas interface to the solid-liquid-liquid/gas interface and have found applications in chemistry, energy, environmental, and biomedical related interdisciplinary fields. For nano-scale systems, we design and prepare smart symmetric/asymmetric nanochannels by physicochemical design of responsive porous materials and realize the regulation of mass transport in the nanoconfined spaces and focus the new research directions on bioinspired nanofluidic iontronics.

BIOGRAPHY

Xu Hou is a Professor and the Director of Institute of Electrochemical Science and Engineering of Xiamen University and the Associate Director of the State Key Laboratory of Physical Chemistry of Solid Surfaces. He focuses on bioinspired smart porous systems, particularly in Liquid Gating Technology and Bioinspired Nanofluidic Iontronics. In 2020, his leading "liquid gating technology" was selected as the 2020 Top Ten Emerging Technologies in Chemistry by IUPAC. In 2024, he was elected as a Fellow of the Chinese Chemical Society.

WITHDRAWN

COST-EFFECTIVE MASS PRODUCTION OF TRUE-3D MICROSTRUCTURES FOR BIOINSPIRED SURFACES WITH MULTIPRONGED DURABILITY

REN, Kangning
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ABSTRACT

Versatile and robust surfaces that utilize bioinspired topologies to manipulate the air-liquid-solid interface hold tremendous promise across various applications, including energy, environment, medicine, and transportation. While significant progress has been made in achieving superwetability and robustness through topology design, mass production of non-randomly shaped structures for large-scale applications and achieving multilevel durability on such surfaces remain challenging. To address these challenges, we have developed an effective approach that leverages material property configurability to enable cost-effective mass production of polymeric true-3D microstructures with sub-micrometer resolution in large batches (*PNAS* 2019, 23909). These structures exhibit exceptional stability in nonlinear deformation, ensuring multilevel durability (*The Innovation* 2023, 100389). The polymeric layer also offers outstanding binding strength to different substrates, serving as a secure coating. Made from inert plastics, these monolithic coatings demonstrate resilience against extreme weathering, aging, mechanical stress, chemical exposure, and photochemical degradation, with the only known limitation being thermal stability (up to approximately 200 ?). We have demonstrated the potential of this strategy in directional wetting, droplet manipulation, and underwater drag reduction. We believe that this scalable and feasible fabrication method, enabling efficient large-scale manufacturing of precise 3D microstructures with robustness, will greatly facilitate the practical implementation and unlock the full potential of bioinspired surfaces in energy efficiency, environmental sustainability, and healthcare.

BIOGRAPHY

Dr. REN, Kangning, Associate Professor of the Department of Chemistry, Hong Kong Baptist University, senior academic Member of the SKLEBA at HKBU; co-founder and Associate Director of the HKAP; and the founder and Director of biomimicking microfluidics translational research center at Tsinghua Research Institute, Pearl River Delta. His research centers on micro/nanotechnologies and their applications in materials andhealthcare. As corresponding author, he has published articles in *The Innovation*, *Science Advances*, *PNAS*, *Advanced Science*, etc. in recent 5 years. Some of the technologies he developed are on the track of commercialization too. He is currently on the editorial board of Biomicrofluidics, and active reviewer for *Nature Nanotechnology*, *Science Advances*, *JACS*, *Aggregates*, *Energy & Environmental Science*, *Chemical Society Reviews*, *CCS Chemistry*, *Chemical Science*, *Small*, etc.

Liquid Manipulation Induced by the Surface Asymmetry

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ABSTRACT

Liquid manipulation is ubiquitous and critical to a range of practical applications, such as microfluidics, chemical reactions, water harvesting, and heat transfer. Over the past decades, achieving liquid manipulation via surface functions rather than mechanical designs has opened up new avenues for research and development due to their energy-saving and versatility. By designing asymmetric features on functional surfaces, we have achieved controlled liquid transport in the desired direction, velocity, shape, and additional functions. All these liquid manipulations are underpinned by asymmetric interfacial effects induced by surface asymmetric features. We envision that these liquid manipulation strategies could access emerging territories in fluid control for exciting applications.

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Short BIOGRAPHY

Personal Information.
Shile Feng, professor, doctoral supervisor, Dalian University of Technology, candidate for the national talent program youth project, winner of an excellent youth project in Liaoning province. I am mainly engaged in research on structural design, component regulation, and fluid manipulation of bionic functional surfaces and their methods, mechanisms, and applications. I have published over 50 SCI papers including Science, Science Advances, and Nature Communications. I have chaired over 5 projects including the National Natural Science Foundation of China (NSFC) Youth Science Fund and Liaoning Provincial Natural Science Foundation Outstanding Youth Fund.

Selective fluid flow steering of arch shape microstructures

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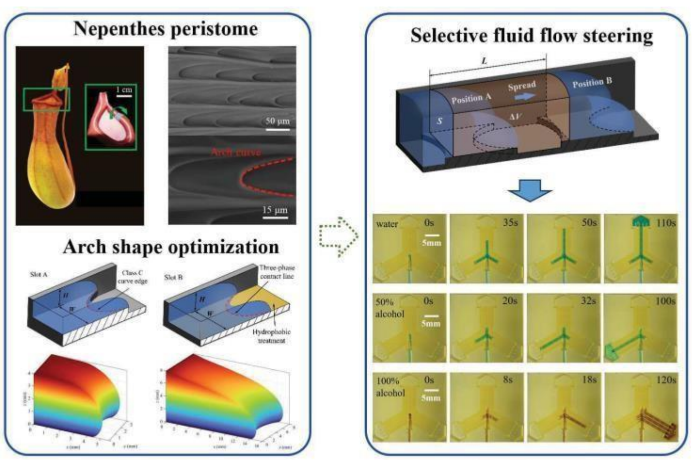
ABSTRACT

Since the discovery of fluid unidirectional self-driven spreading effect of the Nepenthes peristome in 2016, corresponding mechanisms were studied in depth, which facilitate plenty of successful bionic fabrication of artificial surfaces with significant fluid guidance functions. As observed by scanning electron microscope, the micro cavities on Nepenthes peristome present special arch shapes. Although the sharp edge effect of the cavities was widely studied and attributed to be response for the pinning effect of liquid. However, so far, nobody explain why the cavities of Nepenthes peristome evolve such arch shape. The function of and the role played by these arch shape microstructures on liquid is still a mystery. Herein, we studied the resistance effect of the edge shape on the spreading of liquid. The minimum surface energy model was developed, thus facilitating the obtainment of the optimal arch shape, which has the maximum resistance effect on the spreading of liquid. Corresponding experiments demonstrated the validity of the optimization. Based on this theory, the selective flow steering fork road shaped channels were designed, which could steering water, 50% ethanol solution and ethyl alcohol selectively according to their different surface tensions. We even using this theory designed a special fluid channel digital display, which can display number 1, 2 and 3 respectively when water, 50 % ethanol solution and ethyl alcohol were injected into the flow channels. The results of this study may open a promising avenue for smart selective microchannel design in future.

ABSTRACT FIGURE (OPTIONAL)

We are holding a **student keynote abstract competition** in which students and postdocs will have the opportunity to showcase their work with a formal talk. If you want to be considered for this competition, you need to submit an abstract figure and integrate it with the abstract.



4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
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Design and applications of superamphiphobic materials

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ABSTRACT

Superamphiphobic materials can repel both water and oils with different surface tension that demonstrate excellent properties of self-cleaning and anti-fouling. These properties are attractive for both the fundamental research and industrial areas, such as buildings, clothing, photovoltaic industry, or even biological applications. Typically, achieving superamphiphobicity involves designing special reentrant or overhanging topography to obtain a stable Cassie state that prevents liquids from intruding and wetting into material surfaces, even in the absence of low surface energy chemistry, but it involves sophisticated fabrication procedures and low efficiency which hinder the application of the superamphiphobic material. Therefore, design and fabrication of superamphiphobic material with applicable features such as substrate friendly, robust, scalability and low cost, is critical for the expending the application of superamphiphobic material. Here we would introduce the recent progresses on the design and application of superamphiphobic materials in our group, including the design and fabrication of superamphiphobic material with improved strength via nanoparticle assembly via spray coating method, high transparent superamphiphobic material via the nanosphere template method, as well as the applications of the superamphiphobic material in the area of self-cleaning, anti-counterfeiting, radiative cooling materials. We hope our efforts can boost the application of superamphiphobic material in our real life.

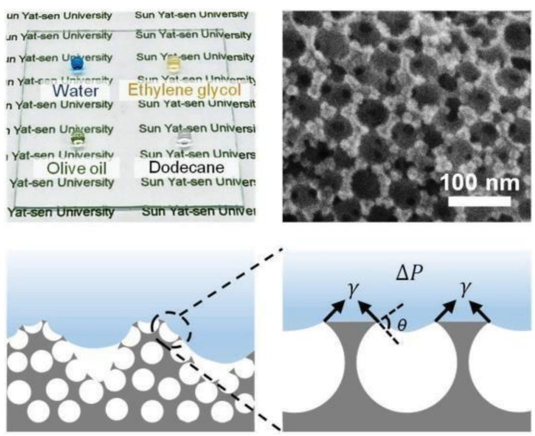

Figure. Transparent superamphiphobic material formed by hierarchical nano re-entrant structure.

BIOGRAPHY

Dr Yanan Li is an associate professor from School of Chemical Engineering and Technology, Sun Yat-sen University. He obtained doctorate in physical chemistry from Institute of Chemistry, Chinese Academy of Sciences, and he involved post-doctoral research at Prof. Zuankai Wang’s group of City University of Hong Kong via the Hong Kong Scholar Program. His research interests include nature inspired functional materials with focus on functional wetting materials and bioinspired nanophotonic materials, especially the design and applications of the superamphiphobic materials and radiative cooling materials.

Multi-Dimensional Manipulation of Solid-Liquid Interaction

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ABSTRACT

Solid/Liquid interaction play important role in many research and application fields. In this presentation, we will introduce a radically new strategy that resolves the bottleneck through the creation of an unexplored gradient in surface charge density (SCD). By leveraging on a facile droplet printing on superamphiphobic surfaces as well as the fundamental understanding of the mechanisms underpinning the creation of the preferential SCD. We will also show that robust superhydrophobicity can be realized by structuring surfaces at two different length scales, with a nanostructure design to provide water repellency and a microstructure design to provide durability. We apply this strategy to various substrates and show that the water repellency of the resulting superhydrophobic surfaces is preserved even after abrasion by sandpaper. This design strategy could also guide the development of other materials that need to retain effective self-cleaning, anti-fouling or heat-transfer abilities in harsh operating environments.

BIOGRAPHY

Dr. Xu Deng received Ph.D. in 2013 from the Max Planck Institute for Polymer Research. In 2014, Dr. Deng served as a postdoctoral fellow at UC Berkeley and Lawrence Berkeley National Laboratory. In 2015, he joined the University of Electronic Science and Technology of China as a professor. In 2017, He was pointed by the president of Max Planck Institute as the head of Max Planck Partner Group at UESTC. Dr. Deng is interested in understanding wetting dynamics and physical chemistry at interfaces. He has published more than 120 articles as the first author or corresponding author in leading journals such as Science, Nature, Nature Materials, Nature Communication, PRL, Angew Chem, to name a few. In 2021, he was admitted as the Fellow of the Royal Society of Chemistry (FRSC). In 2022, Dr. Deng has been awarded the Friedrich Wilhelm Bessel Research Award of the Alexander von Humboldt Foundation, Germany.

Design of Adaptive Water-repellent Surfaces with Stable and Mobile Water/air Contact Line

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[1] *Institute of Fundamental and Frontier Sciences, University of Electronic Science and Technology of China, 610054 Chengdu, P. R. China.*

ABSTRACT

Achieving high stability in superhydrophobicity and low adhesion simultaneously through traditional approaches is challenging. In this talk, we present two strategies to achieve a dynamic equilibrium between stability and adhesion. Inspired by the hydrophobic leaves of Salvinia molesta and the slippery Nepenthes pitcher plants, we designed a Salvinia-like slippery surface (SSS) consisting of protrusions with slippery heads. We demonstrate that the SSS exhibits increased stability against pressure and impact, the enhanced lateral mobility of water drops as well as the reduced hydrodynamic drag. We also present a self-adaptive superhydrophobic surface that can automatically adjust its structure to achieve a dynamic balance of stability and adhesion through the guidance of liquid pressure. We show that the low surface adhesion at moderate pressure and high stability at elevated pressure can be simultaneously achieved on a single surface. The proposed design concept with controllable solid-liquid stability and adhesion provides a rational route for developing high-performance superhydrophobic surfaces.

Controlling the Morphologies of Perovskite Materials Based on Fluid Flows and Interfacial Properties

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ABSTRACT

Fluidic behavior and interfacial properties play a key role in solution-based material assembling processes. We have developed a series of solution-based approaches including "top heating and bottom cooling (THBC) method[1]", "confined-solution method[2,3]"and "epitaxial-assist method[3,4]", successfully obtaining perovskite materials with various morphologies. The "THBC" method applies a flux of heat near the meniscus and builds a temperature gradient, creating a single and stable Marangoni vortex that leads to unidirectional mass transfer which promotes the perovskites assembly. The "confined-solution method" modulates the solubility and nucleation sites of precursor solutions confined in a microcavity by adjusting the temperature. At a higher temperature, $CH_3NH_3PbBr_3$ nucleates away from the meniscus due to the vigorous Marangoni flow and the inverse temperature-dependent solubility of $CH_3NH_3PbBr_3$ while at a lower temperature, nucleation starts from the meniscus due to the relatively high concentration there, producing perovskites with controllable morphologies. The "epitaxial-assist method" makes use of the lattice match between the single crystal ST cut quartz and $CH_3NH_3PbI_3$. The surface lattice of ST cut quartz acts as the template to guide the epitaxial growth of $CH_3NH_3PbI_3$ microribbon arrays.

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Bioinspired Design of Multifunctional Solid-Repellent Coatings

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ABSTRACT

Sticky problems on surfaces from various solid foulants inhibit us from the access to clean toilets, hygiene medical ware, and high-efficient energy transfer. They vastly exist in most industrial, medical, and household interfaces, and they dramatically dysfunction the well-designed surface structures by sticking on them. In contrast, nature has provided us abundant examples of keeping surfaces clean, from duck feather to lotus leaf, to springtail skin, to pitcher plant rim, and to many other insect/animal surfaces. These examples share some common materials design principles for antifouling, particularly for solid repellency. With complex fouling conditions on surfaces for various applications, it is critical to explore the mechanisms of solid-repllent natural surfaces and create effective antifouling coatings.

Herein, we have developed new design principles for developing solid-repellent coatings as well as enhancing their mechanical durability. In particular, we fabricated partially-crosslinked omniphobic coatings that can repel a broad range of foulants, comprised of both liquid and solid phases. The fabricated coatings are an order of magnitude more resistant to cyclic mechanical abrasion than current state-of-the-art slippery surfaces. By integrating of the classic wetting and tribology models, we introduce a new material design parameter for abrasion-resistant polymeric coatings. More importantly, a magnetic responsive anti-icing coating is developed and demonstrates significant anti-icing capability towards large-scale icing. This combination of mechanical durability, broad antifouling properties, and stimuli-responsibility enables the implication of such coatings to a wide variety of industrial and medical settings, including wind turbine blades, heat exchanges, and antifouling robotics.

BIOGRAPHY

Jing Wang is currently an associate professor in the School of Mechanical Engineering at Shanghai Jiao Tong University (SJTU). He completed a B.S. in Mechanical Engineering from Tsinghua University in 2012 anda Ph.D. in Mechanical Engineering at Penn State University in 2018 with Prof. Tak Sing Wong. Prior to joining SJTU in 2022, he was a postdoctoral fellow in the Department of Mechanical Engineering and Materials Science and Engineering at University of Michigan with Prof. Neil Dasgupta and Prof. Anish Tuteja. His research focuses on bioinspired engineering, interface mechanics, and advanced manufacturing. He is the recipient of the NSFC Fund for Excellent Young Scholars (overseas), "Deep Blue" Project Faculty Award, Shanghai Tech 35U35, 2022 36kr Global Chinese Elite Power 100, and Forbs Overseas Returnees 100.

De–railing scaling: From fundamentals of crystallization fouling on nanomaterials to rational design of scalephobic surfaces

Abstract:

Crystallization fouling, a process where scale forms on surfaces, is pervasive in nature and technology, negatively impacting the energy conversion and water treatment industries. Despite significant efforts, rationally designed materials that are intrinsically resistant to crystallization fouling without the use of active methods like antiscalant additives remain elusive. This is because antiscalant surfaces are constructed today without sufficient reliance on an intricate but necessary science–base, of how interweaved interfacial thermofluidics, nucleation thermodynamics, and surface nanoengineering control the onset of nucleation and adhesion of frequently encountered scaling salts like calcium carbonate and calcium sulfate. Such scaling salts are common components of fouling deposits in industrial heat exchangers and membranes, which significantly inhibit heat transfer and flow performance. I will present my recent work on the development of innovative materials and systems addressing these challenges. I will focus on our findings related to understanding the fundamentals of scale nucleation and adhesion and how we use this to rationally engineering intrinsically scalephobic surfaces based on the collaborative action of their composition and topography.

Bio:

Dr. Thomas Schutzius is an Assistant Professor at the University of California, Berkeley where he leads the Laboratory for Multiphase Thermofluidics and Surface Nanoengineering (MTSN). His research intersects the multidisciplinary fields of energy, surface science and engineering, and thermofluidics, and his experimental work captures the fundamental dynamics of a vast array of interfacial and micro–nanoscale transport phenomena. Dr. Schutzius is a recipient of the prestigious ERC Starting Grant. In 2020 he received the ETH “Golden Owl” Award for excellent teaching and was a nominee for the KITE Award 2022 recognizing innovation in teaching. During his graduate studies, he was the recipient of the Dean’s Scholar Award and the UIC Outstanding Thesis Award. He also received the ETH Zurich Postdoctoral Fellowship. In 2018 he was part of the ETH Zurich representation to the prestigious Global Young Scientist Summit (GYSS) in Singapore.

Picture:

Bio-inspired Controllable Liquid Transfer: Towards High-performance Printable Optoelectronic Devices

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Controlled liquid transfer, especially that at micro-/nanoscale, is an important process for fabricating micro-patterned thin-films, which serves as a key process for making high-performance optoelectronic devices. Here, drawing inspiration from the Chinese brush, we proposed a model structure of dual-parallel conical fibers, which enables both the dynamic balance of the liquid at certain position by the conical structure and the uniform continuous distribution of liquid by the unique side-by-side parallel fibrous arrangement. Consequently, the liquid can be steady and controllable transferred onto various substrates into micro-patterns. Taking advantageous, by constructing multi conical fibrous arrays, we developed a facile direct-writing strategy for micro-patterning various functional liquid materials with a centimeter-scale large- area uniformity and a high width-resolution up to ~ 1 μm. Specifically, micro-patterns can be prepared in a well-controllable way at both micro-meter and centimeter scale, with each single pattern unit either highly aligned for the ink of 1D nanowires/polymers or highly homogeneous with extra-small roughness for the ink of 0D nanoparticles. On the basis, various high performances thin-film optoelectronic devices have been constructed, including organic thin film transistor (OTFT), transparent flexible electrode (TFE), and quantum dot light emitting diode (QLED).

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Huan Liu is currently a full professor at Beihang University. She was a recipient of the NSFC grant for Distinguished Young Scholar, Excellent Young Scholar, New Century Excellent Talents in University, the Henry Fok Youth Foundation. Her research interests focused on the controllable liquid transfer in making micro-patterns and its applications in photoelectric thin-film devices. She has published over 100 research papers on journals of Nat. Mater., Nat. Commun., J. Am. Chem. Soc., Angew. Chem. Int. Ed., Adv. Mater. with the SCI citation over 5600 times.

Bionic Functional Devices for Low Carbon Applications

Zhaolong Wang
Harbin Institute of Technology

At present, excessive CO_2 emissions have greatly aggravated the deterioration of the environment and threatened the sustainable development of mankind, and the national strategy of "carbon neutrality" points out the future of China's energy/power technologies. However, low/zero/negative carbon technologies are currently in urgent need of major breakthroughs in many fields such as working principles, functions, materials, structures, processing technologies, devices, and applications, to support the national "carbon neutrality" strategy. Based on the bionic microfluidic functional devices fabricated by using projection microstereolithography (PμSL) 3D printing technique, this report summarizes the fundamental microfluidic theories, design principles of bionic structures, and fabrication methods for low-carbon functional devices. It also discusses the promising applications of these bionic functional microfluidic devices on efficient utilization of solar energy and hydrogen production.

Bioinspired micro/nano-confined solid-liquid composite materials

Zhizhi Sheng

Suzhou Institute of Nano-Tech and Nano-Bionics, Chinese Academy of Sciences

ABSTRACT

Nature creates a variety of unique materials not solely from solid or liquid, but from the composite of solid and liquid. Drawn inspiration from nature, solid–liquid composite materials come to the scene, due to the fascinating properties arising from both the solid phase and the liquid phase. Particularly, we have developed a wide spectrum of micro/nano-confined solid-liquid host-guest materials by infusing functional liquids into micro/nano-porous matrix, enabling rich interfacial properties, such as antifouling, energy-saving, drag-reduction, gating behavior, adaptive function, and selective sorption. Recently, a series of aerogel-confined solid-liquid composites have been constructed by utilizing the high porosity and high specific surface area of aerogels. We realized the nano-confinement of water by hygroscopic holey graphene aerogel fibers (LiCl@HGAFs), elucidating the interaction mechanism between the nanoporous materials and water molecules. LiCl@HGAFs show high water sorption capacity and high water uptake kinetics. Meanwhile, LiCl@HGAFs also experience an efficient heat transfer process, thus being utilized for adsorption-based heating and cooling. With the entrapped water, LiCl@HGAFs exhibit broad microwave absorption with a bandwidth of 9.69 GHz. Additionally, we have also exploited liquid-in- aerogel porous composites (LIAPCs) that allow for highly effective CO_2 capture and selective CO_2/N_2 separation. LIAPCs exhibit superb CO_2 uptake capacity, fast sorption kinetics, and high amine efficiency. Furthermore, the sorbent ensures long-term cycle stability and exceptional CO_2/N_2 selectivity. This study opens up an avenuefor the design of efficient CO_2 capture materials, gas separations, as well as advanced solid–liquid composite materials for further cutting-edge applications.

BIOGRAPHY

Zhizhi Sheng is currently an Associate Professor at Suzhou Institute of Nano-Tech and Nano-Bionics, Chinese Academy of Sciences. She obtained her Ph.D. degree (2015) from Auburn University. She did postdoctoral research at Auburn University (2015.8-2016.2) and afterwards at Xiamen University (2016–2020). She has published 36 SCI papers, including 15 papers in high-impact journals as the first author or corresponding author, such as *Science*, *Sci. Adv.*, *Natl. Sci. Rev.*, *Nat. Commun.*, *Adv. Mater.*, *etc*. She obtained 10 authorized Chinese patents and 1 authorized American patent. She was selected as a member of the Youth Innovation Promotion Association (CAS), Jiangsu Province High-Level Innovation and Entrepreneurship Talent Introduction Plan, and Gusu Innovation and Entrepreneurship Leading Talent Plan. She is a member of the Young Editorial Board of *Chinese Chemical Letters* and *Journal of Bionic Engineering*. Her research interests are focused on aerogel-confined solid-liquid composites and smart porous materials.

Enhancing the Treatment of Gastroesophageal Reflux Disease with an Innovative Ultrastable Recombinant Protein-Based Adhesive Hydrogel

Xiao YANG[1, 2], Yuanting ZHANG[1]*, Yihai CAO[1,3]*, Zuankai WANG[1, 2]*

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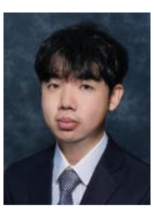
[2]Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hong Kong, 999077, China.
[3]Department of Microbiology, Tumour and Cell Biology, Karolinska Institute, Stockholm, 17177, Sweden.

ABSTRACT

Gastroesophageal reflux disease poses a significant public health concern due to its potential to lead to various gastrointestinal complications, including the development of esophageal cancer. Traditional methods of treating this condition include the use of antacids or acid suppressants, which are associated with adverse consequences such as cardiovascular problems, gastrointestinal complications, and nutritional deficiencies. In recent years, recombinant protein hydrogels with low immunogenicity have emerged as promising alternatives to these drugs. However, their effectiveness is limited by their poor tolerance to highly acidic environments. In this study, we introduce an ultrastable recombinant protein-based adhesive hydrogel that solves the problems of commercially available hydrogel limitation. By employing a hierarchical self-assembly strategy to enhance binding free energy, our hydrogels exhibit excellent interfacial adhesion, acid resistance, and stability under acidic conditions. Therefore, it exhibits highly effective therapeutic results for gastroesophageal reflux disease both in vitro and in vivo. Our innovative approach has great potential to improve the treatment and management of patients with gastroesophageal reflux disease. With enhanced tolerance to acidity and superior therapeutic efficacy, our ultrastable recombinant protein-based adhesive hydrogels represent a major advance in the field.

BIOGRAPHY



Xiao YANG received his Ph.D. from the College of Polymer Science and Engineering, Sichuan University, where he studied under Professors Jianshu LI and Hong TAN. Currently, he serves as an Associate Researcher Scientist at the Hong Kong Center for Cardiovascular and Cerebrovascular Engineering (COCHE), working under Professors Zuankai WANG and Kannie W. Y. Chan. Before joining COCHE, he studied or worked at the Department of Dental Endodontics, West China Stomatological Hospital of Sichuan University; Department of Chemistry, Brandeis University; Wyss Institute of Harvard University; Huaxi MR Research Center, West China Hospital of Sichuan University; College of Biomass Science and Engineering, Sichuan University; and Department of Biomedical Engineering, Chinese University of Hong Kong. His research focuses on bio-inspired wearable medical devices for therapeutics.

Self-Assembly of Soft Matter at the Liquid-Liquid Interface

Yu Chai[1]
[1] *City University of Hong Kong, HK*

ABSTRACT

Introducin a drop of liquid into another inniscible liquid, such as water in oil, results in the fornation of a spherical droplet due to interfacial tension. In nature, re ardless of ravitational effects, surface/interfacial tension nininizes the surface and interfacial area. Therefore, a liquid droplet typically e:hibits a spherical shape. Byintroducin the self-assenblyof soft natter, such as nanoparticles at the liquid-liquid interface, the closelypacked assenblies can jan the liquid interface and even lock the liquid droplet into non-spherical shapes. In this talk, I will overview the recent advances in this topic, includin both fundanental studies and their applications. In particular, I will discuss how we use advanced in situ Atonic Force Microscopy to directly visualize the self-assenbly and jannin of soft natter at the liquid-liquid interface.

Nature-inspired Multiscale Manufacturing Strategy for Strong and Tough Soft Materials

Wei Zhai
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ABSTRACT

Conductive hydrogels have shown great promise for applications in flexible electronics and soft robotics due to their exceptional stretchability and sensing capabilities. However, simultaneously enhancing the strength and toughness of conductive hydrogels remains a significant challenge. In nature, soft tissues such as mammalian skin and tendons achieve an exceptional combination of stiffness, strength, and toughness owing to a complex hierarchical structure, where stiff components are embedded in a softer matrix, interconnected through a robust interface. Inspired by the hierarchical composite design in nature, we have developed various multiscale manufacturing strategies to produce strong and tough conductive organo-hydrogels with hierarchical structures. This involves a freeze-casting assisted solution substitution strategy, a facile combining strategy of self-assembly and stretch training, and a bottom-up shear-stress induced direct ink writing strategy. The strength of our materials has increased from 6.5 MPa to 54.8 MPa, while the toughness has also increased from 58.9 MJ/m3 to 260 MJ/m3, owning to multiple strengthening and toughening mechanisms at different scales. We have demonstrated the potential applications of our materials for monitoring sport behaviors in soccer training, and controlling artificial arms and robots for grabbing objects, etc. Hence, these studies showcase a model strategy that extracts the hierarchical composite design principles from nature and applies them for strong and tough soft materials. Being versatile and applicable in diverse material compositions, this multiscale manufacturing strategy shall also inspire future research on the design and fabrication of bioinspired materials.

BIOGRAPHY

Dr. Wei ZHAI is an Assistant Professor in the Department of Mechanical Engineering at the National University of Singapore. Her research group at NUS focuses on developing advanced multifunctional materials, including hydrogels, lattice structures, and composites, through bio-inspired hierarchical strategies. She has developed various multiscale manufacturing technologies including additive manufacturing and freeze casting to achieve material structure control across multiple length scales. Since joining NUS in 2019, her team has published articles in journals, including *Nature Communications, Science Advances, Advanced Materials, Materials Today, Advanced Functional Materials, ACS Nano, etc.* Dr Zhai received her B.Eng. from the University of Science and Technology Beijing in 2011 and her Ph.D. from the University of Cambridge in 2015. She worked as a Research Scientist at the Singapore Institute of Manufacturing Technology, A*STAR, from 2015 to 2019. She currently serves as the Editor for *Materials & Design* and Section Editor for *Materials Today Communications.*

BIO-INSPIRED ICE BINDING MATERIALS FOR CRYOPRESERVATION OF CELLS AND TISSUES

Jianjun Wang
Technical Institute of Physics and Chemistry of the Chinese Academy of Sciences, China

ABSTRACT

Cryopreservation of biological samples can bring transformative changes to medicine and medical science. However, limited progress has been achieved in the cryopreservation of tissues and organs due to the cytotoxicity and the low ice-controlling efficiency of the traditional cryoprotective agents (CPAs). Freezing-tolerant organisms in nature can express ice-binding proteins (IBPs) to regulate the site of ice nucleation and the afterwards ice growth, so as to protect the living organisms from ice-related damages. We have revealed the ice-controlling mechanisms of the IBPs, which guide to construct of a series of ice-controlling materials (ICMs). Unlike the conventional CPAs which vitrify the water in biological samples, the ICMs allow the formation of ice crystals in cryopreservation but control the shape and size of the ice crystals, thus alleviating the ice-related damages. By using the ICMs, efficient and safe cryopreservation of cell suspensions as well as cell monolayers have been achieved.

BIOGRAPHY

Jianjun Wang is currently a full professor inTIPC-CAS. His current research is focused on the molecular level understanding of ice formation and its applications such as cryopreservation of cells, organs and tissues, and anti-icing coatings with ultra-low ice adhesion; and he has papers published in peer review journals, such as Nature, Nature Materials, JACS, PNAS, and Science Advances. In 2019, he undertakes the Distinct Young Scholar Project of NSFC. In 2022, He was awarded the first prize in natural science by the Beijing Municipal Government. He is a recipient of the 2022 CCF Award for Overseas Outstanding Contribution. Prof. Dr. Wang is Advisory Board member of many research centers and journals such as research center of molecular science of Chinese Academy of sciences, water-ice interface augmentation center of Korea University as well as Acta Polymerica Sinica.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Filter feeding techniques inspired by fan worms: theoretical framework and robotic applications

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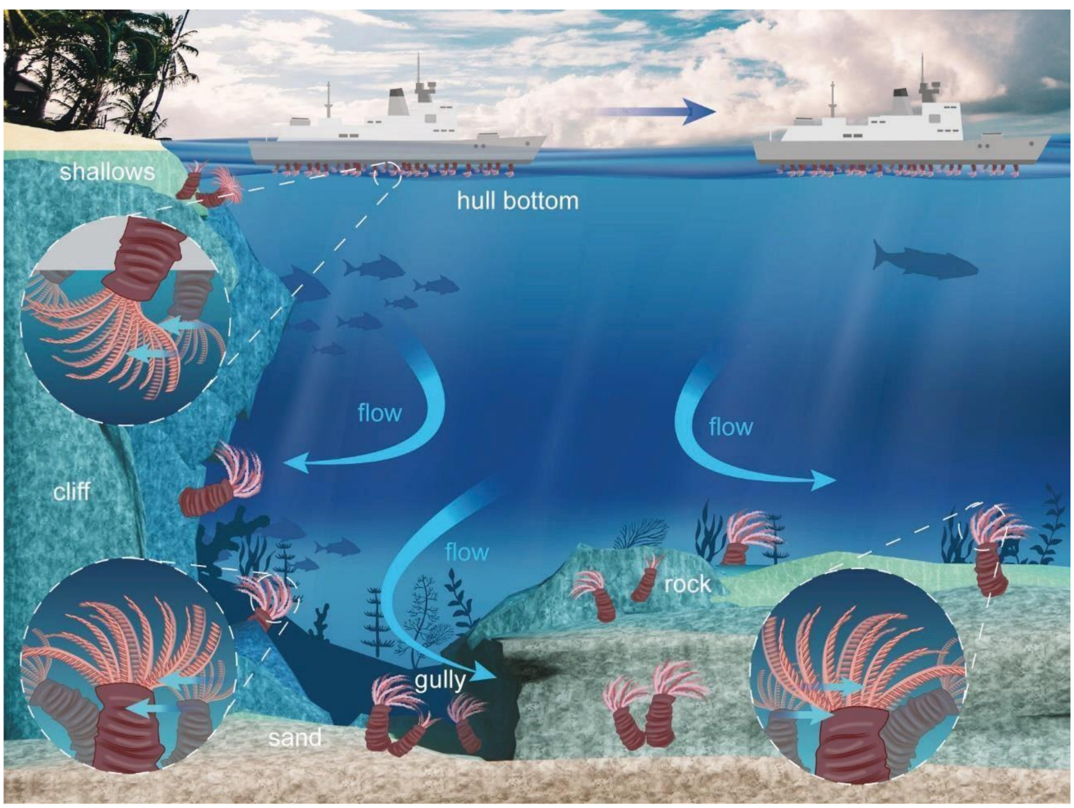
ABSTRACT

Benthic sessile suspension feeders exhibit a wide range of feeding behaviors that enable them to feed in diverse and unpredictable environments. Fan worms (*Annelida: Sabellidae*), which are marine Polychaeta worms that inhabit a tubular sheath and feed on suspended particles in surrounding water using a crown-like gill, are found worldwide and have been adapted to various underwater environments; however, their feeding maneuvers and the underlying filter mechanism remains elusive. Here, we found that the slender filament in the crown-like gill has unique shallow V-shaped morphological and soft porous material properties to passively adjust its posture in response to the flow directions. Using flow visualization and particle trajectory tracing techniques, we show that reorientated gill filament can bring the incoming flow closer to its surface, which enhances the capture of particles by 35%. Our findings reveal a previously unknown feeding strategy in sessile filter feeders that can inspire novel intelligent filtration devices with the ability to passively adapt to random flows.



Fan worms exhibit remarkable adaptability to diverse environments characterized by varying water flow directions. Anchoring themselves to substrates such as sand grains, rocks and hull bottoms, they utilize their radial gill crowns to efficiently filter suspended particles. This adaptive mechanism enables fan worms to thrive across a spectrum of oceanic habitats, ranging from shallow waters to rugged cliffs and gullies.

BIOGRAPHY

Jianing Wu, male, Vice Dean, Associate Professor, Doctoral Supervisor of the School of Advanced Manufacturing at Sun Yat-sen University, is a talent introduced by the "Hundred Talents Plan" of Sun Yat sen University. The research mainly focuses on interdisciplinary fields such as biomimetics and biomechanics. In recent years, more than 70 SCI papers (7 cover papers) have been published in Nature Nanotechnology, PNAS, NSR, etc., and 15 patents have been granted.

BIOINSPIRED MATERIAL ENGINEERING IN HEALTH MANAGEMENT

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ABSTRACT

Biofouling caused by the adhesion of respiratory microdroplets generated in sneezing and coughing plays a vital role in the spread of many infectious diseases. Unlike bulk liquids, tiny respiratory droplets will adhere on most liquid-repellent surfaces, and eventually cause fouling and pathogen spread. To overcome the adhesion and fouling issues, we implemented various bioinspired surface engineering strategies to control and manipulate droplets. For example, we reported a new droplet-driven mechanism on a ferrofluid-infused surface, namely the wetting ridge-assisted programmed (WRAP) magnetic actuation. The WRAP doesn't require magnetic additives in the sample droplets and allows the actuation of droplets with a wide range of sizes or compositions, making it promising for chip-integrated sensing and bioanalysis. In the meantime, we also developed a series of polymer composites with substrate binding, damage-healing, and/or mechanoelectrical properties, which can be coupled with droplet manipulation for applications in specific scenarios.

BIOGRAPHY

Prof. Yao is a professor at the Department of Biomedical Sciences City University of Hong Kong. He received his PhD in chemistry from the Institute of Chemistry Chinese Academy of Sciences, where he worked on bioinspired super wettability. Prior to joining CityU in 2014, he did postdoc training at the School of Engineering and Applied Sciences and Wyss Institute of Biologically Inspired Engineering at Harvard University. Prof. Yao's research interest lies in the interface of polymer chemistry, biomaterials, and wearable technologies. His current research projects include the bioinspired manipulation of microdroplets for pathogen control and biosensing, the development of supramolecular biomaterials for tissue engineering, and the development of wearable devices for healthcare monitoring, by using interdisciplinary approaches in the areas of molecular engineering, polymer engineering, cell biology, and artificial intelligence.

BIOINSPIRED STRUCTURED ADHESIVE SURFACES

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ABSTRACT

In nature, many animals use reversible adhesion for the locomotion. Hierarchical setae or polygonal smooth pad are the two kinds of structures on the feet of these animals, which play a crucial role in the reversible adhesion properties. These two structures can be collectively referred to as pillar arrays and are known as structured adhesives. Previous studies have found that T-shaped micropillars can shift the stress concentration from the contact edge to the central region, inhibiting the crack initiation at the edge of contact interface, and thus improving the adhesion ability; however, the T-shaped structure is easily damaged during the adhesion-detachment cycles, deteriorating the adhesion performance. To solve the problem, combining the structural characteristics of different organisms, we fabricate micropillar arrays with radial and axial modulus gradients, micropillar arrays with micro-nano pits at the end, and hard-core soft-shell structures, which realize the fine control of stress distribution at the separation interface and the initiation and propagation of cracks, resulting in the simultaneous improvement of adhesion performance and structural stability. Combining with the glass transition and phase transition of polymer materials, the conformal contacts with rough surfaces in air and underwater are realized. The adhesion strength, which was much higher than that of gecko foot, and reversible regulation of adhesion are obtained. With asymmetrical design of the micropillars, the application of structured adhesives has been extended to the areas, like droplet manipulation and soft robotics, paving the way for the application of structured adhesives.

Electrically-switched underwater capillary adhesion

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ABSTRACT

Developing underwater adhesives that can rapidly and reversibly switch the adhesion in wet conditions is important in various industrial and biomedical applications. Despite extensive progresses, the manifestation of underwater adhesion with rapid reversibility remains a big challenge. We report a simple strategy that achieves strong underwater adhesion between two surfaces as well as rapid and reversible detachment in on-demand manner. Our approach leverages on the design of patterned hybrid wettability on surfaces that selectively creates a spatially confined integral air shell to preserve the water bridge in underwater environment. The overall adhesion strength can be multiplied by introducing multiple air shells and rapidly broken by disturbing the integrity of the protective air shell in response to the applied voltage on two surfaces. Our design can be constructed on the flexible substrate with hybrid wettability, which can be applied to non-conductive substrates and adapted to more complicated morphologies, extending the choice of underlying materials.

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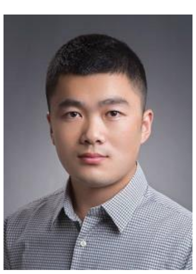
Short BIOGRAPHY



Personal Information.

Huanxi Zheng, professor, doctoral supervisor, Dalian University of Technology, candidate for the national talent program youth project. His research interests mainly focus on bioinspired materials, surface engineering and energy harvesting.

Controllable Adhesion on the Bioinspired Surface

Huawei CHEN
School of Mechanical Engineering and Automation, Beihang University

ABSTRACT
Surface adhesion has attracted worldwide attention owing to its diverse potential applications in medical engineering, flexible electronics and medical engineering field. Generally, solid-liquid-air behavior between contact surfaces have great impact on adhesion performance. Most of excellent adhesion performance discovered in nature come from such micro-nano scale adjustment of interfacial liquid and air. For wet friction of tree frog and grasshopper, self-splitting and self-sucking of liquid film were found as lifting the toe pad from substrate to enhance the adhesion. Air bubble adhesion and transport can also be achieved by comprehensive control of micro-nano surface structure and wettability. Apart from building mathematical model of adhesion, the applications of bioinspired controllable adhesion surface to precision medicine, flexible electronics etc. were also explored.

BIOGRAPHY

Chen Huawei, Professor/ Vice Dean of School of Mechanical Engineering and Automation, Beihang University. Dr. Chen's research interests include bio-inspired functional surface, mi- cro/nano fabrication and micro/nano fluidics. He got the Leading Talent of Ten Thousand Plan, Outstanding Young Scientist Foundation of National Nature Science Foundation of China, Xplorer Prize, a JSPE Fellow etc. Dr. Chen has published more than 100 papers in *Nature, Nature Materials*, Science Advances, Nature Communications, *Advanced Materials*, etc.

Research progress of high-efficiency thermochemical energy storage

Shanghai Jiao Tong University, China

Abstract

Energy storage technology is of great significance for improving the utilization rate of renewable energy and the peak-shaving efficiency of the power grid. However, the current low-cost, large-scale energy storage technology is still immature, becoming one of the main bottlenecks to achieve carbon neutrality. Thermal energy storage is one of the key application areas of energy storage, and thermal chemical energy storage technology, with its advantages of a wide temperature range, cross-temporal and spatial storage, high energy storage density, and low cost, has a broad application prospect. This report introduces the storage mechanism of thermal chemical energy storage technology, the design of high-efficiency thermal storage materials, the improvement of energy storage grade, and the design and operation of reactors. To address the technical bottlenecks of improving the long cyclic stability and charge-discharge efficiency of thermochemical energy storage, active design and preparation of high- performance thermal chemical energy storage materials were carried out based on the theoretical methods of DFT, MD, and LBM. A structure-performance relationship was established between atomic parameters and micropore characteristics, and a method for regulating the thermal storage performance based on the intrinsic characteristics of materials was proposed. Thermochemical energy storage materials with high cyclic stability in hundreds of cycles were prepared, which can be combined with performance regeneration methods to achieve thousands of stable cycles. In addition, reactors of various forms such as fixed beds, bubble beds, and fluidized beds for thermochemical energy storage in different temperature ranges were designed and constructed. The topological optimization method of reaction units was further carried out to improve the characteristics of heat and mass transfer, achieving efficient charge and discharge at the reactor level. Thermochemical energy storage is a frontier discipline at the intersection of multiple disciplines. Future research will focus on the technical bottlenecks in the development of large-scale TCES systems and promote the industrial applications to provide support for achieving carbon neutrality.

Chang-Ying Zhao
Chair Professor, Dean of China-UK Low Carbon College, Shanghai Jiao Tong University

Prof. Changying Zhao is the Chair Professor, the Director of the Institute of Engineering Thermophysics, and the Dean of China-UK Low Carbon College of Shanghai Jiao Tong University. Prof. Zhao is the Principal Investigator for quite a few major research projects sponsored by Natural Science Foundation of China (NSFC) and Ministry of Science and Technology of China. Prof. Zhao's research interests mainly cover micro/nanoscale thermal radiation and metamaterial energy devices, advanced thermal energy storage and hydrogen storage, and heat transfer in porous media. He has published over 300 papers in peer-reviewed high quality journals like Nature Materials, Physical Review Letters, Nano Letters, IJHMT, Annual Review of Heat Transfer, Energy and Environmental Science, Chemical Engineering Journal, etc., which are cited more than 17000 times in total. Prof. Zhao has also been recognized as one of the Most Cited Chinese Researchers by Elsevier every year since 2014. He was awarded the William Begell Medal in 2023 for Excellence in Thermal Science and Engineering, the Shanghai Natural Science Award (First Class) by Shanghai Municipal Government in 2020, and the Best Paper Award of the ASME Micro/Nanoscale Heat and Mass Transfer International Conference for twice, in 2013 and 2019, respectively. Prof. Zhao serves as a member of the Scientific Council of International Center for Heat and Mass Transfer (ICHMT), a Founding Fellow and Executive Board Member of Asian Union of Thermal Science and Engineering (AUTSE), Vice-Director of the Heat and Mass Transfer Society of China, as well as a Board Member of the Nukiyama Memorial Award. He is also the Editor-in-Chief of Carbon Neutrality, Associate Editor of Thermal Science and Engineering Progress, as well as Editorial Board Members of several other international journals.

Thermal coupled PV-EC integrated solar hydrogen production based on field-flow synergy design

Dengwei Jing
Xi'an Jiaotong University, Xi'an, Shaanxi, PR China

Abstract: Large-scale hydrogen production from solar energy is one of the most attractive solutions to simultaneously address the urgent issues of energy crisis and environment pollution. At present, the widely considered solar hydrogen production scheme is photovoltaic power generation plus water electrolysis in a separated mode. However, the energy conversion efficiency of most commercial solar cells is generally around 20%, and other energy is wasted in the form of heat dissipation, which has a serious impact on the efficiency and life of photovoltaics. We integrate and optimize the PV power generation and hydrogen production processes by establishing the "field- flow synergy" theory and method of efficient regulation and control of complex multiphase flow coupled with chemical reaction under unstable solar radiation. Hydrogen production efficiency for the whole-wavelength hybrid solar energy conversion and utilization system attains 25.2%. The results have been evaluated by other researchers in their publication as "innovative", "rare" and "very attractive", for many times. An expert group of 7 academicians organized by the Chinese Renewable Energy Society unanimously agreed that the overall technology of the project has reached the international leading level. The related core technologies have been successfully applied in the field of aerospace and national defense, and civilian technologies have also been promoted and applied in Shaanxi, Xinjiang, Inner Mongolia, Guangdong and other provinces in China.

Refercnes:

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Wang X., Liu M.C., Jing D.W., Mohamad A., Prezhdo O., ***Nano Letters***,2020,20(12):8965-8971.

Biography

Dr Dengwei Jing is a full professor of Xian Jiaotong Unversity and is presently the deputy director of the hydrogen energy committee of the China renewable energy society and a recipient of the National Fund for Distinguished Young Scholars, the Newton Advanced fellowship of the Royal Society of UK, and the project leader of the National Key R&D Program of the Ministry of Science and Technology. He has been selected as one of the 2% of the world's most cited researchers in the field of energy, and has won the second prize of the National Natural Science Award (ranked 2nd), the first prize of Shaanxi Science and Technology Award (ranked 2nd), and the first prize of Technological Invention Award of the Chinese Renewable Energy Society (ranked 1st).

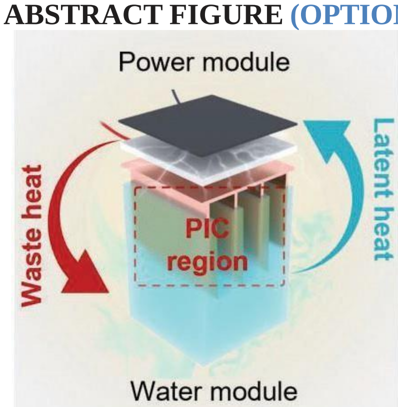
Passive interfacial cooling-induced sustainable electricity–water cogeneration

Zhengyi Mao,[1], Jian Lu[1]
[1]*Department of Mechanical Engineering, City University of Hong Kong, Hong Kong*

ABSTRACT

The utilization of solar energy for electricity and water generation is widely considered as a sustainable solution for water scarcity and electricity shortages. Here we present a rationally designed hybrid system based on the passive interfacial cooling (PIC) strategy. The PIC region within the system intensifies energy exchange between the power generation and water generation modules, thereby boosting the utilization of waste heat and latent heat from the hybrid modules and minimizing the energy loss to air. As a result, the PIC-induced cogenerator exhibited a superior power density of 1.5 W m^{-2} and an outstanding water evaporation rate of 2.81 kg m^{-2} h^{-1} under 1 Sun illumination, which were 328% and 158% higher than those of devices without the PIC effect. The system also exhibited excellent salt rejection ability, stability, durability and applicability under various harsh conditions, demonstrating its potential for practical applications. The effectiveness of the PIC strategy in enhancing photovoltaic-based power generation systems has also been established, resulting in an increase in power density from 55.7 W m^{-2} to 75 W m^{-2}. This study provides insights into the design of power–water cogenerators and advances their application with multiple natural energy sources for high-efficiency power–water cogeneration.

ABSTRACT FIGURE (OPTIONAL)



4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

POTENTIAL FLUCTUATION IN MICRO TWO-PHASE FLOW AND ITS INTERFACIAL PHENOMENA

Wei Li
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ABSTRACT

Liquid-vapor flow phase change is essential in many thermal energy conversion applications. Effectively utilizing these processes requires fine manipulation of interfacial transport. Field synergy indicates the mechanism of single phase convective heat transfer by coordinating the velocity and temperature gradient/heat flow fields through managing the differential energy equation. The mechanisms of two-phase flow are much more complicated. The liquid-vapor flow interface developments play key roles in the processes. Fundamental understanding in micro/nanoscale during liquid-vapor flow phase change remains limited to date as it is generally challenging to characterize the heat transfer at the interface. We discuss potential fluctuation at the interface between vapor and liquid flow decided by the continuity equation. Potential fluctuation presents potential oscillatory wave surface in the spatial and temporal dimensions at the vapor and liquid interface. It is the origin of flow regime in two-phase flow and has great impact on the development of flow-patterns after forces act on the interface. Detailed visualizations in two-phase flow provide a complete pictures on how potential fluctuations are developed into flow-patterns. Both experimental studies and theoretical study confirm that potential fluctuation is decided by the two densities and velocities of the two-phase flow as indicated by the relation of continuity. The talk presents an important attempt to conduct comprehensive analysis on liquid-vapor flow interface development and its phase change convection in microscale.

BIOGRAPHY

Dr. Wei Li, Fellow ASME and professor in Department of Energy Engineering in the Zhejiang University in China, has published 400 peer reviewed papers in English and Chinese journals and proceedings, including 200 archival journal papers as the corresponding author in prestigious journals such as four ASME journals, Int. J. Heat Mass Tran., and Applied Energy. His research experience includes experimental, numerical, and theoretical studies on a wide variety of fundamental and applied topics: two phase heat transfer, chemical reaction flow, chemico-physical characteristics of heat-transfer surfaces, and so on. His group leverages state-of-the-art micro/nanofabrication and synthesis, unique measurement and simulation, and model prediction capabilities to perform in-depth studies and enable mechanistic insights into complex fluidic and thermal transport processes for these applications. His three correlations on micro flow boiling have been adopted in "*ASHRAE Handbook - Fundamentals*" since 2012. He wrote the final chapter of the "*Encyclopedia of Two-phase Heat Transfer and Flow*" (5000 pages, 16 volumes) published worldwide in 2017. He has served as Associate Editor for six SCI journals including four ASME journals including *Journal of Electronic Packaging* (Now) and *Open Journal of Engineering* (Now).

NEW ANALYSIS METHODOLOGY FOR PRECISE DESIGN AND OPTIMIZATION OF HEAT TRANSFER PROCESSES: CONDUCTION-ADVECTION THERMAL RESISTANCE IN PARALLEL

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Xi'an, Shaanxi, 710049, China
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ABSTRACT

Heat convection is always involved in engineering applications such as energy power, metallurgy, refrigeration, aerospace and so on. In heat convection processes, thermal resistance is commonly recognized as a simplified analysis methodology, but largely dependent on the empirical factor: heat transfer coefficient. This report presents a proposed analysis methodology of multi-dimensional conduction-advection thermal resistance in parallel in fluid domain and a constructed the conduction-advection thermal resistance network with heat capacity. The advection thermal resistance in the fluid domain is closely related to the magnitude and direction of temperature gradient and velocity. The higher the velocity, the smaller the advection thermal resistance.

The practicability and advancement of the generalized establishment method of thermal resistance network is illustrated by two examples. One is in the single-phase heat transfer process, and the other is in the solid-liquid phase change heat transfer process. For the single-phase heat transfer process, a relative magnitude of the thermal resistance distribution, a computational expression for the local thermal resistance and a correlation equation between the local thermal resistance and the macroscopic parameters are obtained for guidance in the practical engineering applications. For the solid-liquid phase change heat transfer process in thermal energy storage application, a thermal resistance field evaluation factor was proposed and a comparison of the thermal resistance field evaluation factors over time was conducted for five different aspect ratios of rectangular containers. In a word, the proposed analysis methodology is of great significance for the precise design and optimization of energy saving and storage devices.

BIOGRAPHY

Qiuwang Wang is a Professor of School of Energy & Power Engineering in Xi'an Jiaotong University. His current research interests focus on heat transfer enhancement and energy saving, energy storage fundamental and technology, heat transfer under extreme conditions, heat transfer in porous media, prediction and optimization of thermal and fluid problems. He has been authors or co-authors of 4 books and more than 300 international journal papers. He has also obtained 5 US Patents and more than 50 China Invent Patents. He has been elected as a Fellow of ASME, a China Delegate of Assembly for Intl Heat Transfer Conference (AIHTC) and an executive member of Scientific Council of Intl Centre for Heat & Mass

Transfer (ICHMT). He is also the founding Editor-in-Chief of Energy Storage and Saving, the Associate Editor of International Journal of Heat and Mass Transfer, Heat Transfer Engineering.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

POTENTIAL OF SOLUBLE MOLECULAR ADDITIVES IN BOILING-BASED THERMAL MANAGEMENT SYSTEMS

Avinash Upadhyay, Brijesh Kumar, and Rishi Raj
Indian Institute of Technology Patna, India

ABSTRACT

Thermal management applications relying on boiling require high heat transfer coefficients (HTC) and critical heat fluxes (CHF). Traditional surface modification techniques are often expensive and prone to issues of delamination and fouling. Conversely, fluid modification methods using soluble additives such as surfactants and surface-active ionic liquids (SAILs) are gaining popularity due to their ease of implementation. These additives are known to facilitate HTC enhancement by altering fluid properties. Surfactants, for instance, reduce surface tension and induce foaming tendency, leading to early nucleation and faster ebullition cycles, thereby increasing the HTC. Similarly, certain SAILs outperform surfactants such as sodium dodecyl sulfate (SDS) in terms of HTC and CHF. However, the enhanced CHF values due to these additives are mostly lower than that of baseline water. We here experiment with imidazolium-based IL [C_2mim][Cl] as additives to demonstrate a CHF ≈ 1.6 times that of water. This improvement was attributed to enhanced heater surface wettability through in-situ additive deposition. Consequently, we employed non-foaming [C_2mim][Cl] as a cosurfactant in aqueous SDS solution, leveraging the advantage of both wettability and foamability. This approach leads to simultaneously enhancing the CHF and HTC compared to the SDS-only solution. Furthermore, tuning the concentrations of individual additives resulted in even simultaneous enhancements compared to water. In summary, soluble additives and their mixtures offer the ability to simultaneously tune the CHF and HTC. This advancement not only improves performance but also offers a scalable and robust solution for managing high heat fluxes, which is crucial in various industrial and technological fields.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

HIGH RESOLUTION INVESTIGATIONS OF BOILING HEAT TRANSFER, FROM CRYOGENIC FLUIDS TO HIGH-PRESSURE WATER

Matteo Bucci[1]
[1]*Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, USA*

ABSTRACT

In every field of science, the possibility of discovering and understanding new phenomena or testing new hypotheses is strongly related to and limited by the capability of observation. Here, we will discuss recent advances in experimental boiling heat transfer research made possible by unique experimental facilities and non-intrusive high-resolution optical diagnostics. We will analyze the capabilities and limitations of these techniques in supporting the understanding of fundamental two-phase heat transfer problems, with a focus on extreme boiling conditions such as the boiling of water at high pressure and temperature, close to nuclear reactor conditions, the boiling of dielectric fluids for electronic cooling applications, or the boiling of cryogenic fluids relevant to space propulsion and energy storage. The use of these diagnostics has been instrumental in providing answers to long-standing fundamental questions on the fluid dynamics and heat transfer nature of these processes.

BIOGRAPHY

Matteo Bucci is the Esther and Harold E. Edgerton Associate Professor of Nuclear Science and Engineering at the Massachusetts Institute of Technology (MIT). He has published over 40 journal articles and 70 conference papers. His research group studies two-phase heat transfer mechanisms in nuclear reactors and space systems, develops high-resolution non-intrusive diagnostics and surface engineering techniques to enhance two-phase heat transfer, and creates machine learning tools to accelerate data analysis and conduct autonomous heat transfer experiments. He has won several awards for his research and teaching, including the MIT Ruth and Joel Spira Award for Excellence in Teaching (2020), ANS/PAI Outstanding Faculty Award (2018 and 2023), the UIT-Fluent Award (2006), the European Nuclear Education Network Award (2010), and the 2012 ANS Thermal-Hydraulics Division Best Paper Award. Matteo serves as the Editor of Applied Thermal Engineering, is the founder and coordinator of the NSF Thermal Transport Café, and works as a consultant for the nuclear industry.

Changes in boiling performance modified by charged surfactants with different chain lengths

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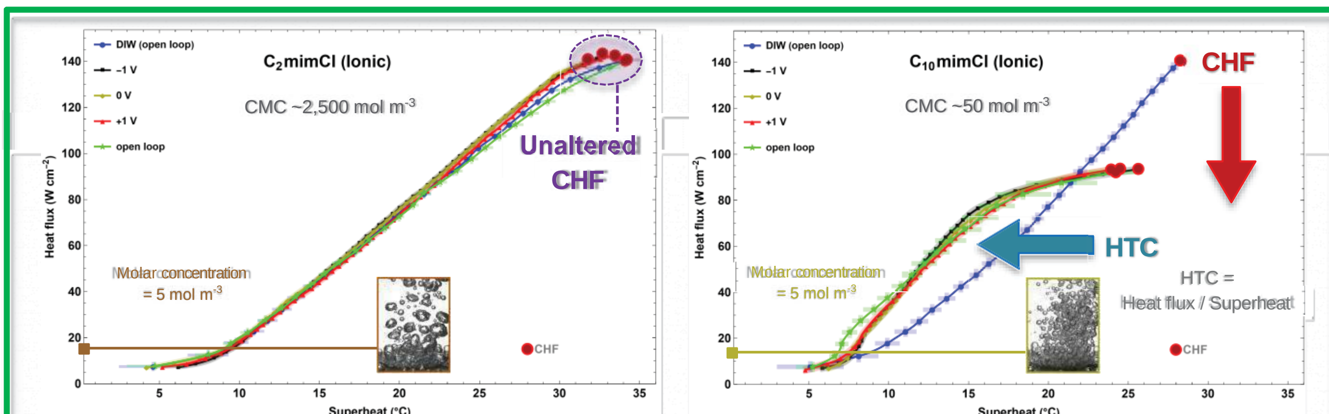
ABSTRACT

The ability of most surfactants to alter liquid interfacial properties has attracted attention for changing boiling behavior, including bubble size and non-coalescence. Surfactants are amphiphilic molecules with a hydrophilic head and a hydrophobic tail. While surfactants commonly enhance the boiling heat transfer coefficient (HTC), they will lower the critical heat flux (CHF), resulting in an HTC–CHF trade-off behavior that we previously verified. However, there has been a recent report of ionic liquid-based surfactants (ILBSs)—1-alkyl-3-methylimidazolium (mim) halides—that seemingly break this trade-off behavior with a simultaneous increase in CHF and HTC. We investigated this further through a set of experiments with mim-chloride surfactants as well as comparable sodium sulfate surfactants—all with varying tail lengths. Puzzlingly, some of the ILBSs reported to simultaneously increase CHF and HTC were at a concentration where practically no surfactant was being adsorbed to interfaces. With no surfactant adsorption, we would not expect to see any modification of boiling behavior. Indeed, in our work, we could not replicate the reported break-in trade-off behavior. Rather, we further confirmed the trade-off behavior as we found a general trend: as surfactant tail length increases, HTC increases and CHF decreases. These results further verify our previous work that the degree to which HTC increases and CHF decreases is directly dependent on how much surfactant is adsorbed at the timescale of the bubble, whether diffusion-limited or equilibrium-limited. Our study elucidates the importance of surfactant adsorption and provides actionable insight on how to select surfactants to modify boiling behavior.

ABSTRACT FIGURE



Extremely high CMC surfactant, C_2mimCl, does not affect the Lower CMC surfactant, C_{10}mimCl, affects the HTC-CHF HTC-CHF trade-off behavior due to the negligible adsorption of trade-off behavior, leading to a leftward shift in boiling curves. surfactants to interfaces exhibiting relatively bigger bubble size This shift enhances HTC while reducing CHF, attributed to the as opposed to the smaller bubble size observed with C_{10}mimCl. adsorption of surfactants to interfaces.

Acoustic Bubbles: Decoding the Physics of Sound Generation and Propagation in Multiphase Flow and Heat Transfer Applications

Rishi Raj
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ABSTRACT

Bubbles are ubiquitous in nature, manifesting across diverse environments, from the fizz of a sparkling beverage to the bubbling brooks in a serene landscape. Yet, beyond their visual charm, bubbles harbor an often-unexplored acoustic dimension. The extraordinary soundscapes of bubbles come to the fore in phenomena such as underwater gas leaks, boiling heat transfer, oceanic noise, and rising bubble streams from the seafloor. In this presentation, we delve into the physics of underwater acoustic emissions, triggered by the ejection of air bubbles from a submerged nozzle into a liquid pool. We scrutinize the impact of numerical models on our understanding of these phenomena. While incompressible multiphase computational fluid dynamics models adeptly capture the shape dynamics, they falter when it comes to representing the associated acoustics. Drawing inspiration from Minnaert's analytical treatment of acoustic bubbles, we incorporate the effects of compressibility through the lens of the ideal gas equation, honing our models for better alignment with experimental data, especially in simulating acoustic aspects. Our exploration unveils unique bubble dynamics, underscoring the crucial role of liquid jet entrainment in sound generation. The results underscore the need for compressible treatment of the gaseous phase in multiphase applications, enriching our nuanced understanding of bubble behavior, a knowledge that holds immense potential for a wide array of engineering applications.

BIOGRAPHY

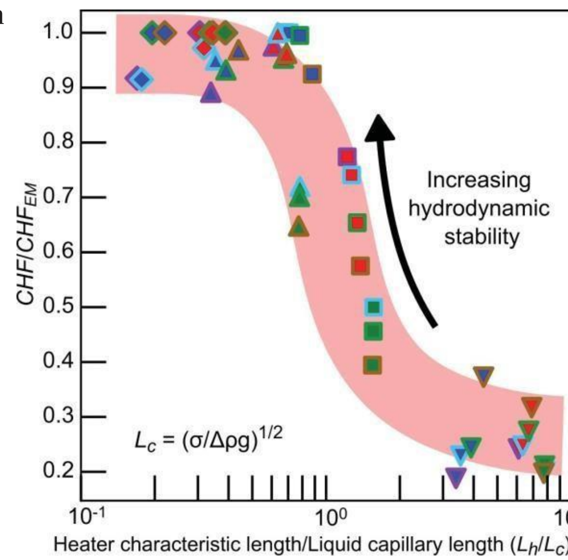
Rishi Raj is an Associate Professor in the Department of Mechanical Engineering at the Indian Institute of Technology (IIT) Patna. He earned his B.Tech. degree in Mechanical Engineering from IIT Guwahati in 2006 and his Ph.D. from the University of Maryland College Park in 2010. Before joining IIT Patna in 2013, he was a Battelle Postdoctoral Fellow at MIT's Device Research Laboratory. His research group at IIT Patna investigates thermal and fluid transport during liquid-vapor phase change for various earth and space-based energy and thermal management applications. He has published over 65 journal articles, 90 conference articles, 3 book chapters, and 7 patents. He received the prestigious Swarnajayanti Fellowship 2021 by the Department of Science and Technology (DST), Government of India. His research has also been recognized with the Prof. K. N. Seetharamu Medal and Prize by the Indian Society for Heat and Mass Transfer (ISHMT), and Young Scientist/Engineer Awards from the Indian National Science Academy (INSA 2019), Indian Academy of Sciences (IASc 2018), and Indian National Academy of Engineering (INAE 2018). He currently serves as the Editor of International Communications in Heat and Mass Transfer.

HYDRODYNAMIC LIMITS OF CRITICAL HEAT FLUX AND ITS ULTIMATE EVAPORATION MOMENTUM LIMIT

SAEED MOGHADDAM
UNIVERSITY OF FLORIDA

ABSTRACT

The upper limit of heat transfer from a heated surface to a surrounding boiling liquid, commonly known as the critical heat flux (CHF), has been extensively studied since Nukiyama's discovery in 1934. Two prevailing explanations concerning the physics of this phenomenon have emerged: one involving hydrodynamic instability proposed by Kutateladze (1948), and the other involving the evaporation momentum force threshold proposed by Steinchen and Sefiane (1996), with correlations associated with these explanations developed by Zuber (1959) and Kandlikar (2001), respectively, predicting similar CHF values. In this study, results of recent experiments conducted on different fluids and variable saturation pressure and heater width are presented, showing that the evaporation momentum limit (CHF_{EM}) is roughly four times higher than the Zuber hydrodynamic instability limit ($CHF_{Z\text{-}HI}$). As indicated in the right Figure, the CHF progressively increases as the heater width (L_h) is reduced and reaches a plateau when L_h drops below the fluid capillary length (L_c). A developed model that considers the balance of forces at the liquid-solid interface accurately predicts this CHF, consistent with the evaporation momentum theory.



Since CHF_{EM} is only observable under stable hydrodynamics conditions, past studies correlating CHF to contact angle based on the evaporation momentum threshold are inaccurate. The model developed in this research accurately captures the effect of contact angle on CHF_{EM}. Furthermore, it is found that the dynamic, rather than the static, contact angle correlates with the CHF_{EM}. Using the model, the evaporation momentum force is calculated and is shown to be much higher than previously assumed.

BIOGRAPHY

Dr. Moghaddam holds the William Powers Professorship in Mechanical and Aerospace Engineering (MAE) at the University of Florida (UF). He earned his PhD from the University of Maryland (UMD) in 2006. Before joining UF, he served as a postdoctoral associate (2007-2010) at the University of Illinois at Urbana-Champaign (UIUC). His significant contributions to the field of boiling heat transfer include characterizing various mechanisms of heat transfer at the interface of a single bubble with a heater, as well as at the solid-fluid interface in flow boiling within microchannels using a unique micro heat flux array. A primary focus of his current research is CHF and the implementation of boiling in cooling Data Centers. Dr. Moghaddam's work on phase-change heat transfer is funded by the U.S. National Science Foundation (NSF), Office of Naval Research (ONR), and Advanced Research Projects Agency – Energy (ARPA-E).

The role of century-old design of Tesla valves in microchannel flow boiling

Wenming Li
Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing, 210096, PR China

ABSTRACT

Two-phase flow in confined spaces is fundamentally interesting and practically important in many practical applications such as thermal management, offering the potential to impart high thermal transport performance owing to high surface-to-volume ratio and high latent heat released during liquid/vapor phase transition. However, the associated physical size effect, in coupling with the striking contrast in specific volume between liquid and vapor phases, also leads to the onset of unwanted vapor backflow and chaotic two-phase flow patterns, which deteriorates practical thermal transport performances. Here, we develop a novel thermal regulator consisting of classical Tesla valves and engineered capillary structures, which is capable of switching its working states and imparts a giant boost in heat transfer coefficient and critical heat flux in its "switched-on" state. We demonstrate that the Tesla valves and the capillary structures serve to eliminate vapor backflow and promote liquid flow along the sidewalls of both Tesla valves and main channels, respectively, which synergistically enable the thermal regulator to self- adapt to varying working conditions by rectifying the chaotic two-phase flow into an ordered and directional flow. We envision that revisiting century-old design opens up a new avenue for developing next generation cooling devices that can achieve switchable and extremely high heat transfer performances for ever-high power electronic devices.

BIOGRAPHY

Dr. Wenming Li, currently, is a full professor at Southeast University, Nanjing, China. Dr. Li mainly focuses on phase-change heat transfer at microscale, thermal management of high-power density electronics and thermoelectric conversion. He has extensive research experiences in flow boiling in microchannels and spray cooling. He got his Master's degree from Huazhong University of Science and Technology in 2012 and then completed his Ph.D degree at University of South Carolina in 2018 under the supervision of Prof. Chen Li. He has worked as a postdoc at Washington University in St. Louis in 2018-2019. After that, he worked as a postdoctoral fellow in Prof. Yogendra Joshi's group at Georgia Tech. Dr. Li joined Southeast University in 2021. By now, Dr. Li has published over 30 peer-reviewed journal papers, including *Nature Communications*, *Advanced Materials*, *APL*, *IJHMT*, etc.

Self-Propelled Ice on Herringbone Ratchets

Jack T. Tapocik, Venkata Yashasvi Lolla, Sarah E. Propst, and Jonathan B. Boreyko
Department of Mechanical Engineering, Virginia Tech, Blacksburg, VA 24060

When droplets are deposited on a surface beyond a critical superheat, they float on their own vapor layer to extend the evaporation lifetime. On anisotropic surface structures, this so-called Leidenfrost effect can be exploited to enable self-propelled droplets by fostering a directional vapor flow for viscous entrainment. Inspired by this liquid-vapor self-propulsion system, here we develop an analogous solid-liquid ratchet using ice pucks melting on a herringbone structure. The physics for the solid-liquid ratchet differ in several key ways. First, a critical onset time must be reached for the channels to fill with meltwater and support the weight of the ice. Second, the terminal velocity of the ice was rate-limited by the viscous resistance of the thin meltwater film above the ridge tops, in contrast to the inertial resistance of self-propelled droplets due to the soft shocks of the bumps. Finally, when using a superhydrophobic herringbone, propulsion was no longer driven by viscous entrainment at all. Rather, the ice puck was dramatically pulled by an asymmetric Laplace pressure in the proceeding meltwater.

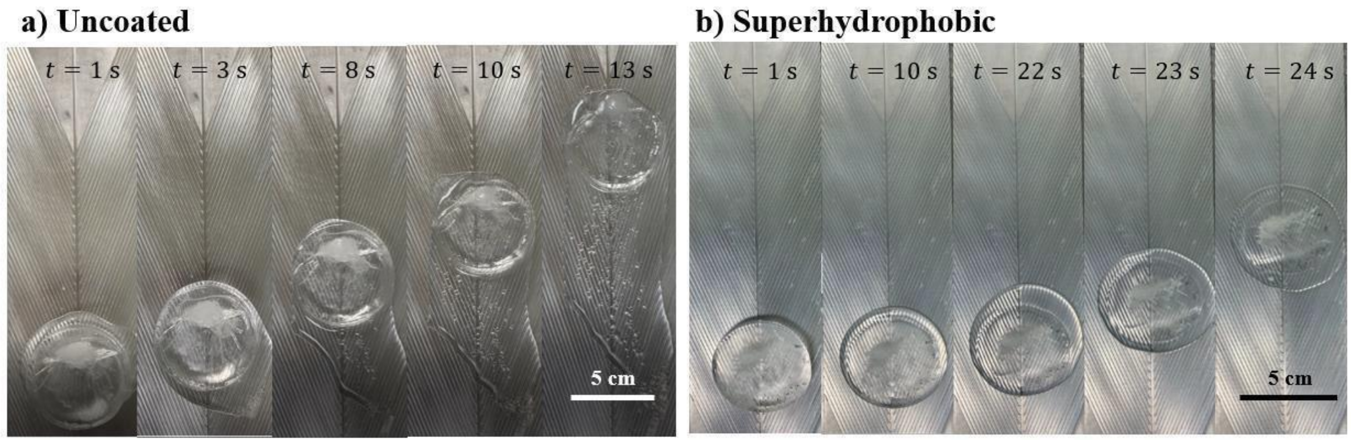


Figure 1: Time-lapse images of ice pucks ratcheting on an aluminum herringbone (T = 65 ºC). (a) For an uncoated herringbone, the ice puck moves almost immediately with a viscous entrainment mechanism. (b) For a superhydrophobic herringbone, the ice puck is quasi-stationary for a long period of time, followed by a sudden slingshot effect triggered by a mismatch in Laplace pressures in the meltwater.

MODELING OF LIQUID-VAPOR PHASE CHANGE HEAT TRANSFER: FROM NANOSCALE TO MACROSCALE

Shuai Gong[1], and Ping Cheng[1]
[1]*School of Mechanical Engineering, Shanghai Jiao Tong University*

ABSTRACT

Liquid-vapor phase change is one of the most efficient processes to transfer energy in nature and industrial applications. Due to its high heat-transfer capability, liquid-vapor phase-change processes such as boiling and evaporation have been widely used for thermal management of high-power-density electronics in recent years. In this talk, I will introduce our recent progresses on the modeling of the multiscale liquid-vapor phase change heat transfer processes. On the nanoscale, we propose a mesoscopic approach for steady/transient nanoscale evaporation heat transfer characteristics. By incorporating a mean-field approximation of solid-fluid interaction which is analytically derived by integrating the molecular level interaction, we successfully capture the disjoining pressure effect and elucidate its suppression effect on nanoscale evaporation heat transfer. We demonstrate that solid-fluid interaction plays dominant roles on the interfacial transport during nanoscale evaporation, and vapor transport resistance has nonnegligible influences on the evaporation heat/mass transport in nano-confined spaces. On the microscale to macroscale, we propose a high-fidelity numerical approach for simulating nucleate boiling heat transfer by considering microlayer evaporation and contact angle hysteresis effect. We demonstrate that our simulated instantaneous bubble shape, bubble growth rate agree very well with the experiments. Notably, we compare our simulated instantaneous and local temperature distribution beneath the bubble with experiments and show very good agreement as well. The multiscale heat transfer mechanisms elucidated are helpful for the design of cooling strategies for next generation ultrahigh heat flux electronics.

ABSTRACT FIGURE

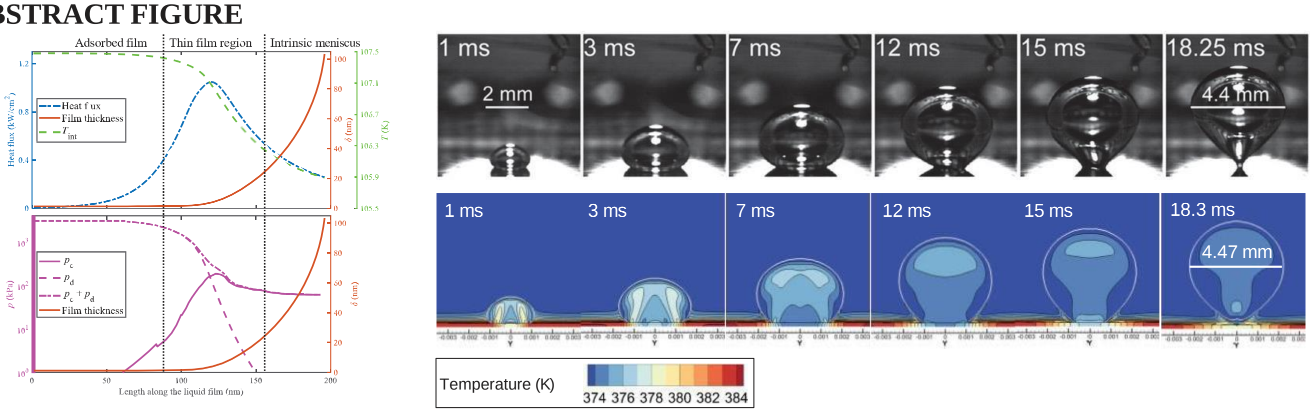


Figure 1 (left) Simulation results for evaporating meniscuses in a nanochannel; (right) Comparison of the evolution of nucleate boiling bubble shapes between the experiment [1] and our simulations. Our simulated temperature field (bottom) is also shown.

Reference

[1] T. Yabuki, O. Nakabeppu, Int. J. Heat Mass Transf. 76 (2014) 286–297.

High-speed microdroplet impact on heated surfaces

Yoshiyuki Tagawa
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ABSTRACT

We investigate the transition from spreading to splashing of droplets with radii *R* ranging from millimeters to tens of microns impacting smooth, dry, partially wetting substrates under normal atmospheric conditions, both at room temperature and on superheated surfaces.

Conventional models often focus on millimeter-sized droplets (d > 1 mm). However, micro-droplets impacting solid surfaces have been found to contradict existing models. Here, we examine micro-droplet impacts on room-temperature and heated solid surfaces using two setups based on droplet size. For room-temperature impacts, droplets transitioned from spreading to splashing as the impact velocity increased, but at higher velocities, they transitioned back to spreading. This suggests that reduced lift due to thinning air under the lamella leads to the following splash condition (cf. Usawa, Tagawa et al., Phys. Rev. Fluids, 6 (2021), 023605):

$$\frac{\rho V^2 \lambda}{\sigma} = We_\lambda \gtrsim K = 0.5 ,$$

where ρ is the liquid density, V is the impact velocity, λ is the mean free path of gas molecules, σ is the surface tension, and K is a constant. Interestingly the splash behavior on heatedsurfaces show the opposite behavior, which will also be discussed in the talk.

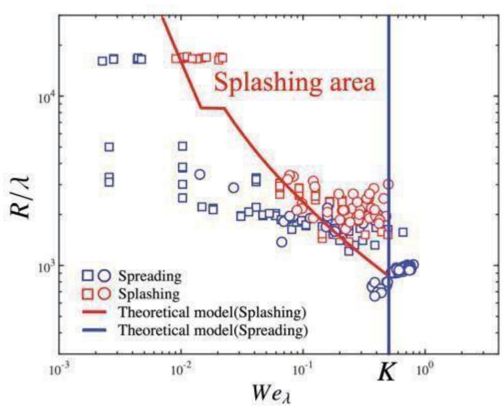

Fig.1 Spreading and splashing conditions in a R/λ-We_λ plane, where R is the droplet radius (cf. Usawa, Tagawa et al., Phys. Rev. Fluids, 6 (2021),

BIOGRAPHY

Dr. Yoshiyuki Tagawa is a Full Professor in the Department of Mechanical Systems Engineering at the Tokyo University of Agriculture and Technology. He earned his Ph.D. in Engineering from the University of Tokyo in 2009. Dr. Tagawa was a Postdoctoral Fellow with the Japan Society for the Promotion of Science (JSPS) and a researcher at the University of Twente in the Netherlands. He joined Tokyo University of Agriculture and Technology as an Associate Professor in 2013, becoming a Full Professor in 2020. His research focuses on developing medical engineering technologies using fluid engineering and studying high-viscosity supersonic microjets. His work has been supported by prestigious grants, and he has received numerous awards, including the Minister of Education, Culture, Sports, Science and Technology Award. Dr. Tagawa serves on the advisory board of the International Journal of Multiphase Flow and holds various professional society roles.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

DYNAMIC CHARACTERISTICS OF DROPLETS ON MICRO/NANOSTRUCTURED SURFACES DURING PHASE TRANSITION

Zhichun Liu

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ABSTRACT

With the continuous miniaturization and integration of electronic products, the rapid increase in heat flux brings persistent challenges to the thermal management of electronics. This report presents the recent progress of our group on the phase change behavior of droplets on micro/nanostructured surfaces. Firstly, we conducted molecular dynamics (MD) simulations to investigate the evaporation process of nanoscale droplets on a series of nanostructured surfaces with different geometric dimensions and wettability properties, investigating the influence of surface physicochemical properties on the evaporation dynamics of the three-phase contact line and the evaporation rate of the droplets. In addition, MD and lattice Boltzmann method (LBM) were applied to investigate the dynamic characteristics of condensation droplets on micro/nanostructured surfaces during nucleation, growth and coalescence, and the phenomena of dewetting and self-jumping were analyzed.

Professor Liu is a professor of Engineering Thermophysics at Huazhong University of Science and Technology. His research focuses on heat dissipation and control technology of electronic devices, heat transfer enhancement theory and technology, water and heat management in proton exchange membrane fuel cells, as well as energy transfer and conversion at micro-nano scale.

BIOGRAPHY

Professor Liu is a professor of Engineering Thermophysics at Huazhong University of Science and Technology. His research focuses on heat dissipation and control technology of electronic devices, heat transfer enhancement theory and technology, water and heat management in proton exchange membrane fuel cells, as well as energy transfer and conversion at micro-nano scale.

NANOCHANNEL-BASED ION TRANSPORT AND OSMOTIC ENERGY CONVERSION WITH THERMAL ENHANCEMENT

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ABSTRACT

Osmotic energy conversion harvests salinity-gradient and solar thermal energies to generate electricity with high efficiency and wide applicability by taking aqueous ions as energy carriers, being of great significance for carbon neutrality. Its critical process lies in directional ion transport in ion-selective nanochannels of nanoporous membranes under the coupling impacts of electric-temperature-concentration fields and interface-dimension-structure effects. Current output performance faces challenges due to the inherent trade-off between ion selectivity and permeability, which seeks interdisciplinary efforts to bridge the gap between microscopic ion transport behaviors and macroscopic power generation performance. In this report, interfacial effects and ion migration mechanisms combining thermal effects are discussed to provide knowledge of the underlying phenomena in confined nanochannels. Dimensionless parameter groups derived from the similarity principle are then delivered to supply unified criteria for the performance evaluation of osmotic power generation, and the equivalent-circuit, data- driven, and pH-temperature coupled models are introduced for accurate performance prediction. In addition to membrane innovation and microgeometry design, various thermal enhancement strategies are presented to achieve high-performance and sustainable outputs, including interfacial or bulk photothermal reinforcement, symmetric or nonsymmetric temperature arrangement, and phase-change thermal storage. Lastly, the thermal-assisted ion migration is highlighted to design a bifunctional device capable of promising water-electricity cogeneration.

BIOGRAPHY

Professor Zhiguo Qu completed his Ph.D. degree in 2005 in Engineering Thermophysics at Xi'an Jiaotong University. His research interests include highly-efficient heat and mass transfer technology, hydrogen fuel cell/electrochemical energy storage, and solar energy utilization. He received over 70 research funding including the National Key Research and Development Program of China (Chair Scientist) and the National Natural Science Foundation for Distinguished Young Scholars. He published 302 SCI Journal Paper (First/Corresponding Author 216) with over 11,000 citations (H-index 57, Google Scholar). He received the First Prize of Shaanxi Province Science Award (2020, ranked No.1) and the Second Prize of Natural Science of the Ministry of Education (2022, ranked No.2). He is expert of "14th Five Year Plan" for National Key Research and Development Program in Hydrogen Energy, Associate Chair of ASME K18 Committee, Associate Editor of Micro & Nano Letters, and Editorial Board Member of Energy & AI.

Ultra-thin vapor chambers for efficient thermal management

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Guangzhou, Guangdong, China

ABSTRACT

High power microelectronic devices are facing the increasingly severe problem of high heat flux dissipation in compact space, which has become a bottleneck restricting the development of today's microelectronic industry. Vapor chamber, as an efficient heat transfer element using the phase change process of liquid working fluid to transfer heat, has gradually become the mainstream adoption in the field of microelectronics heat dissipation, which imperatively demands further research on the optimization of its structural design, manufacturing and performance. This talk will mainly introduce the research progress of our group in the key technologies of manufacturing ultra-thin, flexible, insulating and lightweight vapor chambers, including vapor-liquid structure design, phase change heat transfer mechanism, wick structure fabrication and surface morphology modulation. Besides, the talk will share some specific applications of the research achievements in high-speed rail IGBT modules, aerospace, EV power batteries and other fields.

BIOGRAPHY

Shiwei Zhang is a professor and Ph.D supervisor of School of Mechanical and Automotive Engineering at South China University of Technology, and is elected for the High-Level Young Talents Programme of Guangdong Province. He has long focused on the key technologies and theories of the design and manufacture of phase change based thermal control functional structures and devices. He is the Principle Investigator for about 10 projects, including funding from National Natural Science Foundation of China, Natural Science Foundation of Guangdong, and the Hong Kong Postdoctoral Fellowship Scheme. He was awarded the Second Prize of the Science and Technology Progress Award of Guangdong. He has published about 60 SCI papers (34 papers as the first or corresponding authors) and 12 invention patents.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
20 – 24 June 2024, Hong Kong

FUNCTIONAL SILICONE OIL GRAFTED SURFACES FOR WETTING AND PHASE-CHANGE

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International Institute for Carbon Neutral Energy Research (WPI-I2CNER), Kyushu University, Japan

ABSTRACT

Wetting and phase-change are ubiquitous phenomena relevant to many everyday domestic and industrial applications and their better understanding benefits applications such as thermal management of portable electronics, water treatment and harvesting, energy generation, etc. To this end, functional coatings fabricated via easy and scalable silicone oil grafting are proposed as potential candidates for controlling wetting and phase-change.

On one hand, silicone oil grafting with the suppression of the cleaning and subsequent impregnation step is was adopted here. While all fabrication parameters rendered the surface hydrophobic with equilibrium contact angles near 108°, the different grafting parameters such as oil viscosity and application method (pipette, dip coating and number of layers), allowed for the tuning of the contact angle hysteresis between 1° and 20°. A 2-fold decrease in contact angle hysteresis down to <1° is put forward after one single grafting step by optimizing the fabrication parameters. On the other hand, the different range of contact angle hysteresis anticipates different droplet-surface interactions as a droplet undergoes either evaporation or condensation. By controlling the fabrication parameters the evaporation behavior of a droplet can be tuned within those reported on benchmarked hydrophilic silicon and hydrophobic Teflon. For one single grafting step, the complete suppression of the contact line pinning is achieved.. Last, the different contact angle hysteresis reported also anticipate different interactions between condensing droplets and these grafted surfaces. Despite displaying similar wettability the droplet size distribution during condensation can be controlled with a 66% decrease in the maximum departure radius.

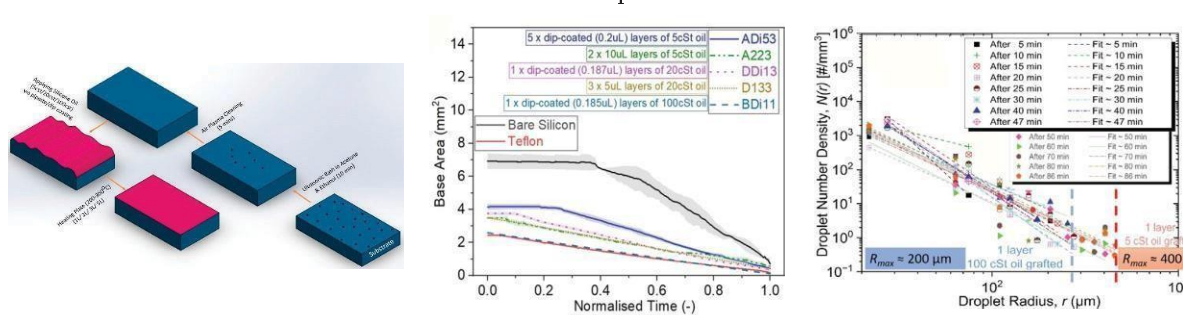

Figure: (left) Schematics of the silicone oil grafting procedure, (middle) Base area (mm^2) of an evaporating droplet function of the normalized time, to note is the continuous decrease of the base area for BDi11. (right) Droplet number density (#/mm3) function of radius *r* (μm) for 5 cSt and 100 cSt grafted oil.

BIOGRAPHY

Dani Orejon is a Senior Lecturer in Chemical Engineering at the University of Edinburgh UoE in Scotland. Dani received his MSc degree in Chemical Engineering from the University of Seville in Spain and PhD on the fundamentals of evaporation phase-change at the droplet scale from the UoE. Thereafter Dani joined the International Institute for Carbon-Neutral Energy Research (WPI-I2CNER) at Kyushu University in Japan as a Post- Doctoral Research Associate and then as Assistant Professor. In 2019 Dani joined the Institute for Multiscale Thermofluids (IMT) at the UoE. In addition, Dani serves as School Postgraduate Progression Committee representative for the IMT, Teaching Laboratory Manager for the Chemical Engineering Discipline, WPI-I2CNER Visiting Associate Professor, and Fellow of the Higher Education Academy. Dani has received several awards and funding from the JSPS, Royal Society, European Space Agency ESA, amongst others.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
20 – 24 June 2024, Hong Kong

Advanced Absorption Thermal Storage and Thermal Management

Wei Wu
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ABSTRACT

Thermal energy storage and thermal management are critical to carbon neutrality. We proposed different absorption thermal battery fluids and cycles to accommodate a wide range of application scenarios with performance improvement in energy storage efficiency, energy storage density, exergy efficiency, charging temperature, and initial cost. Besides, we used the absorption thermal battery for passive PV cooling. Modeling and measurement results demonstrated significant PV temperature reduction and thus electric efficiency enhancement. In addition to passive cooling, this module offers the unique ability to harvest atmospheric water during desorption. Furthermore, we extended this absorption thermal management concept to passive electronics cooling and battery cooling. Proof- of-concept prototypes have been developed for lab measurement, indicating that this strategy can improve the de- vice performance significantly, exhibiting record-high cost-effectiveness. In summary, absorption-based techniques are promising for high-performance and low-cost thermal storage and thermal management.

BIOGRAPHY

Prof. Wu is an Associate Professor at City University of Hong Kong. His research is focused on building energy and sustainability technologies (BEST) towards carbon neutrality, including advanced heat pumps, novel working fluids, thermal energy storage, advanced thermal management, renewable energy utilization, and net-zero energy buildings. He has published more than 150 peer-reviewed papers, obtained/filed 23 CN/US patents, and published a Springer Nature book. Prof. Wu is among the Top 2% Most Highly Cited Scientists Worldwide. He received the IIR Willis H. Carrier Young Researcher Award, the NIST Distinguished Associate Award, the Excellent Young Scholar Award of Energy and Built Environment, the HVAC Distinguished Young Scholar Award, and the Academic New Talent of Tsinghua University. He won two Gold Medals at the International Exhibition of Inventions Geneva. He serves as an expert of IEA-SHC and IEA-HPT. He is an editorial board member of several SCI journals.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

PERFORMANCE ANALYSIS OF ULTRATHIN VAPOR CHAMBER AND IT'S APPLICATION IN BATTERY THERMAL MANAGEMENT SYSTEM

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ABSTRACT

The mesh-type ultra-thin vapor chamber (UTVC) is a highly effective device that spreads heat efficiently and maintains good temperature uniformity, meeting the present trend and demand for compact system heat dissipation. To analyze the thermal behavior of the mesh-type UTVC, a three-dimensional transient numerical model involving the non-isothermal flow and phase change processes of the working medium is developed to solve the hydraulic and heat transfer performance of the mesh-type UTVC. The effects of the mesh parameter including the support coarse mesh and the fine mesh wick on the heat transfer performance of the mesh-type UTVC are analyzed.And the thickness of the fine mesh wick is determined to be the influencing factor of the thermal response performance of the UTVC. Besides, cavities in the supporting coarse mesh inside the vapor core are proposed to form a multiscale combination of vapor channels with the meshes. Utilizing a numerical model that considers microporous evaporation as well as the Marangoni effect, the effects of different flow channel structure and channel widths on the performance of the UTVC are analyzed. The study found that the most significant performance enhancement is achieved. In addition, a novel battery thermal management system based on UTVC with composite wick structure (mesh and spiral woven mesh) is proposed. To analyze the key parameters that affect the thermal performance of the battery thermal management system, an experimental system is established to investigate coolant flow rate, inlet coolant temperature, filling rate, and gravity conditions.

ABSTRACT FIGURE

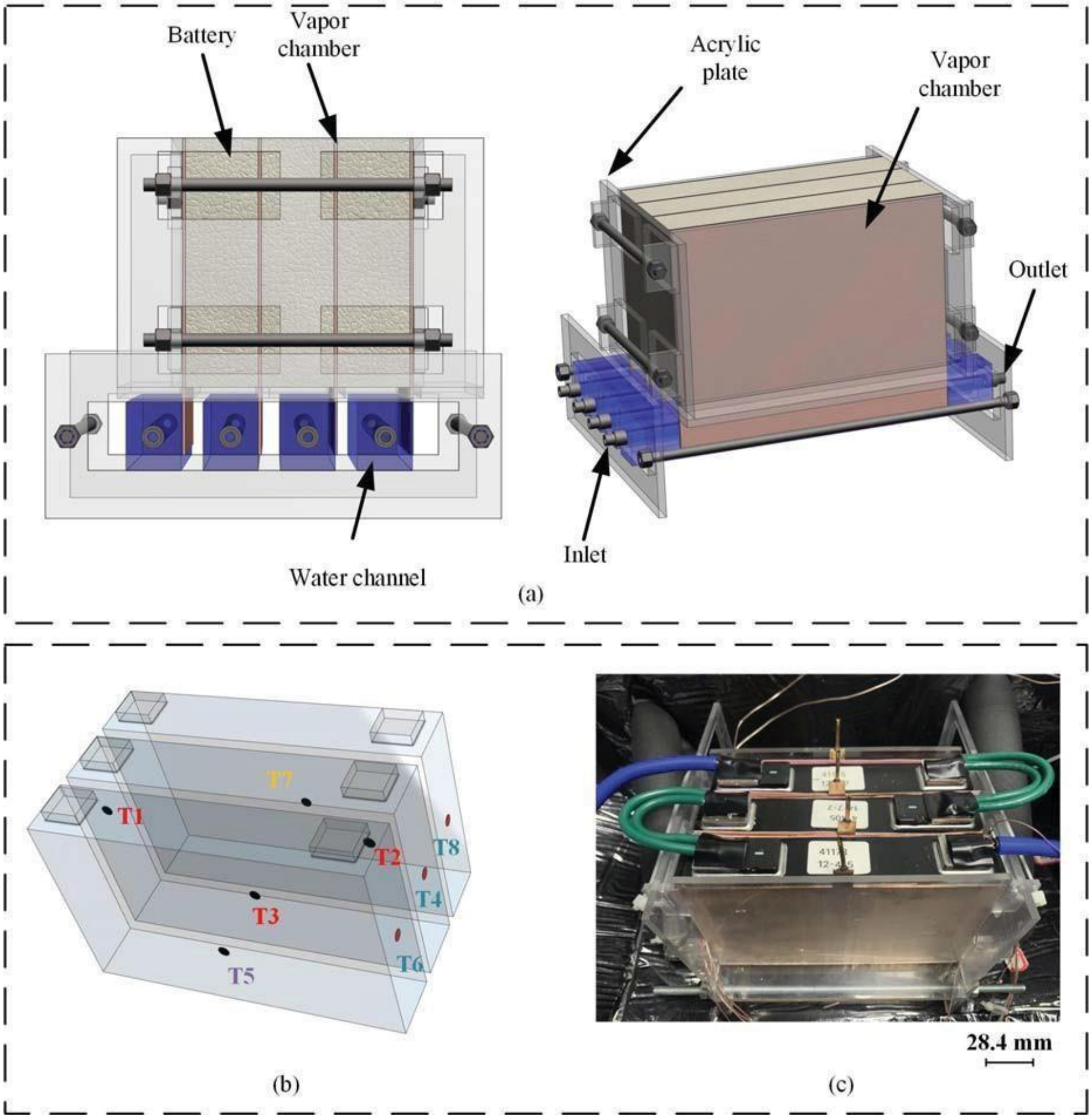

Fig. 1. (a) Schematic of the UTVC-BTMS (b) Temperature measurements on the battery surfaces (c) Diagram of actual BTMS.

SMART THERMAL MANAGEMENTS USING THERMAL SMART MATERIALS OF NANOPARTICLE SUSPENSIONS WITH TUNABLE THERMAL CONDUCTIVITY

Bingyang Cao
Department of Engineering Mechanics, Tsinghua University, Beijing 100084, China

ABSTRACT

Smart thermal management technology is essential in modern technologies to manage heat transfer in diversified and complicated operating and situation conditions. In this study, we proposed a kind of thermal smart system using thermal smart materials of nanoparticle suspension with tunable thermal conductivity for promoting temperature control and energy conservation. The nature of rotational diffusion is the mass transport of particles in its own spherical coordinates. Based on statistical theory, three methods for rodshaped particles and the diffusion tensor for platelike particles are proposed, and they are respectively utilized to calculate the rotational diffusion coefficient. We prepared thermal smart materials using nanoparticle suspensions composed of silicone oil and graphene-based composite nanosheets. The thermal conductivity of nanoparticle suspensions can be tuned by switching on and off electrical field accordingly. The variation of the thermal conductivity can be explained by our proposed two-step model. Then, we demonstrated a kind of thermal smart component based on thermal smart materials, whose thermal resistance can be continuously tuned by electrical field. The thermal smart component has good temperature regulating ability, enabling the decrease of device temperature by 5.3°C when the environmental temperature is 20°C, the input heat flux is 3500 W/m^2, and the electrical field strength is 600V/mm. An energy conservation of 10% can be achieved by using thermal smart component. This smart thermal managements can work well in practical operation conditions with complex and varying heat-flux, showing great potential invarious thermal management systems for electronic devices, spacecraft systems, and power batteries.

BIOGRAPHY

Bingyang Cao is full professor and dean in the School of Aerospace Engineering, Tsinghua University, China. He is fellow of Asian Union of Thermal Science and Engineering, International Association of Advanced Materials, and Engineered Science Society. He currently serves as Delegate of the Assembly for International Heat Transfer Conferences, Secretary General of the Asian Union of Thermal Science and Engineering, vice-chair of the Thermally Conductive Composite Committee of the Composite Society of China, etc. He was awarded MOE New Century Talented Scientists Program (2011), Excellent Youth Funding of NSFC (2013), Wu Zhonghua Outstanding Young Scholar Award from CETS (2014), Outstanding Young Scientists of NSFC (2018), First Prize of Natural Science of MOE (2019), Elsevier Highly Cited Researchers (2021-2023). His main research areas include micro-/nanoscale heat transport, thermally functional materials and advanced thermal management technologies. He has published a monograph: Non-Fourier heat conduction in nanostructures, and more than 200 SCI-indexed journal papers. He is currently serving as Editor-in-Chief of ES Energy & Environment, Associate Editor of International Journal of Thermal Sciences, and editorial member of over 10 international journals.

Exploring the Upper Boundaries of Dropwise Condensation through Controlled Microdroplet Shedding

Xiao Yan[1,2], Chongyan Zhao[3], Rong Chen[1,2], Xun Zhu[1,2], Qiang Liao[1,2], and Nenad Miljkovic[4,5,6]

[1]Key Laboratory of Low-grade Energy Utilization Technologies and Systems, Chongqing University, Ministry of Education, Chongqing 400030, China
[2]Institute of Engineering Thermophysics, Chongqing University, Chongqing 400030, China
[3]Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing 100084, China
[4]Department of Mechanical Science and Engineering, University of Illinois, Urbana, IL 61801, USA
[5]Materials Research Laboratory, University of Illinois, Urbana, Illinois 61801, USA
[6]International Institute for Carbon Neutral Energy Research (WPI-I2CNER), Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan

ABSTRACT

Dropwise condensation represents the upper limit of thermal transport efficiency for liquid-to-vapor phase transition. A century of research has focused on promoting dropwise condensation by attempting to overcome limitations associated with thermal resistance and poor surface-modifier durability. Based on our recent studies, we show that condensation in a microscale gap formed by surfaces having a wetting contrast, termed microscale-confined condensation or MCC, can overcome these limitations. Spontaneous out-of-plane condensate transfer between the contrasting parallel surfaces decouples the nanoscale nucleation behavior, droplet growth dynamics, and shedding processes to enable minimization of thermal resistance and elimination of surface modification. Experiments on pure steam combined with theoretical analysis confirm the breaking of intrinsic limits to classical condensation and demonstrate a gap-dependent heat-transfer coefficient with up to 2X enhancement compared to classic dropwise condensation. Furthermore, we developed a numerical simulation framework for MCC to explore the upper boundary of the condensation heat transfer, through which we constructed a regime map in terms of surface wettability and shedding droplet size. We showed that smaller surface gaps and smaller condensing surface contact angles are preferential to achieve a higher heat flux in pure vapor condensation conditions. The optimized MCC outperforms the state-of-art jumping-droplet condensation, with a 3-5X enhancement of heat transfer coefficient at a steam temperature of 100 °C. Our study highlights a significant room for improvement of the current condensation and presents a promising mechanism and technology for compact energy and water applications where high, tunable, gravity-independent, and durable phase-change heat transfer is required.

BIOGRAPHY

Dr. Yan received his Ph.D. degree from Tsinghua University in 2019. Prior to joining Chongqing University in 2023, he worked as a postdoctoral researcher at the University of Illinois at Urbana-Champaign and the Hong Kong University of Science and Technology. His research focuses on phase change heat transfer, thermofluid, interfacial sciences, and thermal hydraulics, with particular interests in microscale droplets/films for high-heat-flux phase change heat transfer.

Scalable and Sustainable Janus Mesh for Efficient Fog Harvesting and Purification

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ABSTRACT

Fog harvesting plays a significant role in addressing water scarcity which is a global issue affecting numerous regions, particularly those facing arid or semi-arid climates. However, the deteriorating air pollution and bacteria proliferation in humid environments raise concerns about the safety of harvested fog water and the sustainability of fog harvesting systems. Here, we developed a Janus mesh with asymmetric wettability on its two sides via a simple and scalable method. Water droplets on the Janus mesh can transport from the superhydrophobic side to the hydrophilic side overcoming gravity force, but not vice versa. Owing to the unidirectional droplet transportation and photocatalytic characteristics, this Janus mesh enables effective fog harvesting and purification to occur simultaneously, resulting in a 37% higher fog harvesting rate than the unmodified brass mesh and a removal rate of organic pollutants in the fog water up to 94%. Furthermore, the Janus mesh displayed a high efficacy in eliminating bacteria, as evidenced by a 99.975% reduction in *E. coli* and excellent resilience against airborne organic pollution. These multifunctional properties ensure the long-term stability of the Janus mesh, enabling it to reliably provide freshwater resources from the atmosphere to people living in remote and arid regions.

High-performance solar-driven hypersaline brine treatment

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Engineering Research Center of Solar Power and Refrigeration (MOE), Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China

ABSTRACT

Recent advances in solar evaporation highlight the priority of porous evaporator for thermally localized evaporation, which is promising the sustainable freshwater supply. However, porous structure also confines the salt transport and brings crystallization issues, leading to rapid performance degradation especially for hypersaline brine treatment. Here, we demonstrate a high-performance and salt-rejecting solar evaporation strategy, through convection enhancement in a millimeter-scale water layer. By manipulating the temperature and salinity gradients in a confined saline layer, we create strong localized thermohaline convection, which could achieve the local heat transfer enhancement, salt rejection enhancement and overall heat loss suppression simultaneously. With a ten-stage device, we achieve record-high solar-to-water efficiencies of 322–121% in the salinity range of 0–20 wt% under one-sun illumination. More importantly, we demonstrate an extreme resistance to salt accumulation with 180-hour continuous desalination of 20 wt% hypersaline brine. By achieving high freshwater production and extreme salt-resistance simultaneously, our device significantly reduces the water production cost, paving a pathway toward the practical adoption of solar-driven brine treatment for sustainable water economy.

BIOGRAPHY

Dr. Zhenyuan Xu is an Associate Professor in the Institute of Refrigeration and Cryogenics at Shanghai Jiao Tong University. Dr. Xu earned his PhD degree in Shanghai Jiao Tong University, and worked as postdoc in Massachusetts Institute of Technology before joining Shanghai Jiao Tong University as faculty. His research interests include heat pump and desalination technologies for solar energy or waste heat utilization. Dr. Xu has published 60+ papers in *Joule*, *Energy & Environmental Science*, *Applied Energy* with H-index of 29. His new designs on solar desalination were selected as Top MIT Research Stories twice in 2020 and 2023, and featured as the Best Inventions of 2023 by Time Magazine. His contributions in heat pump were awarded the first prize of Mechanical Industry Science and Technology Award (2023) and James Joule Award of International Institute of Refrigeration (2019). He serves as the committee members of the China Association of Refrigeration and China Association of Desalination and Water Reuse.

Enhanced condensation heat transfer on superhydrophobic microporous and multiscale structured surfaces

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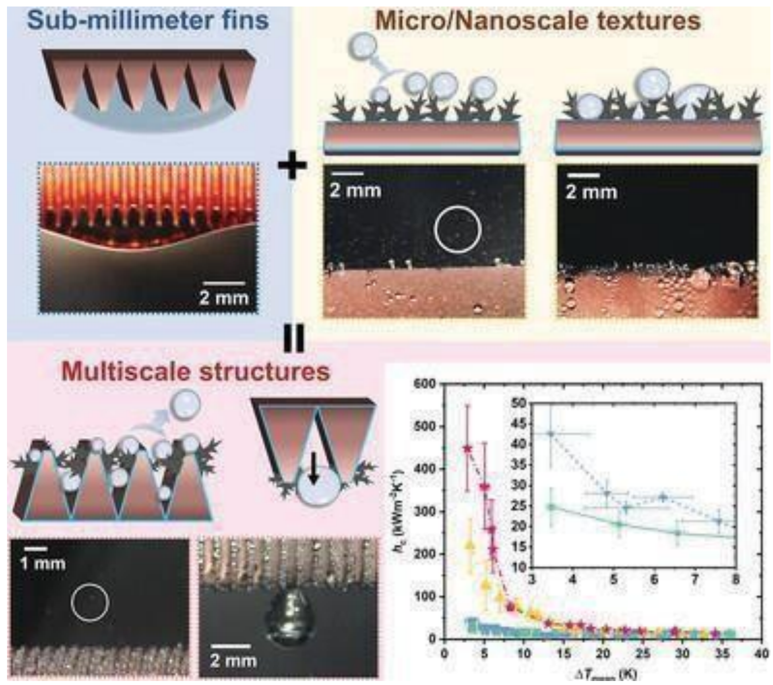
ABSTRACT

Spontaneous droplet jumping on micro-/nano-structured superhydrophobic surfaces has been exploited as an efficient means for enhancing steam condensation heat transfer. However, the good performance of such surfaces quickly decays with raising the degree of subcooling, due to the mismatch between thecharacteristic length scales and droplet sizes when they grow up. Herein, a novel strategy for multiscale droplet regulation is proposed by combining sub-millimeter fin structure with ahierarchical microporous superhydrophobic surface. A superior condensation heat transfer performance is attained on such hierarchical superhydrophobic finned tube (F-SHB), in comparison to the baseline case of superhydrophobic non-finned (SHB) tube under well-controlled test conditions. Although the droplet jumping is not as vigorous as that on the SHB tube, the finned geometry of the F-SHB tube leads to a condensation heat transfer enhancement even under high degrees of subcooling up to 36 K, because of the accelerated departure of large droplets by imposing Laplace force gradient in the presence of V-shaped sub-millimeter fins. This multiscale enhancement strategy is shown to enable a cascading regulation over the entire lifespan of condensate droplets. The fabrication of F-SHB tubes is facile and easy to be scaled up, showing great potential in practical steam condensation applications.



BIOGRAPHY

Dr. Liwu FAN is professor in the School of Energy Engineering at Zhejiang University. He is the Head of the Institute of Thermal Science and Power Systems, and is also affiliated with the State Key Laboratory of Clean Energy Utilization.

Dr. FAN got his Ph.D. degree in Mechanical Engineering from Auburn University on August 2011. Since his doctoral study, he has been focusing on heat transfer and fluid flow at the microscale and with phase change phenomena, with applications to thermal energy storage, cooling of electronics and batteries, energy-efficient buildings, etc. As the first or corresponding author, he has published more than 110 papers in prestigious journals like Nat. Commun., Energy Storage Mater., Adv. Funct. Mater., etc. All of his papers have been cited by more than 6300 times (>5900 without self-citation). His personal H-index is 39, and is listed as one of the "Highly Cited Chinese Researchers" in 2023. He has won the "Wu Chung-Hua" Outstanding Young Scholar Award in 2021.

AMMONIA CROSSOVER IN DIRECT AMMONIA FUEL CELLS

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[1]*Key Laboratory of Low-Grade Energy Utilization Technologies and Systems (Chongqing University), Ministry of Education, Chongqing, 400030 China*
[2]*Institute of Engineering Thermophysics, Chongqing University, Chongqing, 400030 China*
[3]*Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hong Kong, China*

ABSTRACT
Ammonia as a hydrogen carrier has become more arresting recently, primarily because of its zero-carbon emission and cost-effectiveness in production, storage, and transportation. Directly feeding ammonia to fuel cells can produce electricity whenever and wherever needed. Since ammonia fuel solution itself creates an alkaline environment, an anion exchange membrane, which conducts hydroxide ions, is typically employed to build ammonia fuel cells. As a key component, the membrane plays a very important role in the ion conduction and electrode reactions. Hence, it is critically important to investigate and understand its physicochemical characteristics.

In this work, we have built an ammonia fuel cell with an anion exchange membrane. Five commercial anion exchange membranes were characterized in the aspects of ionic conductivity and ammonia crossover rates and their influences on the performance of the ammonia fuel cell were comparatively examined. It is found that both a high conductivity and low ammonia crossover rate of the anion exchange membrane contribute to a higher cell performance. Additionally, a mathematical model incorporating the mass transport, electrochemical reaction, and ammonia crossover occurring in the ammonia fuel cell has been constructed. The model exhibited good agreement with the experiment results. It suggests that a major cause of the voltage loss in the ammonia fuel cell is the anode polarization. Also, it is displayed that the cell performance improves by increasing the reactant concentration because of the increased mass transfer rate of reactants and decreased activation loss of the electrochemical reaction.

ELASTOCALORIC REGENERATORS WITH ENHANCED HEAT TRANSFER STRUCTURES

Shuhuai Yao
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ABSTRACT

Space cooling consumes large amounts of electricity, and the market-dominant vapor compression refrigeration relies on high global-warming-potential refrigerants. Elastocaloric cooling using shape memory alloys is a promising alternative because of its high energy efficiency and greenhouse-gas-free properties. Many research efforts have been focusing on the thermomechanical cycles, material properties, and fatigue life of the SMAs. However, less effort has been made to achieve optimal heat transfer performance of the entire system. We address the challenge by designing compression-loaded convective regenerator with a significantly expanded heat transfer area and by developing a cascade-unit architecture to increase the length of the regenerator without Euler buckling under compression. A numerical model was developed to evaluate this cooling performance. Using a nondimensional analysis of the governing equations, the model simplifies the investigation of the design and operation parameters and greatly reduces the computation complexity of the regenerative elastocaloric cooling systems. Guided by our numerical model, we developed a compression-based regenerative elastocaloric device using tubular nickel titanium (NiTi) regenerator of spiral cross-section and achieved a maximum temperature span of 75 K. Large specific heat transfer area of the spiral structure enables fast heat transfer between NiTi and fluid, while a sufficient regenerative length facilitates a large temperature difference along the fluid-flow direction. We further demonstrated the scaled-up proto-type system with a SMA in-series and fluid-in-parallel architecture to achieve kilowatt-scale cooling, demonstrating the great potential of elastocaloric cooling technology for large-scale space cooling.

BIOGRAPHY

Prof. Shuhuai YAO is a Professor in the Department of Mechanical and Aerospace Engineering and a joint faculty member in the Department of Chemical and Biological Engineering at the Hong Kong University of Science and Technology. She obtained the B.S. degree in engineering mechanics from Tsinghua University and the Ph.D. degrees in mechanical engineering from Stanford, followed by the training as a postdoctoral fellow at Lawrence Livermore National Laboratory. She is a Fellow of HKIE.

Her research interest lies in understanding of micro-/nano-scale fluid dynamics and heat transfer, and integrating theory and experiments to develop innovative technologies for instrumentation. Prof. Yao has published more than 100 scientific publications in peer-reviewed journals and international conferences including top journals of her research fields such as Nature Energy, Nature Physics, Nature Communications, Sci. Adv., Joule, etc. She has over 10 grant patents and patent applications. In addition, Prof. Yao co-founded one startup company based on the microfluidic technology she invented and patented at HKUST.

PHASE-TRANSITION THERMOPHYSICS IN CRYOBIOMEDICINE

Wei Rao
Key Laboratory of Cryogenic Science and Technology and Beijing Key Laboratory of CryoBiomedical Engineering, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, 100190, PR China

ABSTRACT

Cryobiomedicine is a cutting-edge interdisciplinary field that studies the role of matter and energy in organisms at low temperatures and its medical applications. At present, the boundary of cryoablation needs to be expanded 1 cm beyond the tumor edge to ensure that there is no residue at the lesion site. And the lack of long-term cryopreservation methods for large-scale biological samples results in unequal supply and demand of tissues and organs. Facing the urgent challenges in people's life and health, the exploration of precise phase-transition control mechanisms and technology demonstrates irreplaceability in the above challenges. In this report, we will focus on phase-transition thermosphysics in cryobiomedicine, and introduce the following four aspects: 1) Microscale: molecular targeted ice nuleation control strategy and mechanism; 2) Mesoscale: tissue-level energy selective uptake and time-domain regulation mechanism; 3) Macroscale: energy-quality synergistic regulation based on the calculation of the real structure of the system; and 4) Clinical applications. This report will focus on multi-scale precise control of phase-transition, in the cross-disciplinary field of engineering thermophysics, from the breakthrough of the underlying concepts and methods, detailing the team's systematic research work from the development of methods, to the regulation of the system, and then to the development of series of medical equipments.

BIOGRAPHY

Wei Rao is a professor at the Technical Institute of Physics and Chemistry (TIPC), Chinese Academy of Sciences (CAS). Dr. Rao's research is highly interdisciplinary and covers the material science of liquid metal and micro/nanomaterials. She has published 112 papers in peer-reviewed journals such as Advanced Materials, Advances Functional Materials, Nano Letters, Materials Science & Engineering R. In addition, she was one of the leading authors of books entitled "Handbook of Liquid Metals", "Nanoscale Liquid metals", "Advanced Low-cost Medical Technology". Dr. Rao leads 18 national grants (including NSF, National Key R&D Project, etc.). Dr. Rao was the recipient of the "foreign talents" program by TIPC and the Beijing Youth Talent Support program. Dr. Rao's team was awarded for the translation of scientific and technological achievements. At present, Dr. Rao is deputy director of Beijing Key Laboratory of CryoBiomedical Engineering, and director of united lab of liquid metal technology.

THERMAL TRANSPORT IN TWISTED GRAPHITE

Bai Song
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National Key Laboratory of Advanced MicroNanoManufacture Technology, Beijing, 100871, China

ABSTRACT

Twisted van der Waals (vdW) materials attracted immense interest immediately after the 2018 reports of unconventional superconductivity and correlated insulator behavior in magic-angle bilayer graphene. To date, a vast number of studies on the electronic and photonic properties have been published. Of equal importance is the phonon dynamics and heat transport in the moiré superlattice. In particular, by stacking a few layers of polycrystalline molybdenum disulfide with random interlayer rotations, extremely anisotropic heat conductors have been demonstrated for advanced thermal management of electronics. However, despite the great fundamental and applied interest in heat flow across twisted interfaces, most studies are limited to theoretical calculations while reliable experimental measurements are rare due to a range of critical challenges, especially for high-quality single-crystalline interfaces. Here, we develop micro-mesa-based experimental schemes and achieve simultaneous mechanical and thermal characterizations of the intrinsic interfaces in graphite. Remarkably, we observe nearly 40-fold suppression of thermal conductance for the slippery interfaces with low sliding resistance compared to locked interfaces. Nonetheless, the conductance remains well beyond 500 $MWm^{-2}K^{-1}$, approaching the highest values ever measured for any interface. Atomic simulations reveal the predominant role of transverse acoustic phonons. Together, our findings directly highlight a general force-heat correlation and lay the foundation for twist-enabled thermal management which are beneficial to both high-power electronics and emerging devices such as twistronics and slidetronics.

BIOGRAPHY

Dr. Bai Song explores at the intersections of thermal science, nanotechnology, and ultrafast physics, with a keen interest in probing mechanisms and pushing limits. He earned his bachelor's and master's degree at Tsinghua University, PhD at the University of Michigan, Ann Arbor, and worked as a postdoctoral associate at the Massachusetts Institute of Technology before joining Peking University in 2019. His recent projects focus on near-field thermal radiation, extreme thermal conductivity and interfacial thermal conductance (e.g., c- BAs, c-BN, graphite, and 2D amorphous carbon), exotic phonon dynamics and transport, thermal diodes of ultrahigh rectification ratios, unusual isotope effects in condensed matter, and microfluidic cooling of high-power electronics. Dr. Song is a recipient of the 2020 XPLORER PRIZE from the New Cornerstone Science Foundation.

Phononic Friction

Yunfei Chen
Southeast University

ABSTRACT

Friction plays a pivotal role in the dynamics of global energy, accounting for an estimated one-third of the world's primary energy consumption. It is traditionally viewed as a dissipative force, converting kinetic energy into heat at the interface where two surfaces interact. However, our research challenges this conventional understanding by suggesting that interfacial forces actually transform kinetic energy into potential energy within the material's bulk, a process that conserves rather than dissipates energy. This potential energy amasses until it exceeds a specified threshold, culminating in the partial release and dissipation of energy as phonons throughout the bulk. This shift in perspective redefines our interpretation of damping effects in sliding friction. We suggest a new perspective where damping is directly proportional to the speed of oscillation. This contrasts with the traditional belief that damping correlates with the relative sliding velocity, a concept ingrained in the classical Prandtl-Tomlinson and Frenkel-Kontorova models.

Building on this novel concept, we introduce a phononic friction model that provides a robust framework for predicting frictional forces. Our model has been validated by results from atomic force microscopy experiments and molecular dynamics simulations across various speeds and loads. It sheds light on aspects of friction that have remained puzzling, as observed in seismological research and lab experiments, such as the influence of spring stiffness and velocity-dependent behavior. This model provides quantitative understanding without depending on traditional dissipative postulates.

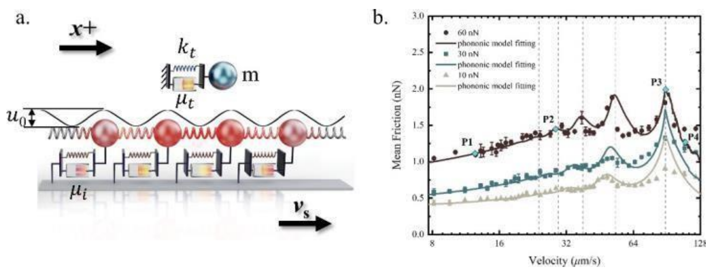

Figure (a) A common setup for assessing frictional forces with atomic force microscopy (AFM) is epitomized by a spherical tip gliding across a flat substrate, representing a simplified model that captures the essence of single-asperity contact interactions. (b) Phononic friction model accurately forecasts the frictional forces ascertained through atomic force microscopy (AFM) and corroborated by molecular dynamics (MD) simulations.

BIOGRAPHY

Yunfei Chen, Chair Professor of Southeast University. Chen's research spans tribology, heat transfer, fluid dynamics, and their practical applications in engineering advanced devices and systems. These include high-speed trains, as well as devices for DNA and protein sequencing, and energy conversion and utilization equipment. Chen, together with his team of students, has pioneered methods to directly observe the excitation of phonons due to friction and identify which phonons are stimulated in the process. Their groundbreaking work revealed that phonons excited by friction prominently concentrate at the washboard frequency and its harmonics. This significant discovery offers quantitative understanding into long-standing puzzles in seismology and engineering, shedding light on the mechanisms behind non-monotonic velocity-dependent friction, anisotropic friction, and frictional fluctuations. By viewing frictional energy dissipation through the lens of phononics, Chen and his team have developed an innovative predictive model for frictional forces that delivers unmatched accuracy. This phononic perspective represents a substantial leap forward, elucidating core principles of friction and heralding a major paradigm shift in the theoretical understanding of friction phenomena.

Micro/Nanostructures for Enhanced Phase-Change Heat Transfer

Ming-Chang Lu
National Taiwan University

ABSTRACT

In this presentation, I'll show how micro/nanostructures enhance phase-change heat transfer, focusing on Leidenfrost (LF) suppression, boiling, and condensation.

Droplet impact on hot surfaces is critical for thermal management. We developed superhydrophilic silicon nanowire arrays to suppress the LF effect, but their LF suppression ability was limited at high temperatures. Hydrophobic double-reentrant grooves improved in reducing droplet contact time but lacked directional removal. The newly developed asymmetric re-entrant microgroove array solved this, reducing droplet contact time, propelling droplets, and significantly increasing the Leidenfrost point synergistically.

Boiling heat transfer is vital for industrial heat removal. A new three-dimensional (3D) hybrid micropillar surface significantly improves heat transfer by combining taller hydrophobic pillars for bubble formation and shorter hydrophilic pillars for better liquid contact. This design achieves a remarkable 107% increase in critical heat flux and a 360% boost in heat transfer coefficient compared to plain surfaces. Additionally, our recent research on a single re-entrant pillar array surface showed promise for re-entrant pillars in retaining liquid water and enhancing boiling heat transfer.

Finally, I'll discuss condensation. While dropwise condensation (DWC) is more efficient, maintaining a stable DWC is difficult. Hybrid surfaces offer potential but struggle with bridged droplet removal. This study proposes a new method to improve condensation heat transfer by removing liquid-bridging droplets on 3D microchannel hybrid surfaces. The surface decreased droplet departure size and increased bridging droplet mobility, leading to stable condensation efficiency across a wide range of surface subcooling.

BIOGRAPHY

Prof. Ming-Chang Lu received his Ph.D. in Mechanical Engineering from the University of California at Berkeley in 2010. He worked at National Chiao Tung University from 2010 to 2019. He joined the National Taiwan University in August 2019. He is currently a Professor in the Mechanical Engineering department at National Taiwan University. He was elected a Fellow of the Asian Union of Thermal Science and Engineering in 2023 and a Fellow of the International Association of Advanced Materials in 2022. He also received the Distinguished Young Scholar award from the Society of Theoretical and Applied Mechanics of the Republic of China in 2015 and the 2015 Ta-You Wu Memorial (Distinguished Young Scholar) Award from Taiwan's Ministry of Science and Technology. His research interests lie in micro/nanoscale and phase-change heat transfer.

Spontaneously grown boehmite nanostructures enhancing phase change heat transfer on aluminium surfaces

Guang Yang, Shanghai Jiao Tong University

ABSTRACT

The lightweight nature of aluminum exhibits considerable potential for applications in the thermal management field, especially for mobile devices or space applications. In this study, the mechanism for enhancing pool/evaporation heat transfer on aluminum surfaces by spontaneous growth of boehmite layers in boiling water was comprehensively explored. The morphology and chemical composition of the nanolayers formed on boiling water-treated (BWT) aluminum surfaces were characterized. The surfaces were found to be covered with abundant cross-linked nanosheets and dispersed microclusters after BWT, which were verified to be superhydrophilic boehmite nanostructures. In addition, the effect of BWT time on the thickness and wettability of the boehmite layer was quantitatively studied. Furthermore, it was found that such stable and dense boehmite nanostructures could be synthesized on arbitrary structures, such as micropillar arrays. Compared to a copper surface, a 49% higher critical heat flux and a 79.6% higher heat transfer coefficient were demonstrated on BWT aluminum alloy surfaces. This study provides insights into the design and fabrication of lightweight aluminum-based high-heat flux thermal management devices.

Guang Yang is an associate professor at the Institute of Refrigeration and Cryogenics, School of Mechanical Engineering, Shanghai Jiao Tong University (SJTU), China. He received his B.S. degree from Tianjin University in 2011 and his Ph.D. degree from SJTU in 2016. From 2016 to 2018, he was a postdoctoral researcher at the Institute of Aerospace Thermodynamics, University of Stuttgart, Germany. His research interests include inferfacial fluid dynamics, heat transfer in porous media, cryogenics, etc. He has published more than 60 papers in peer-reviewed journals such as Advanced Materials, Physics of Fluids, International Journal of Heat and Mass Transfer, etc. He holds more than 20 inventive patents and is the recipient of several national grants.

Optimization of Heat and Mass Transfervia Nano/Micro-Structured Surfaces: utilizing energy barriers between states and "semi-dimensional reduction"

Wei Ding[1], Jin Ming Zhang[1], Peng Fei Zhao[1], Sebastian Reinecke[1] and Uwe Hampel[1,2]

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[2]Institute of Power Engineering, Technische Universitat Dresden, Dresden, 01062, Germany

ABSTRACT

Energy barriers inhibit the transition of a system from one state to another. This is evident in phenomena such as bubble nucleation during boiling, droplet expansion and contraction when it impacts a heated surface, and also cavitation. In this presentation, we will elucidate our insights and understanding of the exploitation of energy barriers post-state transition to augment heat and mass transfer in various processes. Specifically, in processes like bubble nucleation in boiling, the high energy required for nucleation (attributable to the energy barrier) triggers rapid bubble expansion and results in a semi-2D microlayer, just a few micrometers thin, on the surface. This can be viewed as a typical semi-dimensional reduction effect, transitioning a part of system from 3D to 2D. As a result, this thin liquid layer brings high efficiency on heat transfer. A similar phenomenon occurs when a droplet impacts a heated surface. Following impact, the droplet's expansion and contraction on the surface incite capillary waves that propagate along the droplet interface, inducing a semi-1D, prickle-like jet along the droplet's axis on the top side. This jet disrupts the vapor film beneath the droplet, expelling the vapor and delaying the Leidenfrost point. As a one more thing, cavitation, one of the most typical cases of 'dimensional reduction', utilizes a reduction from 3D to 0D and also the large energy barrier for bubble nucleation. Following bubble collapse, the local temperature and pressure reach 5000 K and ~ Mpa, respectively. Combined with O3, this effect facilitates a highly efficient oxidation process.

BIOGRAPHY

Dr. -Ing. Wei Ding graduated with a Bachelor's and Master's degree in Mechanical Engineering from the University Duisburg Essen in Germany in 2003 and 2006, respectively. In 2012, he received his Ph.D. from the same university, specializing in Process and Water Technology. Dr. Wei Ding currently works at the Helmholtz Zentrum Dresden Rossendorf (HZDR), Dresden, Germany, where he is part of the Fluid Research Institute, focusing on thermal fluid direction. His main research involves wall boiling heat transfer, spray cooling, critical heat flux (CHF), and micro-nano scale mechanisms related to the three-phase contact region (micro-liquid layer beneath the bubble, micro-contact angle related to the three-phase contact line, etc.). He has a profound understanding and research on wetting phenomena, the interaction among the wall, bubbles and droplets in different heat and mass transfer processes.

SUPPRESSING THE LEIDENFROST EFFECT ABOVE 1000°C FOR EFFICIENT THERMAL COOLING

Mengnan Jiang[1],Zuankai Wang[2]
[1]*School of Energy and Power Engineering, Dalian University of Technology*
[2]*Department of Mechanical Engineering, The Hong Kong Polytechnic University*

ABSTRACT

Since the old observation of the Leidenfrost effect, characterized by the levitation of water drops on hot solids upon an insulating vapor film, developing strategies to elevate the critical Leidenfrost point (LFP) for efficient heat transfer has remained a long-standing challenge. However, achieving high LFP and efficient thermal cooling across a wide range of temperatures seems mutually exclusive. Here, we design structured thermal armors (STAs) that block the onset of the Leidenfrost effect and meanwhile preserve efficient heat transfer up to 1150°C. Our design consists of thermally conductive, protruding pillars serving as thermal bridges, an imbedded insulating porous membrane for persistently wicking, and U-shaped channels for evacuating vapor. The key point lies in the coexistence of materials with thermally heterogeneous properties (conductive, insulating) and distinct topography (pillar, membrane), which cooperatively transforms normally uniform temperature and vapor profiles into non-uniform ones and counterintuitively reinforces thermal cooling (Fig. 1). The broad range of substrate temperatures for sustained and efficient thermal spray cooling without Leidenfrost effect is only limited by the melting of materials, rather than by the architecture and physical principle of our design. We also fabricate flexible STA that can be closely attached to substrates otherwise challenging to be structured. Our design strategy holds potentials to implement liquid thermal cooling at extremely high temperatures, a property uncharted to date.

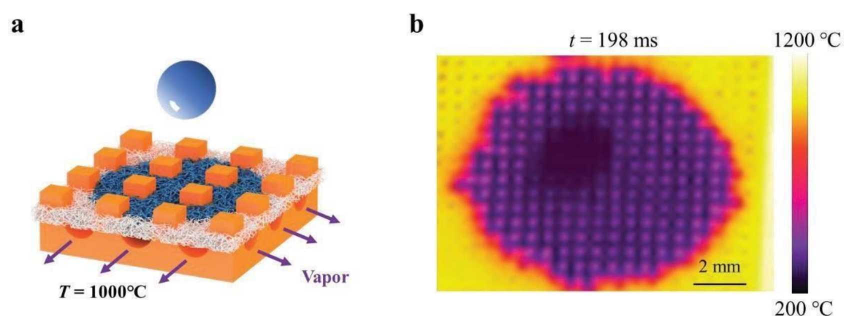


Fig. 1: Suppressing the Leidenfrost effect above 1000°C. a, Schematic diagram of STA. b, Infrared image of droplet spreading on STA with ultra-high temperature above 1000°C.

BIOGRAPHY

Mengnan Jiang, is a professor of Dalian University of Technology. He has previously worked as a Research Assistant Professor (Prof. Zuankai Wang's Team) at The Hong Kong Polytechnic University, and a postdoctoral fellow (Prof. Zuankai Wang's Team) at City University of Hong Kong. His research focuses on heat and mass transfer under extreme environments. As the first author, he successfully suppressed the classical Leidenfrost effect even above 1000°C for efficient phase change heat transfer, and published it in *Nature*. He has published about 20 papers in SCI journals, such as *Nature, Nature Communications, Advanced Materials*.

ULTRA-THIN FILM EVAPORATION ON V- GROOVED NANOWIRE BUNDLES SURFACES

Xuehu Ma

State Key Laboratory of Fine Chemicals, Liaoning Key Laboratory of Clean Utilization of Chemical Resources, Institute of Chemical Engineering, Dalian University of Technology, Dalian 116024, China

ABSTRACT

Ultra-thin liquid film evaporation is a ubiquitous natural phenomenon and has a variety of thermal management devices, seawater desalination and microfluidics area. However, the ultra-thin film evaporation mechanism coordinated with the micro/nano structured surfaces remain many opportunities and challenging. This report will try to elucidate the strategy of enhancing ultra-thin film evaporation using structured surfaces composed of nanowire bundles and interconnected V-grooves. The experimental tests and modelling analysis show that the evaporation rate and the evaporation rate enhancement ratio reach 0.42 mg/s and 12.68 at surface temperature of 60 °C, respectively. The enhancement of the film evaporation rate is attributed to the higher evaporation rate at the top of the nanowire bundles and the quick liquid supply from V-groove due to the capillary pump principle. The evaporation rate increases with as surface temperature increases while the evaporation rate enhancement ratio is decreased as surface temperature increases due to the deflation of the transition region. The ESEM evaporation results manifest that the nanowire bundles act as the main role of evaporation while the V- groove acts as the reservoir and supply liquid to nanowire bundles. Furthermore, it was found that the evaporation flux of nanowire bundles is 10 times higher than that of V-groove. Smaller nanowire diameter and larger nanowire height led to higher evaporation flux at the nanowire bundles due to the enhancement of liquid supply capability. The capillary evaporation mechanism presented in this work provides a rational approach in designing and optimizing hierarchical surfaces.

BIOGRAPHY

Dr. Xuehu Ma is a Professor of Chemical Engineering School at Dalian University of Technology (DUT). He received his PhD from DUT, followed by a postdoctoral Associate at Tsinghua University. He conducted visiting research at Queen Mary University of London, Oxford University, and University of Missouri. He currently serves as the Director of Liaoning Key Laboratory of Clean Utilization of Chemical Resources. His research interests include micro-nano interface transport and process intensification, hydrophobic/hydrophilic surfaces, dropwise condensation, evaporation and boiling, MED seawater distillation, absorption heat transformer. The first industrial-scale LiBr/H2O absorption heat transformer in china with capacity of 4.500MW had been successfully applied in Petrochemical Companies for waste heat utilization. The waste thermal energy driven seawater distillation plant was demonstrated in Dalian Petrochemical Company with 500 T/d pure water. He has published 200 peer reviewed international and Chinese journal papers and over 20 Chinese innovativepatents.

INVESTIGATING THE TEMPERATURE EFFECTS ON ADDITIVELY MANUFACTURED ALLOY

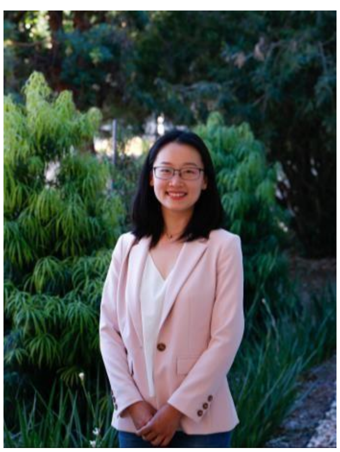
Yangying Zhu
Department of Mechanical Engineering, University of California, Santa Barbara, CA, USA

ABSTRACT

Metal additive manufacturing (AM) processes, such as laser powder bed fusion (L-PBF), can yield high- value parts with unique geometries and features, substantially reducing costs and enhancing performance. However, the material properties from L-PBF processes are highly sensitive to the laser processing conditions and the resulting dynamic temperature fields around the melt pool. We investigate how extreme temperature fields affect the microstructure of additively manufactured superalloy C103 and Mar-M247 using in situ high-speed infrared (IR) imaging and numerical simulation. We first show a simple method of converting raw IR images to temperature maps and illustrate that the grain growth dynamics is highly sensitive to temperature gradients during solidification for C103 and less sensitive to the cooling rates and solidification rates. We then utilize numerical simulation to predict the 3D temperature distribution and the melt pool interfacial velocity using 2D temperature measurement from the IR camera to further correlate thermal features with the microstructure of Mar-M247. Our findings highlight the crucial need for quantitative thermal characterization to fully understand the material properties of additively manufactured alloys.

BIOGRAPHY

Yangying Zhu is an assistant professor in the Mechanical Engineering department at University of California, Santa Barbara. Her work focuses on fundamental understanding of the thermofluids process for energy and water sustainability and advanced manufacturing. She obtained her PhD from MIT, advised by Prof. Evelyn Wang, where she developed microsystems for aggressive cooling of electronics. During her postdoc with Prof. Yi Cui at Stanford University, she investigated thermal effects in lithium-based batteries. She received early career awards from NSF, NASA and ONR, and the ASME Pi Tau Sigma Gold Medal.



Phase Change-Induced Liquid Droplet Actuations on Structured Surfaces – Applications in Colloidal Manipulations

Prof. Jiangtao Cheng
Department of Mechanical Engineering, Virginia Tech,
Blacksburg, VA 24061, USA

ABSTRACT In many cases, handling fluids and particles are regarded as two important but separate tasks, which are approached individually and independently by fundamentally different physical means. Here, I present strategies and methodologies on simultaneous manipulations of fluids and colloidal particles via phase change-induced liquid droplet actuations. The first topic is evaporation-triggered directional transport of asymmetrically confined droplet in beak-like structures. When a liquid droplet is confined between two non-parallel hydrophobic surfaces, the droplet morphology under confinement will continuously evolve during evaporation, leading to the directional transport of the droplet towards the cusp. The second topic is partial Leidenfrost evaporation-assisted rapid analyte enrichment in droplet and ultrasensitive surface-enhanced Raman spectroscopy (SERS) on micro/nano-structured plasmonic surfaces. And the third topic is violent and explosive jumping of boiling droplet on hot micro-structured surfaces for deep cleaning of fouling even in surface roughness and interstices. Our findings on the intrinsic mechanisms of droplet actuations shed light on a novel approach to regulating the sessile or confined droplets' behaviors in a passive and decisive fashion.

BIOGRAPHY Dr. Jiangtao Cheng is a professor in the Department of Mechanical Engineering at Virginia Tech. He has published more than 80 peer reviewed papers in the fields of surface wetting, heat transfer and thermal-hydrodynamics. Dr. Cheng has won numerous awards in his career including 6 times Best Paper Awards in various international conferences and 2013 Outstanding Overseas Young Scholar Award from China NSFC. He was awarded the Junior Faculty Award by Institute for Critical Technology and Applied Science of Virginia Tech in 2016 and became elected faculty fellow of College of Engineering of Virginia Tech in 2019 and elected fellow of American Society of Mechanical Engineers (ASME) in 2021.

PERSONAL IMAGE

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

THERMAL RESPONSES OF SURFACE NANOBUBBLES AND MICROPANCAKES

Hideaki Teshima[1,2], Qin-Yi Li[1,2], and Koji Takahashi[1,2]
[1]Department of Aeronautics and Astronautics, Kyushu University, Fukuoka, JP and
[2]International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University, Fukuoka, JP

ABSTRACT

Nanoscopic gas phases at solid-liquid interfaces are ubiquitous and play crucial roles in various fields, such as electrochemistry, phase-change heat transfer, and nanofluidics. Despite their importance, the detailed behaviors, particularly their responses to temperature changes, remain poorly understood. In this study, we report the thermal responses of nanobubbles on highly ordered pyrolytic graphite in water measured by atomic force microscopy. We found that surface nanobubbles nucleated by heating do not sit directly on the graphite surface but on micropancakes, which are a gas phase spreading laterally across the surface to widths of up to a micrometer with a uniform thickness of several nanometers. Furthermore, upon heating, the nucleation, growth, and dissolution of the nanobubbles were simultaneously observed on the same surface, which could not be explained by the traditional Ostwald ripening. This behavior was explained by taking into consideration the temperature change-induced mass transfer between the nanobubbles and underlying micropancakes. Specifically, the trend of the growth and dissolution of the nanobubble was found to be determined by the relative size of the underlying micropancake. Our findings will be valuable for the understanding of gas molecular dynamics near solid-liquid interfaces.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Leidenfrost Phenomenon on Superhydrophilic Copper Foams

Jiahao Yang[1], Xin Wang[1], Shuai Guo[1],Nan Zhou[1] , Zhenqian Chen[1, 2] , and Bo Xu [1, *]

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ABSTRACT : The phenomenon of a liquid droplet suspended above a hot solid surface by a vapor layer created by droplet evaporation is known as the Leidenfrost state. In the Leidenfrost state, the vapor layer insulates the droplet from the heated surface, leading to deterioration of heat transfer in countless important engineering applications. Therefore, it is essential to suppress the Leidenfrost effect and increase the Leidenfrost temperature point. Although layered structures have increased the Leidenfrost point to over 1000°C, the current performance mechanisms of single-scale structures remain under-analyzed. Here, we propose a simple high-temperature treatment to prepare superhydrophilic copper foams that exhibit ultrafast droplet penetration within tens of milliseconds, greatly increasing the Leidenfrost temperature. Based on the theoretical analysis of pressure balance, we find that the superhydrophilicity, high porosity and large pore size of copper foams that promote capillary suction and vapor evacuation. Compared to a smooth copper surface with a Leidenfrost temperature of approximately 200 °C, the copper foams nucleate boiling at high temperatures, triggering heat flux several orders of magnitude higher. Furthermore, the cooling performance is also discussed in terms of the Weber number (We=1.427~35.683). The results show that the Leidenfrost temperature point increases with increasing droplet impact velocity and strengthens with increasing We number. We envision that this work provides a new strategy for thermal management of high temperature systems such as spray cooling.

Keywords: Leidenfrost suppression, superhydrophilic copper foam, droplet permeation, heat transfer, droplet impact

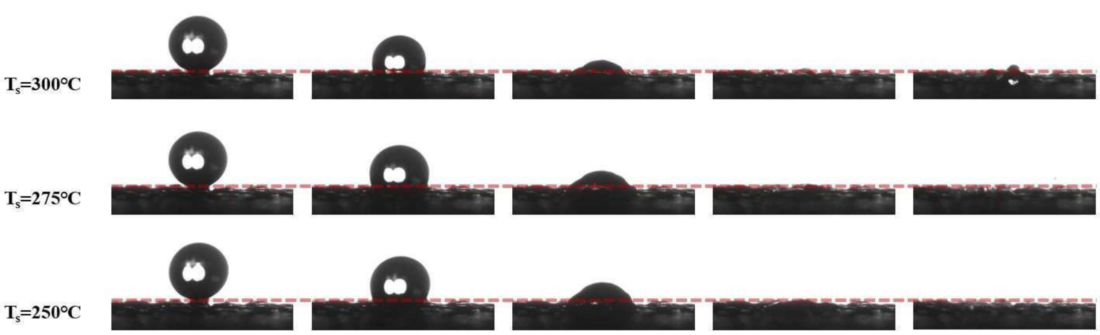

Figure 1. Dynamic evolution of water droplets on superhydrophilic copper foam

BIOGRAPHY

Corresponding Author

Bo Xu – School of Energy and Environment, Southeast University, Nanjing, P. R. China ; Research interests major in microgravity condensation heat transfer, flow heat transfer in extreme environments ; Email: xubo@seu.edu.cn

Authors

Jiahao Yang– School of Energy and Environment, Southeast University, Nanjing, P. R. China

Janus Vitrification of Droplet via Cold Leidenfrost Phenomenon

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ABSTRACT

Janus particles with asymmetric crystals show great importance in optoelectronics, photocatalysis, and self-propulsion devices, but their synthesis usually requires complicated processes. Here we observe an unexpected Janus vitrification phenomenon in a droplet induced by the Leidenfrost effect at a cryogenic temperature, which is commonly regarded as symmetric. The Leidenfrost phenomenon levitates the droplet when it encounters liquid nitrogen, which causes different cooling conditions between the top and bottom surfaces of the droplet. Therefore, it forms a Janus vitrified particle with asymmetric crystallization after cooling, as further evidenced by cryo-transmission electron microscopy (cryo-TEM) experiments. We found that the observation window of the Janus vitrification phenomenon is determined by the chemical concentration of the droplet, and the position of the asymmetric crystallization borderline is dependent on the droplet's radius and density. Our finding reveals the Janus vitrification phenomenon in droplet vitrification for the first time and provides new insight into creating Janus particles through the Leidenfrost phenomenon.

BIOGRAPHY

Meng Shi is an Associate Professor in the School of Mechanical Engineering at Xi'an Jiaotong University. From 2019-2023, he was employed as a Postdoctoral Fellow in Prof. Sigurdur Thoroddsen's lab at the King Abdullah University of Science and Technology (KAUST). In 2018, he obtained his Ph.D. degree in the major of Power Engineering and Engineering Thermophysics at Xi'an Jiaotong University. He enrolled in a two-year joint-cultivated Ph.D. program in Prof. Costas Grigoropoulos' group at the University of California Berkeley. Meng Shi's research focuses on interfacial fluids and heat transfer, including droplet behaviors on micro/nanostructures, Leidenfrost phenomenon, droplet impact, thermal management, and heat and mass transfer in cryopreservation and porous media. In 2019, he was awarded the Athanasiou ABME Student Award by the Biomedical Engineering Society. In 2022, he got the Milton van Dyke Award from the Division of Fluid Dynamics of the American Physical Society.

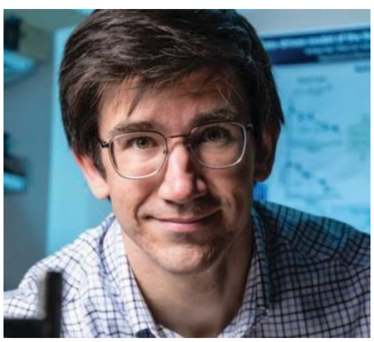
SCALABLE HOT-WATER-REPELLENT SUPERHYDROPHOBICITY

Daniel J. Preston
Rice University, Houston, TX 77005, USA

ABSTRACT

Superhydrophobic surfaces exhibit an extreme ability to repel water, imparted by a combination of surface texture and chemistry. While superhydrophobic surfaces have garnered interest for their utility in a broad range of engineering applications, they often lose their repellency when contacted by hot water (> 40 °C), primarily due to irreversible condensation of water vapor within the surface texture. We developed a scalable multilayered insulated superhydrophobic (MISH) coating that mitigates condensation within the surface texture by moderating heat transfer. Experiments show that superhydrophobicity is extended to 90 °C with the MISH coating, with durability demonstrated via jet bouncing and long-term droplet impingement experiments. We explain the underlying mechanism enabling improved performance with a detailed thermal model. The MISH coating accommodates curved geometries and large surfaces, and it is over four orders of magnitude less expensive than cleanroom-fabricated alternatives, indicating promise for practical use in the power, food, and medical industries.

BIOGRAPHY



Daniel J. Preston directs the Preston Innovation Laboratory at Rice University conducting research at the intersection of energy, materials, and fluids. He is a recipient of the NSF CAREER Award, the ASME Old Guard Early Career Award, and the Energy Polymer Group Certificate of Excellence. His lab is funded by NASA, the National Science Foundation, and the Department of Energy, among other sources. Dr. Preston earned his B.S. (2012) in mechanical engineeringfrom the University of Alabama and his M.S. (2014) and Ph.D. (2017) in mechanical engineering from MIT. Following his graduate degrees, he trained as a postdoctoral fellow from 2017–2019 at Harvard University in the Department of Chemistry and Chemical Biology prior to joining Rice University in July 2019.

Promising Membraneless Microfluidic Fuel Cells: Challenges, Solutions, and Applications

Xun Zhu

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Abstract

Owing to the rapid development of information technology, the increasing portable micro-electronic devices have urgent demand for micro power source with superior performances, including high power density, long-period operation and low-cost. Membraneless microfluidic fuel cells (MMFCs) are considered as promising micro power sources due to their advantages of competitive cell performance, easy fabrication and integration, flexible cell design, wide fuel adaptability, and wide application range.

However, the cell performance has still needs to be further improved to meet practical applications in different scenarios. This report firstly analyzes the physical and chemical processes in a typical MMFC, illustrates the existing challenges, and then reveals the key scientific issues inside the MMFC. With the goal of thinning the concentration boundary layer over the electrode, eliminating fuel permeation from anode to cathode, and accelerating gas bubbles remove, a variety of solutions and several innovative cell architectures are proposed. Thereafter, the research achievements on four aspects will be shared: 1) coupling fluid-solid motion characteristics during catalyst slurry preparation process as well as the high efficiency catalytic layer preparation; 2) fuel transport and reaction characteristics in porous electrodes and its regulations; 3) two-phase flow, mass transport and conversion characteristics the in micro-channel with porous electrochemical reaction boundaries; 4) dynamic behaviors of gas-liquid two-phase flow in the microchannel, as well as the mechanisms of two-phase flow coupling with electrochemical reaction and parameters influence on cell performance. Finally, the extensional research on passive and flexible fuel cells are briefly introduced.

Keywords: Microfluidic fuel cell; gas-liquid two-phase flow; fuel transport enhancement

Bio:

Xun Zhu

Professor; Winner of the National Outstanding Youth Science Fund project, leading talent in scientific and technological innovation under the National "Ten Thousand Talents Plan", leader of the innovation team in key areas of the Ministry of Science and Technology's Innovation Talent Promotion Plan, expert with special government allowances from the State Council, academic and technological leader in Chongqing, specially appointed professor for Bayu scholars in Chongqing, and a model for women in scientific and technological innovation in Chongqing. She has been engaged in research in the fields of energy conservation and emission reduction, micro and nano energy devices, fuel cell technology, microbial carbon sequestration and conversion for a long time. She has taken charge of more than 20 national and provincial level projects, including the National Outstanding Youth Science Fund, National Key R&D Program, National Natural Science Foundation Key Projects, and Key International Cooperation Research Projects. She has published more than 400 SCI international academic journal papers, authorized more than 80 invention patents, and won 5 first prizes in natural science from the Ministry of Education.

Jumping-droplets Gap Membrane Distillation: A Novel Configuration with Enhanced Energy Efficiency

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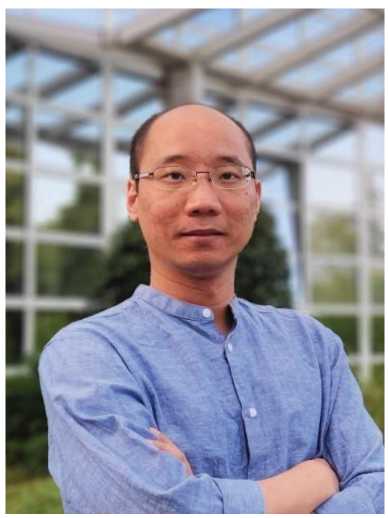
[2]Max Planck Gesellschaft - Wuhan University Partner Group, CN
[3]Max Planck Institute for Polymer Research, DE

Abstract

To address the pressing issue of global freshwater scarcity, membrane distillation (MD) stands out as a promising desalination technology. However, significant challenges such as low water flux, high energy consumption, and susceptibility to membrane wetting have impeded its further development and widespread industrial application. In this study, we introduce a novel MD configuration featuring a jumping-droplets gap, aimed at overcoming these limitations. This innovative configuration enhances MD performance by harnessing the sensible cooling stored within condensed droplets. As subcooled droplets jump from the condensing surface towards the membrane, they effectively capture vapor within the gap, facilitating substantial droplet volume growth. Our lab-scale Jumping-droplets Gap Membrane Distillation (JDMD) device demonstrates exceptional performance, exhibiting consistent and ultra-high freshwater production capacity (>120 $L\cdot m^{-2}\cdot h^{-1}$) and low specific energy consumption (770.38 $kWh\cdot m^{-3}$) during a 48-hour test. We anticipate that this innovative approach will provide a new avenue for optimizing and upgrading existing MD systems.

Biography



Dr. Youmin Hou obtained his Ph.D. in Mechanical Engineering from The Hong Kong University of Science and Technology. Following his doctorate, Dr. Hou joined the Max Planck Institute for Polymer Research in Germany as an Alexander von Humboldt Postdoc Fellow and Marie Skłodowska-Curie Fellow, focusing on studying the wetting dynamics on soft matter interfaces. Dr. Hou is currently a Professor in the Department of Power Engineering at Wuhan University. His research intersects the multidisciplinary fields of thermo-fluid sciences, surface engineering, and energy. He aims to enhance transformational efficiency in water technologies, thermal management, green building, and air pollution control by fundamentally manipulating heat-fluid-surface interactions across multiple length and time scales.

ENGINEERED SURFACES FOR A SUSTAINABLE FUTURE

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ABSTRACT

Water is ubiquitous on earth and is also a renewable energy source. Electrokinetic flow, which can generate streaming potential and streaming current through the flow of an electrolyte over a charged surface, cab be used for liquid energy harvesting. However, the yielded low energy conversion of electrokinetic flow on flat surface and superhydrophobic surfaces limited its practical applications. Here, I will present the advances of our group in improving the energy conversion via novel engineered surfaces. We showed that an enhanced streaming potential can be obtained through the flow of salt water on slippery liquid-filled surfaces to harness both of the electrolyte slip and associated surface charges. The highest figure of merit, in terms of the voltage generated per unit applied pressure, of 0.043 mV/Pa is obtained. I will also show the tunability of streaming potential by changing the geometry of liquid-filled surface and the properties of filled liquid. These results lay the basis for innovative surface engineering methodology for the study of electrokinetic phenomena at the microscale with possible application in new electrical power sources. Besides, I will also show our recent results of droplet impinging and pressure driven flow over other novel rising slippery surfaces.

BIOGRAPHY

Dr. Bei Fan received her Ph. D in Mechanical Engineering University of California San Diego in Dec 2019 and completed her postdoc training at Lawrence Berkeley National Laboratory in June 2021. Currently, she is an Assistant Professor in Mechanical Engineering at Michigan State University. Her research interests cover broad areas including thermal fluid science, microfluidic devices, electrokinetics, energy conversion and harvesting, desalination, and micro/nano fabrication. Her work has been published on high-reputation journals such as Nature Communications, Langmuir and Applied Physics Letters and reported by public media including Science Daily, Phys.org, Physics Today, etc. She was awarded with NSF grant awards.

ELECTRICITY-FREE HEATING AND COOLING STRATEGIES FOR WATER AND ENERGY

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ABSTRACT

Addressing global challenges necessitates advancements in energy and water sustainability. Direct solar desalination, for instance, holds immense promise for alleviating the worldwide freshwater crisis. This presentation will delve into practical considerations for developing solar heating and radiative cooling applications that promote water and energy sustainability.

Specifically, I will discuss our recent advancements, spanning manufacturing to application development. We will begin by exploring our research efforts to create low-cost solar-driven evaporation architectures using photothermal materials and systems [1-3]. Additionally, we will discuss the potential applications of these architectures for zero-liquid-discharge water treatment using evaporation ponds.

However, if the evaporated moisture cannot be collected, it merely contributes to atmospheric pollution. As the entropy sink, the cold source plays a crucial role in completing the thermodynamic cycle of all heat-producing technologies. The unique challenge lies in obtaining coldness from renewable and sustainable sources. In the second part of this presentation, we will discuss our recent efforts on radiative cooling in water and energy sustainability [5-9]. Specifically, we will examine the potential of passive cooling technology to recycle atmospheric water. We will also highlight potential pitfalls to avoid in radiative cooling reporting, as summarized in our recent work [10].

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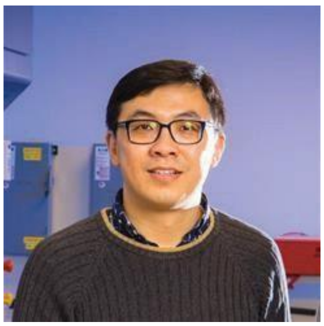

Dr. Qiaoqiang Gan is a Full Professor in the Material Science Engineering, KAUST. He is the Fellow of Optica (formally OSA) and Fellow of SPIE. He is the recipient of Exceptional Young Investigator of University at Buffalo (2016) and SUNY Chancellor's Award for Excellence in Scholarship & Creative Activities (2019). His research publications include over 100 technical papers and 4 patents, with the total citation of over 8600 and H-index of 44. He serves as the editor in chief for IEEE JSTQE, associate editor for J. of Photonics for Energy (SPIE), PhotoniX (Springer), and sub-committee chair of S&I9 Photonics Integration (CLEO 2019-2020), Program Chair of S&I program CLEO 2021 and the General Chair of S&I program CLEO 2023. His research activities on optical sensing and energy sustainability have been widely featured by Science, Nature, Nature Middle East, Nature Photonics, Nature Sustainability, BBC, Mirror, Salon, etc.

Biopolymer Nanofibers for Sustainable Water Harvesting

Wenshuai Chen

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Abstract: Biopolymer nanofibers, such as nanocellulose, are novel polymer nanomaterials synthesized by organisms. Owing to the intrinsic nanofiber structure and the advantageous mechanical, thermal, and optical properties, biopolymer nanofibers have become star materials in recent material science fields. In this talk, a comprehensive review of recent advances in developing biopolymer nanofibers for sustainable water harvesting will be introduced. It will be begun with a brief introduction of species diversity and the processes of obtaining various biopolymer nanofibers from organisms. The fabrication of bulk materials will be then illustrated, with a specific focus on the use of cellulose nanofibers as building blocks to construct various hydrogels/aerogels. Next, the representative applications of biopolymer- nanofiber bulk materials for dehumidification, atmospheric water harvesting, power generation, and water purification are systematically presented. An outlook on future challenges and key issues worthy of attention will be finally discussed.

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Biography: Wenshuai Chen is a professor in the College of Materials Science and Engineering at Northeast Forestry University. He received his B.S. degree (2008) and Ph.D. degree (2013) in Wood Science and Technology from Northeast Forestry University, China. His research interests include wood physics, biopolymer nanofibers, and the development of wood-based materials and functional systems for sustainable energy and environmental sciences. He is co-author of more than 100 publications in peer-reviewed journals. He has received many awards and honors, including the Heilongjiang Youth May Fourth Medal, the Outstanding Youth Foundation of National Natural Science Foundation of China, the Young Elite Scientists Sponsorship Program of CAST, 2023 energies award, Second Prize of LiangXi Natural Science Award, the China Forestry Youth Science and Technology Award, and the Youth Science and Technology Award of Heilongjiang Province of China.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Enhanced Fog Harvesting Techniques

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Due to their superior droplet drainage enabling anti-clogging, Fog Harps collect 2-7 times more fog water than the conventional Raschel mesh. However, these tests were performed in a laboratory with ultra-dense engineered fog. Here, we perform comparative field testing of large-scale Fog Harps versus Raschel mesh harvesters in the variable climate of Monterey Bay, California. These outdoor tests revealed that the performance multiplier for Fog Harps varies dramatically with the natural fog conditions. Under light or heavy fog conditions, the Fog Harp retained a substantive multiplier, albeit smaller than that under an ultra-heavy lab fog. However, under moderate fog intensity, the performance of the Fog Harp and the Raschel mesh became comparable. This suggests that under real-life conditions, Fog Harps might not harvest enough water relative to mesh structures to justify the cost and weight of a reinforced steel frame for tensioning the vertical wire array. To bypass this issue, we developed 3D-printed hybrid fog harvesters that resembled Fog Harps with intermittent horizontal interconnects. The interconnects prevent elastocapillary wire bundling of the harp wires but without requiring any tensioning, while at the same time, they were sparse enough to prevent appreciable clogging. Future work could include the integration of electrostatic techniques to increase the fog harvesting efficiency further and exploring techniques for mass manufacturing hybrid fog harvesters.

THEORETICAL ANALYSIS OF DAYTIME DEW-HARVESTING

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ABSTRACT

Due to its merits such as the simple setup and the compatibility in both humid and arid climates, the dewharvesting technology has attracted a lot of interest in response to the worldwide scarcity of clean water. While harvesting dew at daytime has significant potential to enhance the round-the-clock yield, the current paradigm has been limited to scenarios with cumbersome sun-shades to block the direct sunlight, which hinders their large-scale deployment. Here we clarify the potential and address the challenges of achieving dew-harvesting under direct sunlight. In addition to the high solar reflectivity, we highlight a guideline in photonic designs to achieve high-performance daytime dew-harvesting: every 13% reduction in the absorptivity outside atmospheric transparency window (8-13μm) is equivalent to a 10% increase in the emissivity within the window. We provide a numerical design of such selective condenser, which, under typical conditions, could produce nearly the same water at daytime as that as nighttime. We further comment on a scenario, which isolates the local environment from the atmosphere and thus could manipulate the local humidity to be much higher than that of the atmosphere. This scenario could potentially mislead the comparison to the theoretical limit of the nighttime dew-harvesting that we pointed out in our previous work [Nanoscale and Microscale Thermophysical Engineering 24, 43 (2020)].

BIOGRAPHY

Zhen Chen is currently a Professor of Mechanical Engineering at Southeast University. He received his doctoral degree with Chris Dames in Mechanical Engineering at the University of California, Berkeley in 2014, and was a post-doctoral associate supervised by Shanhui Fan in Electrical Engineering at Stanford University. His current research interests emphasize fundamental studies of heat transfer, and applications on energy, water, and thermal management of micro-processors and spacecrafts.

OBTAINING FRESHWATER BY REGULATING FUNCTIONALIZED SOLID-LIQUID INTERFACES

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Jiangsu University, Zhenjiang 212013, P.R. China;
[2]State Key Laboratory of Structural Analysis for Industrial Equipment,
Dalian University of Technology, Dalian 116024, P.R. China*

ABSTRACT
The scarcity of freshwater is one of the most significant challenges for the survival of human beings, influenced by factors such as population growth, climate change, and water pollution. Desalination, fog collection, and oil-water separation have received much attention at home and abroad as essential ways to obtain freshwater resources in an environment-friendly approach. However, Membrane-based desalination technologies have long been constrained by the trade-off rule between permeability and selectivity, the long-distance continuous self-transport of droplets on gradient functionalized surfaces is the critical difficulty in fog collection, and the oil-water separation as an essential way to obtain water from wastewater is still challenging to achieve oil droplet adsorption-collection integration and functionalized surface reuse. Here, a novel concept of "temporal selectivity" is proposed to realize ultrahigh water permeability and salt rejection simultaneously by rotating nanoporous monolayer graphene cylinder with large pores (2 to 4 nm), which breaks the permeability-selectivity trade-off in RO process. As for fog collection, a dual-mode droplet transport mechanism based on Young-Laplace pressure difference and capillary suction pressure-induced fluid transfer in microchannels on cone surfaces is proposed. A novel cross-hatch textured cone with gradient microchannels and circular grooves is fabricated to realize ultrafast long-distance self-transport of multi-scale droplets. In the field of oil-water separation, ultra-hydrophobic-ultra-oleophilic micro-pillar array surfaces are prepared to realize rapid adsorption and collection of underwater micro-oil droplets. The mechanism of rapid self-transport and collection of oil droplets on underwater micro-pillar array surface is clarified. The findings provide critical theoretical foundations and technical support to address the green collection of freshwater resources.

Key Words: water collection; fluid-solid interface; desalination; droplet transport; oil-water separation.
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Zhongqiang ZHANG

BIOGRAPHY

Prof. Zhong-Qiang Zhang studied computational mechanics at Dalian University of Technology and obtained his Ph.D. in 2010. He was a visiting scholar at University of California at Berkeley in US cooperated with Prof Shaofan Li. Currently, he is a professor and Dean of School of Mechanical Engineering at Jiangsu University in China. He serves as IOP journal Advisory Board, Member of Micro/Nano Devices and Systems Technology Branch of Chinese Instrument Society, Member of Computational Mechanics Committee of Jiangsu Mechanics Society, and Member of Energy Structural Mechanics Committee of Jiangsu Mechanics Society. His research interests include micro/nano-fluidics and devices, flexible mechatronics and soft robots. So far, more than 100 papers have been published, and more than 20 national or provincial science foundation projects were presided. His innovations have won the 6th China Youth Science and Technology Innovation Award, First Prize of Jiangsu Province Science and Technology, and 2023 ICCES Outstanding Young Researcher Award *etc*.

The Splash Lab: skipping spheres to the water collection of desert moss

Tadd Truscott, PhD
King Abdullah University of Science and Technology (KAUST)
Splash Lab™

ABSTRACT

Join me for an engaging keynote presentation where I unravel the mysteries of physics through imagery and playful curiosity. Since founding the Splash Lab in 2010, my goal has been to demonstrate the significance of basic science and engineering in society. By combining experimental investigation with analytical and numerical analysis, my lab provides both visual and physical insights into hydrodynamics and high-speed imagery. Our research has led to discoveries in water entry dynamics, uncovering surprising phenomena such as how to break the world record for stone skipping, and how cavitation occurs at near-zero fluid velocities. Collaborating with international partners, we've validated our findings and explored nature's solutions, like the water-collecting mechanisms of desert moss awns. Through advancements in digital high-speed imaging, we've developed techniques to visualize fluid flows in three dimensions. Join me as I delve into our achievements, discuss remaining questions, and outline future research directions. Let's embark on a visual journey of scientific discovery together.

From left to right, a skipping viscoelastic sphere, cavitation causes a bottle to shatter, a tiny moss collects water on a leaf hair.

BIOGRAPHY

Dr. Tadd Truscott is an Associate Professor at King Abdullah University of Science and Technology (KAUST), renowned for his groundbreaking contributions to the field of fluid dynamics and its applications. With a PhD in Ocean and Mechanical engineering from MIT, he has established himself as a leader in experimental fluid mechanics, particularly in the areas of multiphase flows, bubble dynamics, and fluid-structure interactions. Professor Truscott's research focuses on understanding the fundamental principles governing complex fluid phenomena through innovative experimental techniques, such as high-speed imaging and advanced flow visualization methods. His work has far-reaching implications across various disciplines, including engineering, physics, and biology. He is committed to fostering the next generation of scientists and engineers, inspiring students with his passion for discovery and pushing the boundaries of scientific knowledge. Through his research, teaching, and mentorship, he continues to shape the future of fluid dynamics and contribute to advancements in science and technology.

Interfacial Structure, Ion Transport and Heat Generation in Electrical Double Layers

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ABSTRACT

Electrical double-layer capacitors (EDLCs), also called supercapacitors, store electrical energy via ionelectrosorption directly at the electrolyte-electrode interface during the charging process, suggesting that EDL structure and the charging kinetics play a dominant role in the underlying energy storage mechanism and the resulting device performance. Despite considerable work on EDLs, the details of what would happen at electrolyte-electrode interfaces still require in-depth exploration, in particular, how heat would be generated during charging/discharging. Developing constant-potential molecular dynamics modeling techniques[1-2], we studied IL electrolytes with different electrodes, in comparison with experimental measurements, to understand energy storage mechanisms underlying EDLs and thus to help the design of supercapacitors. The contents of this talk would include:

(1) Exploring the influence of water impurity on ionic liquid (IL) EDLs, which presents water adsorption on electrode surfaces in contact with humid RTILs and the possible strategy to reduce the water electrosorption at polarized electrodes.[3]

(2) Studying the capacitance and charging dynamics of ILs in porous electrodes, which would show how nanoporous carbon and conductive MOFs as electrodes could achieve promising capacitive performance[4].

(3) Exploring the heat generation of EDL formation in aqueous and IL electrolytes, which reveals that EDL formation in aqueous electrolytes exhibits endothermicity under negative polarization and shows new complexity of endothermicity followed by exothermicity in ILs, regardless of electrode polarity[5].

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BIOGRAPHY

Guang Feng received his Ph.D. degree in 2010 from Clemson University, USA as the Outstanding Student in the Doctoral Degree Program awardee in the Department of Mechanical Engineering. From 2010 to 2013, he worked in Vanderbilt University and The Fluid Interface Reactions, Structures and Transport (FIRST) Energy Frontier Research Center as a postdoctoral research associate and then a research assistant professor. By November 2013, he became a professor in the School of Energy and Power Engineering at Huazhong University of Science and Technology, China.

He has published 3 book chapters and more than 100 papers in peer-reviewed journals, with more than 70 as the first or corresponding author (including Nature Materials, Nature Computational Science, Nature Communications, Physical Review Letters, Advanced Materials, Chemical Reviews, etc.). His current research interests are focused on the study of micro-/nano-scale interface and transport phenomena in electrical energy storage, with developed molecular modeling. He was selected as a Fellow of the Royal Society of Chemistry in 2019, obtained the first prize of Natural Science in Hubei Province in 2023, and right now serves as an editorial board member of Green Energy & Environment, ChemElectroChem, Fluid Phase Equilibria, and Journal of Ionic Liquids.

Interfacial Design for Flexible Sensors

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ABSTRACT

Interfacial design is important for flexible sensors to enhance performances. A superior interface can enable flexible sensors to be conformally attached to the soft skin of the human body, stably collect physiological signals, and also improve the sensitivity of the sensor. Through material innovation and imitation of natural structures, our team has proposed various interfacial designs for flexible sensors, achieving high sensitivity stable detection of physiological signals and physical signals. We have prepared interface materials with gradient crosslinking density, realized the integration of rigid chips and flexible substrates, and attached them to postoperative free flaps and replanted digits to accurately detect microvascular conditions (figure 1a). In addition, we have developed highly adhesive hydrogel materials inspired by the adhesion mechanisms of mussels and barnacle, realizing close contact between the sensor and the skin (figure 1b). We have also developed adhesive large-range fast adjustable hydrogel materials for establishing a tight neural diagnostic system/skin interface while ensuring benign removal (figure 1c). Additionally, we have fabricated interlocking microstructures on the dielectric interface of the sensor by replicating the surface morphology of plants, which increased the sensitivity of the sensor by 14 times (figure 1d). Based on the multilevel microstructure of *Myosoton aquaticum* plant pollen, we have further optimized the functional interface of the sensor to prepare ultrahigh sensitivity and extremely small detection limit flexible sensors, realizing robot needle threading task (figure 1e).

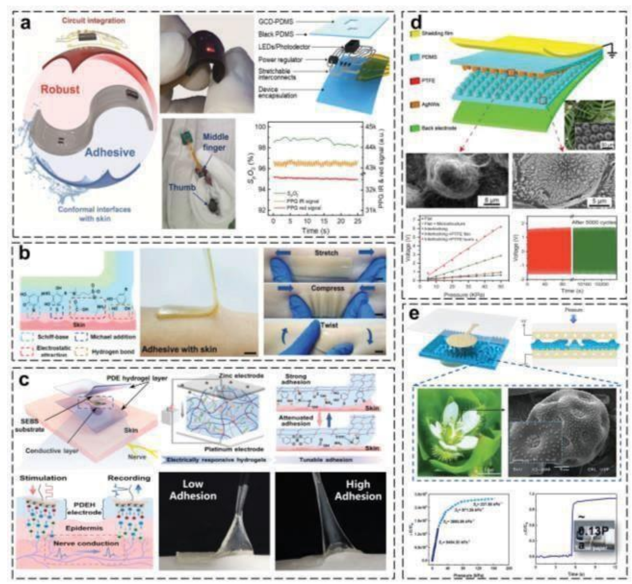

Figure 1 Interfacial design for flexible sensors.

BIOGRAPHY

Hao Wu is a Professor in the School of Mechanical Science and Engineering, Huazhong University of Science and Technology (HUST), Wuhan, China. He received his B.E. from HUST and Ph.D. from Georgia Institute of Technology, Atlanta, USA, both in mechanical engineering. He was a senior engineer with Intel Corporation before returning to HUST in 2016. His research interests include flexible and stretchable electronics system integration for robotic sensing, human–machine interfaces, wearable healthcare, as well as advanced electronic packaging processes and equipment.

MICROFLUIDIC ENERGY HARVESTING FOR BATTERYLESS BIOMEDICAL SYSTEM

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ABSTRACT

Droplet electricity generation shows great promise for applications in water energy conversion, where their performance can be enhanced by increasing surface charge density or solid/liquid interfacial contact area. However, achieving an appreciable level in efficiency remain difficult owing to the unknown interfacial charge transfer mechanism, especially for confined droplet in a limited space. Combing the hydrodynamic behavior of the droplet and the corresponding electrodynamic response, we show the dramatic impact of surface charge distribution and surface charge trapping on the efficiency. Droplet electricity generator based on the heterogeneous tube with opposite surface charge density exhibits an outstanding output voltage and current performance in contrast to the homogeneous tube. More interesting, droplet slipping with the same surface and same effective contact area can generate significantly different electricity energy conversion efficiency. We also propose an effective theoretical model based on interfacial contact electrification, bulk electrostatic induction, surface charge trapping, and switching effect to interpret these processes. This work provides new fundamental insight into the underlying mechanism of the droplet electricity generation, and is of great relevance in various practical applications including water energy harvesting, microfluidic sensor, liquid wetting, liquid droplet operation, and micro/nanofluidics.

BIOGRAPHY

Zhiran YI is an assistant professor in School of Mechanical Engineering at Shanghai Jiao Tong University, China. Before this, he carried out his postdoctoral research in Department of Mechanical Engineering at City University of Hong Kong, China, and School of Mechanical Engineering at Shanghai Jiao Tong University, China. He received his Ph.D. degree in electronic science and technology from Shanghai Jiao Tong University in 2020. His research mainly focuses on mechanics in smart materials, hydroelectrodynamics, and batteryless biomecial devices. Now, he has published one book as a co-editor. As the (co-)first author, he has published 16 SCI-indexed articles.

Chill-and-Charge: A Synergistic Integration for Future Compact Electronics

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ABSTRACT

The advancement of modern electronic devices is fuelled by the prominent trends of high integration and increased power density. Nevertheless, introducing intricate thermal management techniques to address the cooling demands of high-power density chips imposes limitations on the further downsizing of device dimensions while concurrently resulting in increased power consumption. Here we report an innovative integration of cooling and powering functionalities within electronic devices. Our approach involves the utilization of a vanadium-based electrolyte as an embedded cooling medium for high-power GaN-on-Si devices. The electrolyte serves a dual purpose by efficiently absorbing the heat generated by the electronics, thereby mitigating thermal concerns and exhibiting a temperature elevation that enhances the energy conversion efficiency of the flow battery. Experimental results validated the efficacy of embedded microfluidic cooling with vanadium electrolyte, demonstrating significant heat flux extraction of 236 W/cm^2, highlighting a cooling Coefficient of Performance of 6.82×10^4 and an additional net power generation of 180.14 mW/cm^2. This integrated approach synergistically improves both the cooling performance and the power delivery capacity of the system, presenting a promising avenue for high-power electronic applications.

Biography: Dr. Muxing Zhang is currently working in MIIT Key Laboratory of Thermal Control of Electronic Equipment, Nanjing University of Science and Technology. She received her Ph.D. degree in Engineering Thermophysics from Southeast University (2022) and the National University of Singapore (2022), and her M.S. degree in Mechanical Engineering from Carnegie Mellon University (2017). Her research interests include thermal management for electronics, enhanced heat and mass transfer, molecular dynamics computation, etc. Her research has been supported by the National Natural Science Foundation of China and the Natural Science Foundation of Jiangsu Province.

Neuro-inspired ionic energy and computing devices

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ABSTRACT

The language of intelligent life is "ions", and the language of artificial intelligence is "electrons". To build a high-throughput and low-power brain-like computing system, the "Neuro-inspired Materials and Devices Lab" conducts interdisciplinary research of ionic energy and computing materials and devices involving chemistry, materials, information, and biology, which has the potential to break through the barriers of information exchange between intelligent life and artificial intelligence. We constructed a bioinspired multi-scale ion transport system, including nanofluidic system and soft ionic conductor system, revealed the interaction law between ion transport behavior and material structure/interface, fabricated a series of ionic energy devices (e.g., ion pump/ion-electron Coulomb drag energy generator) and ionic brain-like devices (e.g., ionic memristor/ionic neuromorphic chips). We hope the energy and neuromorphic devices using "ions" as language have the potential for realizing brain-machine hybrid intelligence.

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BIOGRAPHY

Dr. Kai Xiao is an associate professor at the Department of Biomedical Engineering, Southern University of Science and Technology, China. Kai Xiao received his bachelor's degree from Jilin University (Changchun, China) in 2012, and his PhD from the Institute of Chemistry, Chinese Academy of Sciences (ICCAS, China) in 2017. After that, he moved to the Max Planck Institute of Colloids and Interfaces (MPIKG, Germany) working as an Alexander von Humboldt (AvH) Fellow. From 2021, he works as an Associate Professor at the Southern University of Science and Technology (SUSTech, China), and leads a research group of "Neuro-inspired Materials and Devices Lab". He has au- thored over 60 academic papers published in peer-reviewed journals and two book chapters, with citations of over 4000. His research interest lies in nanofluidic, ionic soft materials, and ionic energy/neuromorphic devices.

ENGINEERING CELLULOSE FIBER MATRIX FOR THE ANALYTICAL LAB ON PAPER

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ABSTRACT

Paper-based sensor has emerged as a cost-effective platform with great potential for diagnostics and analysis in low-resource settings. Although there have been significant advances in the fabrication and the analytical techniques in recent years, the problem of non-uniform display of colorimetric signal has not been overcome, which directly affects the sensitivity and specificity of the assays, and limits the further development and applications of the paper sensors. This report briefly reviews our previous work in the field of paper-based analytical sensors from 2008 to present, with a focus on discussing the significant influence of cellulose fiber matrix on the flow, penetration, and evaporation of the biochemical fluids within it. We have investigated the formation mechanism of non-uniform colorimetric rings, which is not only caused by the coffee ring effect during the evaporation of biochemical fluids, but also by the chromatographic effect and filtration effects of the fiber matrix to the biochemical fluids. Based on the pulping and papermaking techniques, the paper substrates with desirable physical and chemical properties are customized, which can significantly weaken the non-uniform colorimetric signal and improve the sensitivity and specificity of analytical assays. Moreover, we have proposed various results reporting and measurement techniques such as text reporting and QR code reporting, greatly improving the user friendly property and functionality of paper-based sensors. These findings contribute to enhance the performance of the quantitative/semi-quantitative detection in the field of paper-based analysis and diagnostics.

SHORT BIOGRAPHY

Junfei Tian received his B.Eng degree from Soochow University, China, and Ph.D degree in chemical engineering from Monash University, Australia. After working at Monash University as a research fellow for 3 years, he has been with the school of light industry and engineering, South China University of Technology as a professor since 2015. His research has been primarily in the areas of paper-based functional materials, point-of-care test, printing and packaging materials. He has published more than 100 papers in international journals, and been authorized 30 Chinese invention patents as well as 5 international patents (PCT). His achievements has been attested to by awards including the Australian Museum Eureka Prize and IChemE Innovation Award and the First-class Technological Invention of Chinese Society for Imaging Science and Technology.

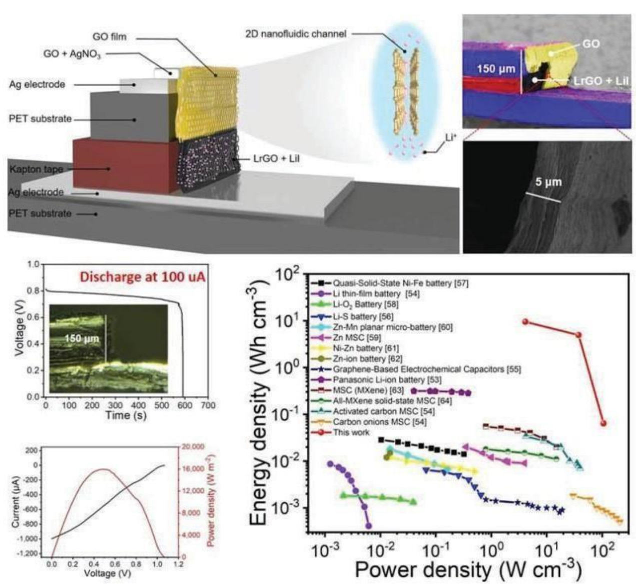
Control of charge flow by nanoconfined iontronics

Prof. Di Wei

Beijing Institute of Nanoenergy and Nanosystems (BINN)

ABSTRACT

Making salinity gradient energy practical is a great challenge. Despite recent advancements, the practicality of osmotic energy for portable electronics remains doubtful due to its limited power output and portability constraints. Here we report a method for optimizing the transport of alkali metal ions within two-dimensional nanofluidic channels and coupling it with tailored interfacial redox reactions to store the osmotic energy in a space of tens of micrometers within the cut edge of a polymer film. An ultrahigh output power density of 15,900 W m^{-2} has been achieved. By connecting the devices in series, commercial electronics can be powered due to the high volumetric specific energy density (9.46 Wh cm^{-3}) and power density (106.33 W cm^{-3}). This work introduces an approach for control of charge flow and storing iontronic energy based on osmotic effects, providing a platform for developing renewable, ultrathin and safe power sources.



Reference: Z*hong Lin Wang**, ***Di Wei**** *et al.* Vertical iontronic energy storage based on osmotic effects and electrode redox reactions. ***Nat. Energy*** 9, 263-271 (2024).

BIOGRAPHY

Prof. Wei serves as the Principal Investigator at BINN and heads the Iontronics Laboratory. As Fellow of the Royal Society of Chemistry (FRSC) and Senior Member of Wolfson College at Cambridge University, he has published over 100 papers including Nature Energy, Nature Commun., PNAS, Adv Mater, Energ Environ Sci., Matter etc. as the first/corresponding author. Prof. Wei also has a portfolio of over 200 international patents (including PCT). Notably, 57 international patents and 28 Chinese patents have been successfully granted, many of which have been transferred to leading companies like Nokia in Finland and Lyten in the USA. Additionally, Prof. Wei has edited three English books, published by Wiley and Cambridge University Press etc., focusing on nanotechnology for energy and sensor applications.

Highly efficient thermal management materials and devices based on electrocaloric effect

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ABSTRACT
Traditional refrigeration equipment commonly uses environmentally polluting Freon and has low cooling efficiency. The current increasingly integrated electronic chips need more efficient cooling technology to extend their service life. A compact and portable solid-state refrigeration system with high cooling efficiency and performance parameters can provide effective heat dissipation for current wearable electronics and can be widely used. Whereas electrocaloric cooling with ferroelectric materials is an efficient and novel alternative to Freon. Here, we utilize a flexible ferroelectric electrocaloric polymer film and an electrostatic driving mechanism to enable effective heat transfer between the heat source and the heat sink [1-5]. The use of reversible electrostatic force reduces the parasitic power consumption and enables effective heat transfer through instantaneous formation of good thermal contact between the polymer film and the heat source or heat sink. Electrocaloric effect refrigeration system performance factor exceeds existing vapor compression refrigeration technology. The high efficiency, non-polluting electro-thermal effect cooling device not only spans the performance of existing solid-state cooling technologies, but in the future it can be made into a very small cooler to be carried around in a pocket. Moreover, it can also effectively cool down cell phones, computers and wearable electronics to extend their service life.

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Rujun Ma is a professor in the School of Materials Science and Engineering of Nankai University, selected by the National Youth Thousand Talent Program. He has led many key projects of the National Key R&D Program of the Ministry of Science and Technology, the National Natural Science Foundation of China, and the key projects of the Tianjin Natural Science Foundation, etc. He graduated from the College of Nanotechnology, Sungkyunkwan University, South Korea, with a Ph.D. degree in February 2013, and then worked as a postdoctoral researcher in the School of Energy Science and the Institute of Basic Science of the same university. In April 2015, he joined Prof. Qibing Pei's group at UCLA as a postdoctoral researcher, and in September 2018, he joined the School of Materials Science and Engineering at Nankai University.
His main research interests are flexible active/passive solid-state cooling materials and devices and multifunctional flexible thermoelectric materials and devices. In recent years, he has published in Science (2), PNAS, Nature Communications, Joule (2), Chemical Society Reviews, Energy & Environmental Science, Advanced Materials (4), Advanced Energy Materials (2), Nano Letters (7), ACS nano (2), etc. He has been authorized more than 10 patents in the United States, China, and South Korea, and has applied for 2 international patents.

TRIBOELECTRIC NANOGENERATOR FABRICS FOR INTELLISENSE AND ARTIFICIAL INTELLIGENCE PERCEPTION

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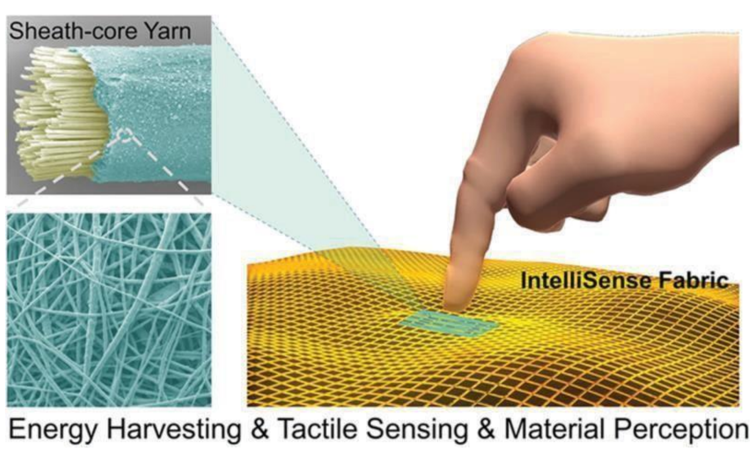
[3]*Shanghai Clinical Research and Trial Center, Shanghai, China*

ABSTRACT

In the domain of wearable technology and energy harvesting, Triboelectric Nanogenerator (TENG) fabrics emerge as a forefront solution for converting mechanical energy into electrical power. This investigation presents an innovative sheath-core structured TENG yarn, intricately designed for IntelliSense fabrics (IS-fabrics), engineered to discern various dynamic mechanical stimuli with heightened sensitivity and swift response. The core yarns, fabricated utilizing an electroassisted core spinning technique, are enveloped by a dielectric nanofiber sheath, fostering a rough nanoscale surface that substantially enhances the triboelectric effect. Woven from these TENG yarns, the resultant IS-fabrics showcase remarkable mechanical robustness and flexibility, enabling them to endure rigorous bending trials while upholding structural integrity. Exhibiting a remarkable response time of as little as 5 milliseconds and the capability to detect forces as minute as 0.41 mN, these fabrics stand poised to revolutionize human interaction with wearable devices and the surrounding environment. A pivotal facet of this inquiry is the incorporation of machine learning algorithms aimed at categorizing and forecasting the nature of contact materials based on the distinctive electrical signatures elicited by the TENG fabrics. This AI-driven methodology has been effectively deployed to discern and categorize objects composed of diverse materials with an impressive accuracy rate of 93.75% across a series of ball sorting experiments. The integration of TENG technology within these fabrics proffers a sustainable solution for energizing wearable electronics, obviating the necessity for external batteries, thus aligning seamlessly with the escalating demand for energy-efficient smart textiles.

ABSTRACT FIGURE



Nanogenerators Based on the Water/Solid Interface

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South China University of Technology

ABSTRACT

When water comes into contact with a specific solid surface, it can either generate static surface tribo - charge or induce electrostatic charges. Sometimes, both phenomena occur simultaneously. By strategically utilizing the interaction between water and a pre-charged hydrophobic surface or employing water/solid contact electrification, it is possible to convert the mechanical energy from water movements into electricity. This innovative concept allows for the harvesting of various environmental mechanical energies, such as water droplets, ocean waves, and body movements, through the implementation of water-based electric nanogenerators. In this presentation, I will introduce various types of nanogenerators based on the water/solid interface, focusing on their device design, mechanisms, and practical applications.

BIOGRAPHY

Hao Wu is a professor at the School of Physics and Optoelectronics, South China University of Technology. She received her Ph.D. from the University of Twente, the Netherlands, and went on to work as a postdoctoral fellow at the Chinese University of Hong Kong and the City University of Hong Kong. In 2022, she joined the South China University of Technology and established the energy harvesting research group. Her research focuses on understanding the fundamental principles of the conversion between small mechanical energy and electrical energy, especially the power generation mechanism based on water / solid interaction. Leveraging the fundamental understanding, she develops technologies and applications to efficiently harvest energy from waves, droplets, and biomechanical motions.

TRIBOELECTRIC POLYMER AND ENERGY GENERATION ON SOLID-LIQUID INTERFACE

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The development of micro nano scale energy systems that collect energy from the surrounding environment and achieve multifunctional self-powered sensing has important practical value. Triboelectric and piezoelectric technology are similar, both of which achieve active sensing and energy generation through specific force electricity conversion mechanisms. This report focuses on the micro energy and functional sensing achieved by frictional power generation technology, with a focus on the research of self-powered micro-nano systems and wearable intelligent devices. We explain the atomic scale electron transfer phenomenon during contact electrification based on the physical model of electron cloud overlap and quantum potential wells, reveal the mechanism of the molecular structure and functional group composition of polymer materials on contact electrification, and propose a complete processing technology and modification method for preparing high-performance triboelectric polymers. Finally, we have achieved the highest surface charge density thin film electrification material currently available and prepared high output characteristic micro energy devices. Based on our previous research on piezoelectric ceramic actuators, we have extended the study of frictional electricity to areas such as plastic films and dielectric elastomer materials, virtual reality, and augmented reality technology for self-powered functional systems. We have achieved a series of novel applications in flexible sensing systems, biomimetic muscles, and other fields.

Short Bio

Dr. Xiangyu Chen is a professor in Beijing Institute of nanoenergy and nanosystems, Chinese Academic of Sciences. He received his B.S. degree in Electrical Engineering from Tsinghua university in 2007 and his Ph.D. degree in Electronics Physics from Tokyo Institute of Technology in 2013. His research interests are mainly focused on self-powered nano system, smart materials, microfluidics systems and the nonlinear optical system for characterizing the electrical properties of the devices. He has been awarded by National Natural Science Foundation of China for Excellent Young Scholar, Beijing overseas talent sea gathering project and selected as Specially-invited Expert of Beijing. He has also been selected by the Beijing Youth top talent support program. Dr. Xiangyu Chen been granted many funds with a total amount over 15 million RMB, including National Natural Science Foundation of China, Ministry of science and technology of China and Natural Science Foundation of Beijing. He has published more than 40 scientific papers as first author or corresponding author. Most of those papers are published on the top level journals, such as Chemical reviews, Science advances, Nature Communications, Advanced Materials, Materials Today and so on.

Leveraging Surface and Interfacial Phenomena for Applications - Sensing, Droplet Manipulation, and Energy Harvesting

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ABSTRACT

Interfacial phenomena involve with surface charge state variations which can be used for sensing and energy harvesting applications. Recent advances in droplet-based wearable devices and microfluidics are endowed with advantages such as flexibility, sensing ability, and automation for novel applications. For example, a flexible microfluidic pressure sensor based on liquid-solid interface triboelectrification when liquid flows in a microfluidic channel. The proposed microfluidic pressure sensor is able to have a conformal contact with human skin and no separation gap is required due to the microfluidic chamber and channel design. This self-powered microfluidic pressure sensor can monitor both the magnitude and frequency of the pressure applied on the device simultaneously. On the other hand, technology for enabling drug delivery with precise control is strongly demanded by patients with diabetes or other chronic diseases. Intelligent functions such as drug loading and delivery in controllable manner without requiring electrical power are demanded for wearable transdermal drug delivery applications. This talk highlights the wearable transdermal drug delivery patch with embedded self-powered sensors and energy harvester. The recent work of microfabricated piezoelectric thin film membrane reports an acoustofluidic actuator aiming at dynamically control of microparticles in microfluidics. The membrane acoustic waveguide actuator offers a prom- ising pathway for acoustofluidic applications such as biosensing, organoid production, and in-situ analyte transport. Given the challenges and advances in materials, fabrication, and system integration, this talk highlights these works which indicate opportunities toward multifunctional, self-sustainable, and intelligent microsystems.

BIOGRAPHY

Dr. Chengkuo Lee received his Ph.D. degree in precision engineering from The University of Tokyo, Tokyo, Japan, in 1996. Currently, he is the GlobalFoundries Chair professor in Engineering, and director of *Center forIntelligent Sensors and MEMS* at National University of Singapore, Singapore. He cofounded Asia Pacific Microsystems, Inc. (APM) in 2001. From 2006 to 2009, he was a Senior Member of the Technical Staff at the Institute of Microelectronics (IME), A-STAR, Singapore. His research interests include MEMS, NEMS and flexible devices for IoT, energy harvesting, metamaterials and biomedical applications. His google scholar citation is more than 34000. He is associate editor-in-chief (EiC) of Trans. Nanotechnology (IEEE). He is EiC of Intern. J. Optomechatronics (Taylor & Francis) and Sensors International (Elsevier). He is in the Executive Editor Board of J Micromechanics and Microeng. (IOP, UK), He is associate editor of J. MEMS (IEEE), Chip (Elsevier), and Internet of Things (Elsevier).

Tea-Leaf-Dancing Inspired Device for Energy Conversion Application

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ABSTRACT

Steeping is a typical process to prepare most Chinese tea for drinking by leaving tea leaves in heated water for the release of flavor or nutrients. Observing the morphology and motions of tea leaves while steeping is a primary step in Chinese tea culture. One of the most amazing view is the elegant 'dance' of needle-shaped tea leaves (e. g. the tea category of Junshan Silver Needle): after the added hot water turns steady, tea leaves stand on end vertically and some will repeatedly rise and sink, which indicates good luck in some local culture. To interpret the underlying mechanism, we have studied the structure, surface wettability, water infiltration kinetics, and temperature changes during diving-floating. The repeated diving-floating was attributed to the hydrophilic surface and porous interior to trap air, which results in the density fluctuation during steeping. Inspired by the diving-floating phenomenon, we have designed a system of miniaturized device consisting of chamber filled with air, conductive line connected to a electrochemical workstation, and a magnetic field. The device underwent repeated diving-floating cycles under a temperature gradient similar to the tea leaves. Electric energy was harvested during the reciprocating motions, leading to a stable output of 3V.

BIOGRAPHY

Prof. Feng Shi obtained his BSc (2001), MSc (2004) degree from Jilin University, and PhD (2007) from Tsinghua University (supervisor: Prof. Xi Zhang). He had cooperative research in University of Muenster in 2002 (supervisors: Prof. Harald Fuchs and Prof. Lifeng Chi), and in Hebrew University of Jerusalem in 2004 (supervisor: Prof. Itamar Willner). He did post-doc work in Max Planck Institute for Polymer Research (2007-2008), and works as a full professor in Beijing University of Chemical Technology since 2008. His research interest is macroscopic supramolecular assembly and its applications in Micro-LED display, energy conversion, chemical robotics, self-healing, wet adhesion etc. He is the chief editor of Supramolecular Materials, which is launched in 2022 and has been indexed by DOAJ and Scopus. He has been awarded with Distinguished Young Scholars of NSFC, and is a committee member of Beijing Municipal Natural Science Foundation.

Biomimetic infrared radiative regulation mechanism and research progress in radiative cooling

Fuqiang Wang, Ziming Cheng, Xinping Zhang, Yan Dong
Harbin Institute of Technology

By exploiting the 3 K coldness of outer space as heat sink of terrestrial thermal radiation, passive daytime radiative cooling (PDRC) can achieve sub-ambient temperatures without any energy consumption, and thus exhibiting extraordinary application potentials. Specifically, the theoretical cooling power of PDRC technology can reach 146 W/m^2, and the practical application can reach 120 W/m^2. This talk will introduce the basic physical mechanism and the latest progress of PDRC technology, especially focusing on our recent work on the large-scale application of biomimetic photonic structures in PDRC by drawing on the exquisite bio-photonic structures of nature. The methods of functional group selection for infrared absorption, optical band gap selection for solar reflection and photonic phonon microstructure enhancement of resonance are discussed, which provides a comprehensive guiding strategy for increasing the practical cooling power of PDRC technology. The latest work regarding to all-season PDRC coatings, "warm in winter and cool in summer" type temperature- adaptive coatings, PDRC metafabric and transparent PDRC glass are presented.

Fuqiang Wang is a full professor in the School of Energy Science and Engineering at Harbin Institute of Technology, and a full professor in the School of New Energy at Harbin Institute of Technology at Weihai. He received the B.S. degree in 2005 from China University of Petroleum. He received the Ph.D. degree in Power Engineering and Engineering Thermophysics in Harbin Institute of Technology in 2012. His current research interests are radiative cooling, solar spectral radiative transfer regulation, and energy-saving film related to thermal radiative transfer regulation fabrication.

Electrochemical Li^+ intercalation in 2D TMDs and their interfacial study via in-situ Liquid Phase TEM

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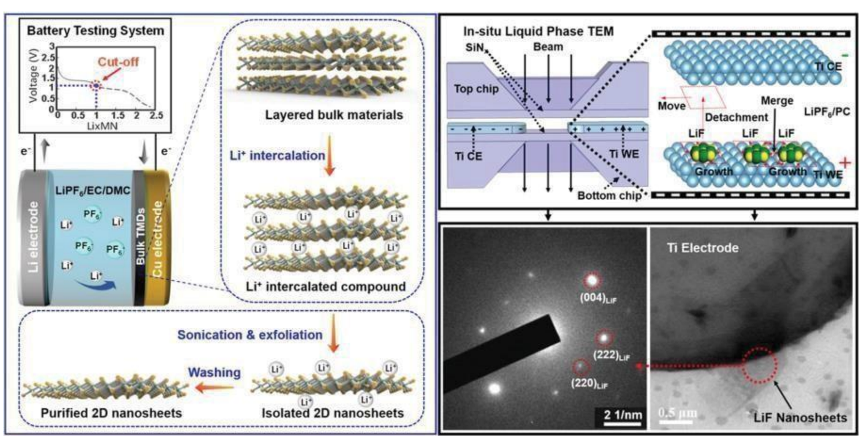
ABSTRACT

We developed a lithium ion battery intercalation & exfoliation method with detailed experimental procedures for the mass production of 11 two dimensional TMDs and inorganic nanosheets, such as MoS_2, WS_2, TiS_2, TaS_2, ZrS_2, graphene, h-BN, $NbSe_2$, WSe_2, Sb_2Se_3 and Bi_2Te_3, among them 3 TMDs achieved mono- or double layer yield > 90%. This method involves the electrochemical intercalation of lithium ions into layered inorganic materials and a mild sonication process. The Li insertion can be monitored and finely controlled in the battery testing system, so that the galvanostatic discharge process is stopped at a proper Li content to avoid decomposition of the intercalated compounds. The intercalation strategy can also be used to tune 2D TMDs' physical and chemical properties for various applications. For example, we developed a one-step covalent functionalization method on MoS_2 nanosheets for membrane fabrication, which exhibited excellent water desalination performance. For lithium intercalation mechanism, the state-of-the-art In-Situ Liquid Phase TEM is an ideal technique for identifying the phase changes during intercalation process. With self-designed electrochemical liquid cell utilized, we can directly vapture the dynamic electrochemical lithiation and delithiation of electrode in a commercial $LiPF_6$/EC/DEC electrolyte, such as LiF nanocrystal formation, lithium metal dendritic growth, electrolyte decomposition, and solid-electrolyte interface (SEI) formation. Combining with other in-situ techniques, such as in-situ XAS, XRD and Raman, etc, the underlying lithium intercalation mechanism in TMDs were further investigated, which render us a comprehensive understanding of the intrinsic correlation between the intercalation process and TMDs.



BIOGRAPHY

Prof. Zhiyuan Zeng received his BSc, MPhil and PhD degrees from Central South University, Zhejiang University and Nanyang Technological University in 2006, 2008 and 2013, respectively. After 4 years postdoc in Lawrence Berkeley National Laboratory and 2 years Senior Process Engineer industry experience in Applied Materials Inc. He joined City University of Hong Kong as an Assistant Professor in 2019. His research interests are electrochemical Li^+ intercalation in TMDs, in-situ liquid phase TEM technique. He has published 146 SCI papers (101 IF>10) with total citation 22028 times and H-index 59 (google scholar), which include *Nat. Mater.*, *Nat. Rev. Chem.*, *Nat. Protoc.*, *Nat. Synth.*, etc. He has been listed as the Highly Cited Researcher (Top 1%, Clarivate Analytics) in 2023, 2022, 2020 and 2018. His was awarded 2023/2024 Young Collaborative Research Grant (Y-CRF) by UGC Hong Kong. and the Rising Star by Advanced Materials (2022) and Small (2022).

ELECTRICITY FROM MOVING BOUNDARIES OF ELECTRICAL DOUBLE LAYER

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ABSTRACT

Electrical double layers (EDLs) at the solid-liquid interfaces set the base for electrokinetic phenomena, such as streaming current and pressure-retarded osmosis, in which ionic currents generated under pressure or ion-concentration gradient. To detect and utilize the ionic current, consumable electrodes for ion-electron exchange have to be adapted, hindering their applications. Our research has unveiled a novel avenue: moving boundaries of EDLs can directly induce electronic currents within solids. Instead of selective ions transport, these phenomena rely on capacitive coupling between ions in liquid phase and electrons in solid phase at the interface. The EDL boundaries can be in the form of solid-liquid-gas three-phase contact lines. For instance, moving a droplet of water on graphene or waving water surface across graphene can both induce a electronic current in graphene. [1-2] It were recently extended into boundaries between EDLs with distinct properties. A fascinating example is that, when illuminating a silicon/water interface par- tially, the movement of light/dark boundaries would result in a potential gradient across the silicon strip.[3] Furthermore, electrets with abundant surface charge enable ultrahigh instantaneous output voltage (up to 1200 V) when water droplets contact an electrode placed on the electret surface, achieving energy conversion efficiencies close to 10%.[4-5] In summary, the dynamic boundaries of electrical double layers provide innovative pathways for harvesting energy from water, making them a crucial component of hydrovoltaic technology. [6]

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Curriculum Vitae

Prof. Yin obtained his Ph.D. degree from Nanjing University of Aeronautics and Astronautics (NUAA) in 2016, following which he worked in the University of Manchester as a research associate for three years. Then, he joined in NUAA in 2019 as a full professor. His work has focused on understanding the interfac interaction of vdW materials and hydrovoltaic science for energy conversion. He has published over 80 papers with more than 10 Nature series, with total citations over 6,000. Email: yinjun@nuaa.edu.cn.

SOIL WATER HARVEST INSPIRED BY DESERT HORNED LIZARDS

Ho-Young Kim[1], Seungjoo Lee [1], Junhee Choi [1], Wonseok Kim [2], Sohyun Jung [3], Sung Jae Kim [2], and Wonjung Kim[4]

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[2] Department of Electrical and Computer Engineering, Seoul National University, Seoul, South Korea
[3] Department of Robotics and Mechatronics Engineering, Daegu Gyeongbuk Institute of Science & Technology (DGIST), Daegu, South Korea
and
[4] Department of Mechanical Engineering, Yonsei University, Seoul, South Korea

ABSTRACT

Adaptations for water acquisition are crucial for species inhabiting arid regions. Here we study the specialized cutaneous hydration method utilized by the desert horned lizard (*Phrynosoma platyhinos*) of western North America. The lizard's integumentary structure, comprising multi-layered and contoured surfaces, forms capillary channels that facilitate water transport from ambient moisture sources, such as precipitation and wet soils. If the water movement in the cutaneous channels purely relies on the capillary force, it should stop once the channels are saturated, which contradicts our observation of the continuous flow even after channel saturation.

Through our investigation employing visualization techniques, we uncovered that the lizard's jaw movements are instrumental in drawing water towards the corners of the mouth, with subsequent ingestion occurring during jaw closure. A simplified bioinspired model was utilized to assess the relationship between jaw kinematics and water intake, revealing a preference for slower jaw movements to enhance hydration efficiency. Inspired by the lizard's water collection strategy, we developed a synthetic soil-water extraction device, which incorporates a permeable porous medium and articulated jaws. Furthermore, by integrating ion-exchange membranes into the porous structure, our device not only harvests water but also facilitates the removal of heavy metal pollutants, demonstrating its potential utility in purifying water resources in drylands

BIOGRAPHY

Ho-Young Kim is a professor and the head of the Department of Mechanical Engineering at Seoul National University (SNU). He obtained his B.S. degree from SNU in 1994, followed by his M.S. degree in 1996 and Ph.D. in 1999 from the Massachusetts Institute of Technology. He has been honored with several awards, including the SNU President's Award for Research Excellence, and has been recognized as an American Physical Society Fellow since 2017. His research interests revolves around mechanics of microfluids and soft matter, with applications to bioinspired technologies, soft machines, and robots.

BIOGRAPHY

Bionic Strategy Optimized 3D Fog Harvesting System

Shangzhen XIE
Ministry of Education Key Laboratory for the Green Preparation and Application of Functional Materials, Hubei Key Laboratory of Polymer Materials, Hubei University, Wuhan, China

ABSTRACT

(250 Words Max, optional to include figure/caption)

According to the United Nations World Water Development Report 2023, two billion people will be without access to safe drinking water and 3.6 billion people will lack access to well-managed sanitation, driven by a combination of population growth and socio-economic development. To address this issue of scarcity of freshwater, water harvesting from atmosphere and fog flow offers a passive and green approach. Inspired by nature creatures such as desert beetle, nephila silk, and cactus spines, we developed several surfaces and devices for efficient water harvesting, such as 3D inclined structures with mixedwettability, superslippery and superhydrophobic devices, and integrated harp-bionic efficient fog collection system. The superhydrophilic regions fast capture the water molecular and the superhydrophobic and superslippery regions take the responsibility to transport the captured droplet, facilitating by the effect of Laplace pressure difference, water flow is collected in a high-efficiency way. In addition, absorbing water molecular at night from atmosphere and desorbing water molecular at daytime through the interface evaporation is another significant water harvesting approach to relieve the global water shortage problem.

Biography

Dr. XIE obtained her Ph.D degree from the department of mechanical and nuclear engineering at City University of Hong Kong, and then was a Post-doc at the school of energy and environment. She is now an assistant professor and master supervisor at the school of material and engineering and themanchester metropolitan joint institute at Hubei university. She is recently focuses on atmosphere water harvesting, fog collection, anti-icing, thermal management of batteries and photovoltaic cells, and heat transfer enhancement. She obtained the provincial talent project and title, all her studies is founded by National Natural Science Foundation of China and the Hubei Provincial Department of Education.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

THERMOFLUIDIC OPTIMIZATION OF HYDROGEL-BASED WATER HARVESTING DEVICES

Chad T. Wilson[1], Carlos Diaz-Marin[1], Gang Chen[1], Bachir El-Fil[1]
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ABSTRACT

Recent innovations in material chemistry highlight hygroscopic hydrogels as promising candidates for use in atmospheric water harvesting systems, potentially addressing the increasingly global challenge of water scarcity. However, optimal system integration of hydrogel materials in sorption systems remains a significant limitation to realizing cost-effective high-performance devices. In this work, we consider deployment of lithium chloride-loaded polyacrylamide (PAM + LiCl) hydrogels in a passive atmospheric water harvesting device to provide clean, potable water to the end user. A comprehensive thermofluidic model is used to design an optimal device architecture for maximal thermal efficiency and water output. Furthermore, we show the validity of the design by fabricating and testing an atmospheric water harvesting device in a variety of extreme environmental conditions. Overall, we demonstrate a wholistic thermofluidic optimization of the sorption system, and present an atmospheric water harvesting device which achieves 2 L/m^2/day water output with a thermal efficiency of over 50% in arid climates. This work highlights the potential for system-level improvement of atmospheric water harvesting devices, and provides initial design guidelines for producing optimal systems with regards to both material performance and environmental conditions.

ABSTRACT FIGURE

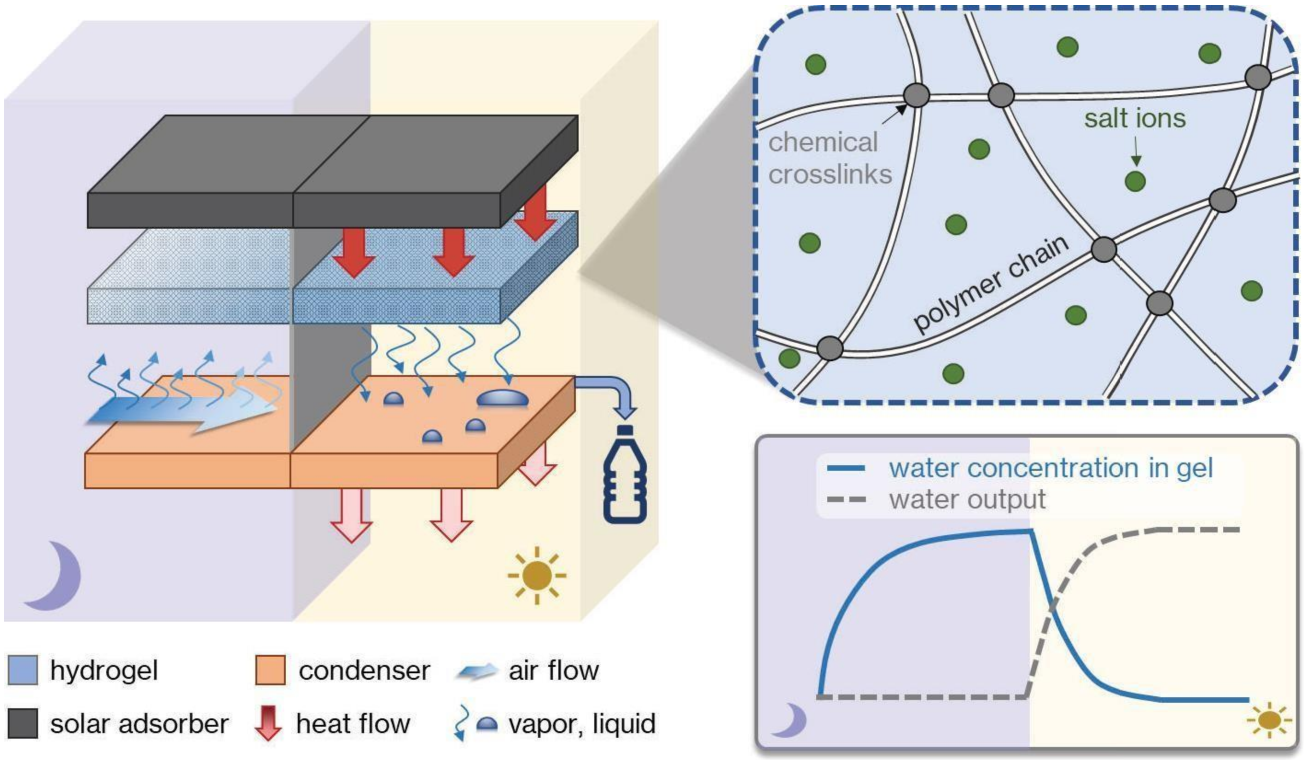

Figure 1: Breakdown of the hydrogel-based atmospheric water harvesting device, highlighting critical components and energy flows (left), sorbent material composition (top right) and device operation (bottom right). The system operates on a daily cycle, adsorbing water vapor from ambient during the nighttime and producing potable water during the daytime. To do so, an optimally-sized salt-loaded hydrogel sorbent is integrated with a solar adsorber. This assembly is heated and releases water vapor during the day, which condenses on a passively cooled condenser plate situated an optimal distance from the gel.

4th Conference on Micro Flow and Interfacial Phenomena(μFIP)
21 – 24 June 2024, Hong Kong

THE INFLUENCE OF CONDENSATION ON SORBENT-BASED ATMOSPHERIC WATER HARVESTING DEVICE PERFORMANCE

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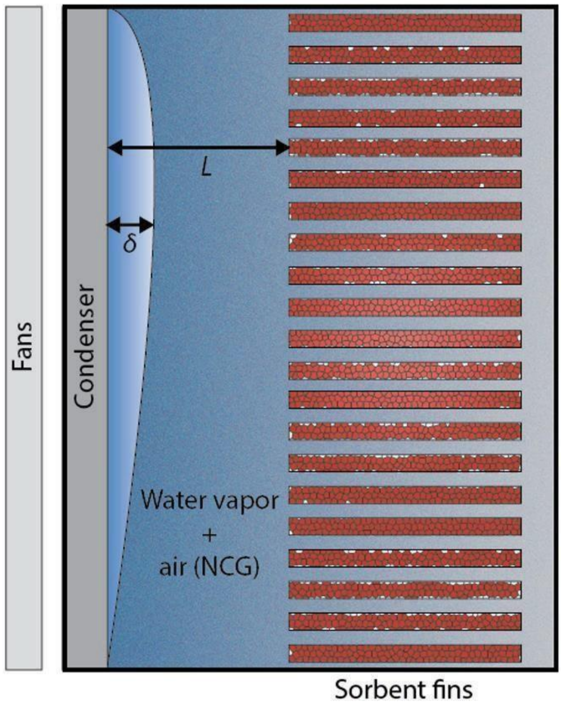
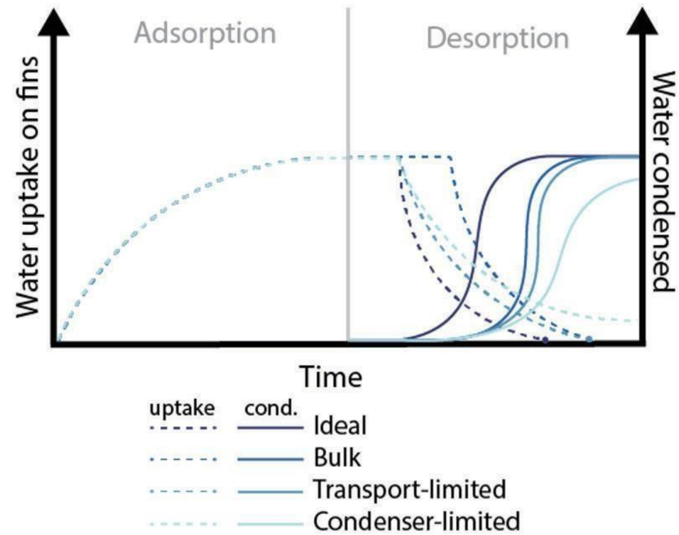
ABSTRACT

Sorbent-based atmospheric water harvesting (SAWH) has the potential to address the growing need for clean, potable water. Although much focus has been on sorbent bed design and optimization, the water productivity of SAWH devices is still constrained by the condenser. Low heat transfer coefficients and poor and degradable surface wettability are the main causes of condenser performance limitation. Slow condensation kinetics lead to vapor build-up in the system, resulting in a slower desorption rate and slower vapor transport from the sorbent bed to the condenser. Partial wettability and contact angle hysteresis cause poor drainage of condensed water from the system. Previous work has demonstrated that non-condensable gases (NCGs) and surface wettability are limiting for condensation in open systems, such as for fog harvesting and dewing. In a closed system, we investigate the effects of NCGs, surface wettability, mode of condensation (i.e., dropwise or filmwise), and thermal gradients between the sorbent bed and the condenser. We develop and experimentally validate a numerical, coupled condensation-desorption model to quantify the extent to which the condenser is a limiting factor for SAWH devices. A higher desorption temperature enhances the condensation rate by >2× by reducing the NCG concentration. This increased condensation rate must be compared with the tradeoff of a longer heating time and greater energy consumption to heat the sorbent bed. Integrating numerical modeling with experiments is vital for predicting device performance and guiding efficient design strategies for future SAWH systems to maximize water production while minimizing energy usage.

ABSTRACT FIGURE



(a)



(b)

Figure 1. (a) Schematic of SAWH device and (b) qualitative plot of water uptake on sorbent fins and water condensed on the condenser versus time. Different aspects of a SAWH device can limit the amount of water it can produce in a given time period. Devices with well-designed sorbent beds tend to be condenser-limited, either due to thermal bridging from the sorbent bed or insufficient heat being rejected by the back of the condenser. Condenser surface chemistry and the concentration of non-condensable gases (NCGs) in the system can also reduce the rate of condensation, making them key design parameters for SAWH devices.

1.05 Energy or Water Harvesting

Super-stable hygroscopic hydrogels for household-scale atmospheric water harvesting

Chang Liu[1, 2], Xiaoyun Yan[2], Shucong Li[2] and Xuanhe Zhao[2]
[1] The Hong Kong University of Science and Technology (Guangzhou), China and
[2] Massachusetts Institute of Technology, USA

ABSTRACT

Addressing the pressing global challenge of water scarcity, particularly in underserved, off-grid arid regions, our study introduces an innovative atmospheric water harvesting (AWH) technology using super-stable hygroscopic hydrogels. Through meticulous molecular-level design, these hydrogels are constituted of poly(vinyl alcohol) matrices embedded with lithium chloride as a hygroscopic agent, and a non-volatile additive, to ensure exceptional stability and water uptake efficiency over prolonged periods. This research demonstrates the application of origami structures to further amplify the hydrogels' physical integrity and water sorption/desorption kinetics. Moreover, the AWH system operates by absorbing water during the nighttime and allowing water evaporation and subsequent recondensation during the daytime, all without the need for electricity input to complete a water collection cycle. This approach yields a daily water yield several times higher than current state-of-the-art methods.

This advancement not only addresses the limitations of prior AWH methods, such as the need for complex thermal management and the challenge of small-scale prototypes, but also significantly contributes to meeting the water needs of individuals in underserved regions.

Hybridized and coupled Nanogenerators

Ya Yang
Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences

ABSTRACT
A hybridized electromagnetic-triboelectric nanogenerator is to utilize electromagnetic and triboelectric nanogenerators to simultaneously scavenge mechanical energy from one mechanical motion. As compared with the individual energy harvesting unit, the hybridized nanogenerator has much larger output power, higher conversion efficiency so that it can be used to solve the power source issue of some devices with larger power consumption. The hybridized nanogenerators have the potential applications in self-powered sensors, wearable devices, and networks. Rapid advancements in various energy harvesters impose the challenge on integrating them into one device structure with synergetic effects for full use of the available energies from our environments. We report a multi-effects coupled nanogenerator based on ferroelectric barium titanate, promoting the ability to simultaneously scavenging thermal, solar, and mechanical energies. By integration of a pyroelectric nanogenerator, a photovoltaic cell and a triboelectric-piezoelectric nanogenerator in one structure with only two electrodes, multi-effects interact with each other to alter the electric output, and a complementary power source with peak current of ~ 1.5 μA, platform voltage of ~ 6 V and peak voltage of ~ 7 V is successfully achieved. Compared with traditional hybridized nanogenerators with stacked architectures, the one-structure-based multi- effects coupled nanogenerator is smaller, simpler and less costly, showing prospective in practical applications and represents a new trend of all-in-one multiple energy scavenging

BIOGRAPHY

Prof. Ya Yang has developed various new hybridized and multi-effects coupled nanoenergy-related materials and devices, opening up the new principles of the device design and coupled effects, and the new approaches of improving output performances of nanoenergy-related devices. His main research interests focus on ferroelectric nanomaterials and devices, hybridizd and coupled nanogenerators, self-powered sensors, other energy-scavenging devices, and some new physical effects. He has published more than 200 SCI academic papers in Nature Energy, Nature Electronics, Joule, Nature Communications, Science Advances and other journals. These papers have been cited by more than 20000 times, and the corresponding H-index is 85 (web of science). He has served as the session chairman of the international academic conferences for six times, and he is the editor-in-chief of Nanoenergy advances, and the editorial committee member of InfoMat, Nano-Micro Letters, Nanoscale, Nanoscale Advances, iScience, and some other journals. Details can be found at: http://www.researcherid.com/rid/A-7219-2016

Bioinspired regulation of two-dimensional ion transport

Zhen Zhang[1,2]
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[2]*Suzhou Institute for Advanced Research, University of Science and Technology of China, Suzhou 215123, China*

ABSTRACT

Controllable confined mass transport has attracted great attention because it plays an extremely important role in living bodies. Compared with one-dimensional channel systems, membrane channels reconstructed from two-dimensional materials can control ion transport at nanometer or even sub-nanometer scales more accurately and efficiently. Studying strategy of regulating two-dimensional confined transport is of great fundamental significance, not only for our understanding of the mass transfer process of life, but also for solving key bottlenecks in related application fields such as salt difference energy conversion. We build bioinspired series of two-dimensional membranes with high flux and high selectivity, propose systematic two-dimensional ion transport regulation strategies, and at the molecular level, advanced theoretical simulation methods are used to study the basic factors affecting mass transport and reveal the multiple effects of chemical components, structures, charges, and wettability on the ion transport. We establish a theoretical model of the correspondence between "membrane micro-nano structure—ion transport—energy conversion performance".

BIOGRAPHY

Zhen Zhang, specially appointed professor of the University of Science and Technology of China (USTC). He received his Bachelor’s degree in materials chemistry from the Department of Chemistry, Jilin University in 2013. In 2018, he received his Doctorate degree in physical chemistry from the Institute of Chemistry, Chinese Academy of Sciences under the supervision of Prof. Lei Jiang. Then he worked as a post-doctoral fellow with Prof. Xinliang Feng at the Technische Universität Dresden and the Max Planck Institute for Microstructural Physics. In 2022, he joined the School of Chemistry and Materials Science/Suzhou Advanced Research Institute of USTC. His has been long engaged in the research of nanoscale ion flow and related interfacial phenomena, with applications encompassing separation, sensing, and energy conversion.

Construction of biomimetic nanofluidic channels for ion sieving and wastewater power generation

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Biological ion channels sieve ions with high selectivity. If such ion transport performance is replicated in artificial nanofluidic materials, the development of metal (*e.g.*, lithium) extraction from ocean or salt-lake, water treatment, and energy conversion fields may be significantly advanced. However, artificial nanofluidic materials typically have low selectivity. To address this problem, we utilized a material design approach to realize highly selective alkali metal ion sieving. We do so by matching the material pore size with the ion size and matching the binding energy of the channel/ion with the dehydration energy of ions, such that target ions can transport nearly barrierlessly. The designed materials showed a selectivity ratio that exceeds that of conventional materials and even biological ion channels. Moreover, we can use the design method to construct lithium-selective nanofluidic channels, and the selective ratio of lithium/sodium reached 1,422. Such material may find application in seawater lithium extraction technologies. Based on the highly selective ion sieving, we can also realize simultaneous wastewater treatment and power generation. The material transports Na^+ ions with high rate, which generates net ionic current and produces power. At the same time, the material blocks the transport of heavy metal ions and other toxic species. Such method avoids the energy consumption problem of wastewater treatment and should be carbon-negative.

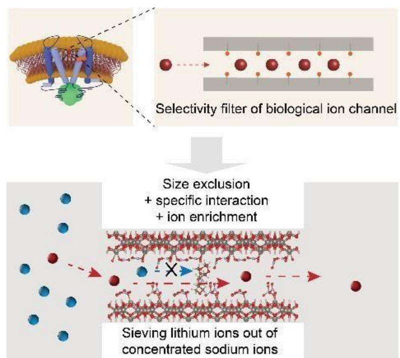

Figure 1 Artificial nanofluidic channels for lithium sieving

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Short biography

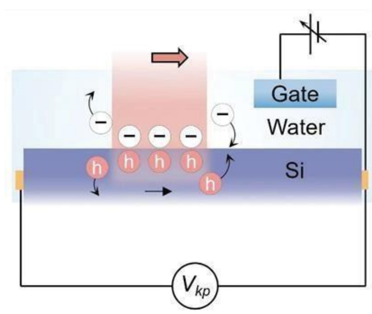
Jun Gao, Professor of Material Science and Engineering in the QIBEBT, CAS. He received his bachelor's degree in Physics from Shandong University in 2009 and PhD from the Institute of Chemistry, CAS, in 2014, under the supervision of Prof. Lei Jiang. Afterwards, he joined the group of Prof. Jiaxing Huang as a postdoctoral researcher in Northwestern University, USA. Then he worked as postdoc in Prof. Frieder Mugele's group in Twente University, the Netherlands. In 2020, he joined QIBEBT. Jun Gao's research focuses on bioinspired and biomimetic ion transport and their energy applications, particularly the ionic energy harvesting from wastewater.

Kinetic photovoltage from moving boundaries of electrical double layer and its modulation

Jidong Li
Institute for Frontier Science, Nanjing University of Aeronautics and Astronautics

ABSTRACT

External photo-stimuli on heterojunctions commonly induce an electric potential gradient across the interface therein, such as photovoltaic effect, giving rise to various present-day technical devices. In contrast, in-plane potential gradient along the interface has been rarely observed. Here we show that moving a light beam at the semiconductor-water interface, i.e. creating a moving boundary of electrical double layers between the illuminated and dark regions, induces a potential gradient along the semiconductor. It is attributed to the following movement of a charge packet in the vicinity of the silicon surface, whose formation is driven by a built-in electrical field associated with interface capacitance. By applying a bias at the semiconductor-water interface, a transistor-inspired gate modulation of kinetic photovoltage is further developed. The kinetic photovoltage signals can be facilely switched on/off due to the electrical-field-modulated surface band bending. In contrast to the function of solid-state transistors relying on external sources, passive gate modulation of the kinetic photovoltage is achieved simply by introducing a counter electrode with materials of desired electrochemical potential or dissolved oxygen in water. This architecture opens up a new way for silicon-based photoelectronics and self-powered optoelectronic logic devices.



Schematic illustration of the kinetic photovoltage and its gate modulation

BIOGRAPHY

Jidong Li is an associate researcher at the State Key Laboratory of Mechanics and Control for Aerospace Structures, Nanjing University of Aeronautics and Astronautics (NUAA). He received his bachelor's degree from Harbin Engineering University and his Ph.D. from NUAA. In 2019, he joined the Institute for Frontier Science at NUAA. His research focuses on experimental exploring of the physical and mechanical behavior of solid-liquid hydrovoltaic interfaces and the solid-solid van der Waal interfaces. Over the past five years, he has published relevant research results in journals such as Nat. Commun., Angew. Chem. Int. Ed., Sci. Adv., Joule, and Small. He is currently presiding over a General Program and participating in a Major Program of the National Natural Science Foundation of China.

Wick-free solar evaporator enabled by density-driven natural convection with high energy efficiency and salt rejection

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[1]*Massachusetts Institute of Technology, USA and*
[2]*University of Tennessee Knoxville, USA*

ABSTRACT

Thermally localized solar evaporation provides a sustainable solution to address the water-energy nexus, which is promising for applications in vapor generation, seawater desalination, wastewater treatment, and rare earth mining. State-of-the-art solutions of solar desalination utilized wicking structures combined with thermal insulation to localize interfacial heating at the evaporating surface, enabling higher energy efficiency. However, salt accumulation has been identified as one of the main practical challenges, which induces undesired fouling and reduces device lifetime, due to slow fluidic flow and salt diffusion within the wicking structures. In this work, we develop a novel confined water layer structure with millimeter-scale channels, without any wicking structures, to enable simultaneously highly efficient and salt-rejecting solar evaporation. Specifically, a density gradient is created due to accumulated higher salinity in the confined water layer and initiates natural convection through straight channels. The natural convection enhances salt transportation to avoid fouling but poses negligible effects on thermal transport, due to the significant difference between the thermal diffusivity and salt diffusivity. Through high-fidelity modeling, and experimental characterization, we optimize the solar evaporator design to enable salt transport without sacrificing energy efficiency. The work also includes an analytical model of the steady-state operation and direct fluid flow observation using particle image velocimetry, to guide further device design. The fundamental understanding of salt transport shown in this work paves a new avenue toward high-performance and reliable solar evaporation with low cost and high material flexibility.

An Investigation into the Fundamentals of Salt Creeping on Vertical Flat Surfaces

Joseph P. Mooney[1,2], Omer Refet Caylan[1], Evgeny Shatskiy[4], Bachir El Fil[1], Lenan Zhang[1], Gang Chen[1], Jeff Punch[2,3], Vanessa Egan,[2,3]

[1]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

[2]School of Engineering, University of Limerick, V94 T9PX, Ireland

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Abstract: Salt deposition, or "creeping," arising from the evaporation of water in highly concentrated solutions, presents significant challenges across various sectors such as agriculture, automotive, maritime, and art conservation. Conversely, controlled creeping on hydrophilic substrates, particularly those integrated with solar absorbers, offers opportunities for sustainable applications like zero liquid discharge, salt mining, and carbon capture. The initiation of salt growth is believed to depend on achieving critical concentrations at the contact line and reaching a crystal-pinning contact angle of the solution with a substrate. Researchers have explored manipulating these parameters through surfactants to modify contact angles and inhibit salt creeping. However, deeper insights into the underlying mechanisms governing creeping are needed. Moreover, comprehensive studies on how surface modifications control salt creeping are lacking. We investigated the creeping mechanisms of NaCl salt on hydrophilic, hydrophobic, and bi-philic surfaces using a rate-of-rise test facility, for mass and crystal height, and micro-computed tomography. We distinguished potential mechanisms initiating salt crystal pinning and growth due to the competition among surface tension, Marangoni flow, and crystal size. Our analysis also revealed differences in crystal growth between the hydrophilic and hydrophobic surfaces of the bi-philic samples. Creeping on hydrophilic surfaces occurred between the meniscus, resulting in larger crystals adhered to the surface. Conversely, creeping on the hydrophobic region appeared to originate from intrinsic wicking within the formed salt substrate and growth at the liquid front. The fundamental insights from this work establish operational parameters to manipulate salt creeping, inspiring the development of novel surfaces for conservation and sustainability applications.

Funding: *European Commission - Marie Sklodowska Curie Actions*

EERE Department of Energy

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
20 – 24 June 2024, Hong Kong

Efficient Solar Interfacial Evaporation: From Interface Properties to Large-Scale Devices

Meng Lin
Southern University of Science and Technology, Shenzhen, China

ABSTRACT

Solar-driven interfacial evaporation presents a promising solution for efficiently producing fresh water from seawater and contaminated sources, addressing global water scarcity. This method utilizes solar heat for localized evaporation, minimizing heat loss and ineffective heating, thereby enhancing performance. Despite advances in nanomaterials and device structures, gaps remain in understanding the photothermal conversion processes, including light absorption, heat and mass transfer, and energy conversion.

In this talk, I will first introduce "interface position" and "interface thickness" to quantify interactions of optical transmission, heat transfer, and vapor transport within the evaporator, guiding design optimizations. Using a physics-based model, optimal interface conditions were identified, with the best position located within the internal heat-absorbing layer, reducing environmental heat losses and improving efficiency. Experimental results demonstrate that a multistage evaporator operating in the transitional evaporation zone achieved an evaporation rate of 5.38 kg m^{-2} h^{-1}, a 12% increase over surface zone devices. Further enhancements were made by designing the device's optical window, where a 6 mm thick SiO_2 aerogel cover increased the rate to 6.25 kg m^{-2} h^{-1}, a 16% improvement. Further, an optimized 1 m^2 outdoor device achieved a water collection rate of 3.56 kg m^{-2} h^{-1} under average irradiance of 720 W m^{-2}.

This study provides critical design insights for interfacial evaporation devices via optimized interface properties and advanced optical and thermal management, which supports the further improvement of system performance for practical applications.

BIOGRAPHY

Meng Lin is an Assistant Professor and leads the Solar Energy Conversion and Utilization Laboratory (SECUL) at the Southern University of Science and Technology (SUSTech) in Shenzhen. He earned his PhD in Mechanical Engineering from the École Polytechnique Fédérale de Lausanne (EPFL), Switzerland, in 2018. From 2018 to 2019, he held a postdoctoral researcher position at the Joint Center for Artificial Photosynthesis (JCAP) and the Chemistry and Chemical Engineering Division at the California Institute of Technology (Caltech). In 2019, he joined the Department of Mechanical and Energy Engineering at SUSTech. His research primarily focuses on the engineering of high-performance solar conversion materials, devices, and systems to meet industrial-scale demands for electricity, heat, fuels, or a combinations thereof.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Theory of Wetting and Capillarity on the Nanoscale

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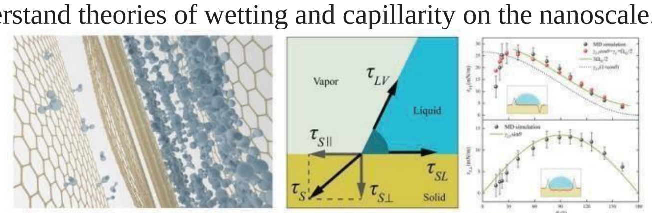
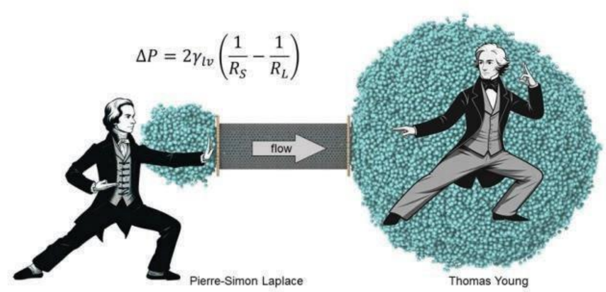
ABSTRACT

Wetting and capillary phenomena on the macroscale are ubiquitous and have been well understood. However, the relevant physics and mechanics on the nano-scale still remain mysterious. In this talk, I would like to discuss the exploration of capillarity from a nanoscopic perspective, including wetting, evaporation and condensation. At the solid/liquid interface, the liquid exhibits a pronounced layered structure that extends over several intermolecular distances from the solid surface. Our recent studies have shown that such molecular detail could provide some new understanding on century-old classical theory in this field, such as Young's equation, Young-Laplace equation and Kelvin equation. In specific, we offer a novel approach to describe and quantify the capillary force on the liquid in coexistence with its vapor phase. Our findings not only provide a theoretical insight into capillary forces at the contact line, but also validate Young's equation based on a mechanical interpretation. Moreover, we provide a more generalized form of Kelvin equation which can describe the capillary condensation under extreme confinement down to the angstrom-scale. Since the contact angle and the meniscus curvature cannot be precisely defined, we introduced the size effect of solid-liquid surface energy. The deviations in the solid–liquid surface energy from its bulk value may be considered as extra work spent to rearrange water molecules into the strongly layered structures. The abnormal structure formed at solid-liquid interface and the molecular interactions are crucial to understand theories of wetting and capillarity on the nanoscale.





BIOGRAPHY

Fengchao Wang is a Professor at the University of Science and Technology of China, in Hefei, China. He obtained his Ph.D. in 2012 from Institute of Mechanics, Chinese Academy of Sciences. He has published more than 100 research papers, many in prestigious peer reviewed journals, including Nature, Science, Physical Review Letters, etc. He is the Associate Editor for Capillarity (ISSN: 2709-2119). His group combines theory, molecular modeling and experiments to investigate the mechanics of solid/liquid interfaces on the nano scale. His research interests include mass transport through nanocapillaries, confined liquid, evaporation/condensation, moving contact line, wetting & capillarity.

Enhancing the turbulent transport by oscillating boundary deformation

Leiqi Yuan[1], Shufan Zou[1], Yantao Yang[1], Shiyi Chen[2,3]
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3. Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology, Shenzhen 518055, China

ABSTRACT

Achieving higher transport efficiency is strongly desired for flows in many engineering applications. In this talk we introduce a novel strategy to enhancing the transport in fluid flow systems by using the oscillating boundary deformations. Two examples are presented to illustrate the efficiency of the proposed strategy. For the Rayleigh-Bénard convection system where a fluid layer is heated from below and cooled from above, a standing-wave boundary deformation is introduced at both walls. Numerical simulations show that when the amplitude of wall oscillation is comparable to the boundary layer thickness, the heat-flux can be doubled with moderate frequency and wave length. The enhancement can be explained by the change of flow morphology near the wavy walls. Another system is the mixing enhancement in microchannels. Here we introduce traveling waves moving in the opposite directions at the two walls. The traveling wave deformation of boundary causes the nearby fluid moving in the same direction. Then a shear is generated in the bulk region and flow may be unstable. As the frequency increases, the deforming walls can efficiently break the laminar state of fluid layer and even induce a turbulent state. The mixing efficiency can be as large as 60 times the laminar case. The above two cases demonstrate the great potential of the flow modulation by boundary deformation.

BIOGRAPHY

Yantao Yang is an Associate Professor with tenure at College of Engineering, Peking University, Beijing, China. He received the bachelor degree of Theoretical and Applied Mechanics in 2004, and Ph.D of Fluid Mechanics in 2009, both from Peking University. He then did postdoc researches at CAPT of Peking University and Physics of Fluids Group at University of Twente, the Netherlands. He moved back to Peking University in 2017. His research fields include turbulence, convection, computational fluid dynamics, and flow controls. Currently he is interested in the double diffusive convection in the Ocean and porous media, and the immersed boundary method with applications in multiple flows and hemodynamics. He has published scientific papers in JFM, PNAS, PRL, JCP, etc.

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Tapping Atmospheric Rivers as Future Freshwater Reserves

Mengqian

LU Associate Professor, Civil and Environmental

Engineering The Hong Kong University of Science and

Technology

Abstract

In response to global warming, the atmosphere's capacity to hold moisture is expected to escalate, as dictated by the Clausius-Clapeyron relationship. This anticipated shift suggests that the future may hold a greater abundance of atmospheric freshwater than recorded historically, concurrently with a transformation in global hydrological patterns. Such changes will manifest in altered moisture recycling processes and atmospheric transport mechanisms, influencing the spatial-temporal distribution of water sources and their destinations. Additionally, these shifts will likely impact the intensity and regularity of the meteorological phenomena prominently known as atmospheric rivers.

In the face of these developments, and with the objective of identifying untapped freshwater reserves, our research introduces a comprehensive framework designed to quantify the moisture transport network across scales, ranging from local watersheds to the planetary scope. Utilizing this model, we have compiled an extensive dataset that details atmospheric moisture availability and its fluctuations. With this information, we can delineate the origins of atmospheric moisture, forecast its movement, and evaluate the feasibility of capturing this resource as an alternative to traditional freshwater supplies. The talk will concentrate on findings pertinent to the East Asian region, subsequently broadening the scope to incorporate a global perspective.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Inhibiting the Leidenfrost effect by using structured thermal pillars: A 3D lattice Boltzmann study

Penghao Duan

City University of Hong Kong

ABSTRACT

A three-dimensional central moments lattice Boltzmann method, which couples the pseudopotential model for phase-change fluid dynamics with a fourth-order Runge-Kutta scheme for the temperature field, is employed to investigate the impact of Leidenfrost droplets on overheated structured thermal pillar surfaces. The numerical method is validated through simulations of liquid-vapor phase-change processes and dynamic Leidenfrost droplet impingement on overheated walls. A comprehensive parametric study is conducted by varying the plate temperature, droplet inertia, and pillar dimensions to gain insights into the mechanisms of complex droplet dynamics and Leidenfrost point (LFP) enhancement on the pillar surfaces. The results demonstrate that structured thermal pillars can significantly elevate the LFP compared to flat surfaces by inducing an uneven distribution of vapor pressure beneath the droplet, which enhances heat transfer by reducing the vapor layer thickness and promoting liquid-solid contact. Detailed analyses of the transient droplet movement and pressure near the liquid-vapor interface reveal that increasing the plate temperature promotes the Leidenfrost phenomenon, while droplet inertia does not change the LFP but affects the rebounding height, resulting in a lower overall evaporation rate. Finally, the influence of pillar dimensions on the LFP is explored by establishing phase diagrams of the Jacob number (Ja) against pillar width, height, and amount, which indicates that narrower and taller pillars are more advantageous in suppressing the Leidenfrost effect and when the pillar height exceeds 50% of the droplet radius, the suppression effect diminishes. Increasing the number of pillars, which leads to smaller tunnel and pillar widths, tends to enhance the Leidenfrost effect.

DYNAMICS OF COMPOUND DROPLETS: SIMULATIONS AND MODELLING

Hang Ding
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ABSTRACT

Compound droplets have gained considerable attention due to their potential uses in pharmaceutical formulations, tissue construction, drug delivery and inkjet printing, to name but a few. In these industrial processes, the compound droplets are comprised of two or more immiscible fluids. To optimize the processes, it requires us to gain insights into the dynamics of compound drops. In this talk, we will show our numerical studies of dynamic behaviours of compound droplets using a ternary-fluid diffuse interface method, including the impact of a compound droplet onto a substrate and the rotation of a Janus droplet in shear flow. In particular, we focus on how the deformation of the inner droplet affects the maximum spreading of the whole compound droplet at various impact conditions, and whether the rotation dynamics of the Janus droplet can be modelled based on Jeffery's theory for rigid particles.

BIOGRAPHY

Dr. Hang Ding is a professor in the department of modern mechanics at University of Science and Technology of China (USTC). He received his Bachelor's degree at Nanjing University of Aeronautics and Astronautics in 1993, and Doctor degree at National University of Singapore in 2005. Later he worked as a research associate at Imperial College London, and then an assistant researcher at University of California, Santa Barbara, and joined USTC in 2011. He was supported by the National Science Fund for Distinguished Young Scholars in 2014. His research interest mainly focuses on multiphase flows and interfacial phenomena. He has published more than 90 journal papers in the field of fluid mechanics, including Journal of Fluid Mechanics and Journal of Computational Physics.

Thermodynamics and Dynamics of Thin Brine Films Confined between Oil and Rock Interfaces

Chao Fang
The Hong Kong University of Science and Technology (Guangzhou)

Thin brine films are commonly found at oil and rock interfaces, and play a crucial role in regulating the efficacy of applications such as enhanced oil recovery. Molecular dynamics simulations were first employed to systematically illustrate the interfacial structure, electrical double layer, disjoining pressure, and dynamic properties of molecularly thin brine films confined between a model oil and rock interface. The impacts of environmental salinity and thinning of brine film were elucidated by integrating molecular phenomena with DLVO theory and coarse-grained models. Next, considering the abundant narrow pores in deep geological reservoirs, the feasibility of recovering oil trapped in nanopores by lowering environmental salinity was evaluated via a atomistic model at the single- pore scale. The study demonstrated that the expansion of brine films drives the trapped oil out of the pore, a process driven by the slow osmosis of water molecules from the brine reservoir. Furtheremore, to understand the kinetics of oil detachment from rock surfaces upon salinity reduction, the depletion dynamics of ions from brine films was investigated using the Poisson- Nernst-Planck model. An unexpected acceleration of ion depletion from brine films by surface charge was elucidated through a reduced ion depletion model.

Predicting the Performance of Proton Exchange Membrane Fuel Cell Stacks: from Computational Fluid Dynamic to Digital Twin

Fan Bai
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ABSTRACT

Nowadays, as an important hydrogen energy utilization equipment, the commercialization of the proton exchange membrane fuel cell (PEMFC) stack has gained significant attention. In the last three decades, the computational fluid dynamic (CFD) approach is widely adopted on the research topic of performance enhancement of PEMFC. In this talk, firstly, we will review the development of the CFD models on the macro scale and their application scopes. Then we will report our recent work applying the CFD models for the investigation of PEMFC stack in the aspects of flow field plate design, manifold analysis, operational condition analysis, etc. Following, we will discuss the introduction of digital twin technology in the design and operation of PEMFC. Finally, we will discuss the methodology we have proposed for the digital twin of PEMFC and the detailing applications.

BIOGRAPHY

Fan Bai received his B. Eng and Ph. D degrees in Energy and Power Engineering from Xi'an Jiaotong University, China in 2016 and 2022, respectively. Since 2022, Dr. Bai has been an Assistant Professor of the Key Laboratory of Thermo-Fluid Science & Engineering of MOE in Xi'an Jiaotong University. His major research interests are the analysis, optimization and digital twin for a proton exchange membrane fuel cell stack. On those topics, he published more than 20 refereed papers. For his research achievements, he received many awards including the Hartnett-Irvine Award from the International Centre for Heat and Mass Transfer (ICHMT), 2021. He now serves as a Scientific Council member in ICHMT.

Surface Wettability's Impact on Interfacial Heat Transfer in Liquid Hydrogen Boiling: A Molecular Dynamics Simulation

Heyin Chen, Xiaojia Li
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ABSTRACT

Liquid hydrogen is attracting significant attention in the realm of sustainable development and clean energy owing to its high energy density and environmentally friendly characteristics. Understanding the nucleation mechanisms and boiling heat transfer properties of liquid hydrogen is imperative in this context. Presently, experimental and macroscopic simulation methods are inadequate in providing comprehensive insights into the nucleation and boiling processes of liquid hydrogen. This study utilizes molecular dynamics simulation techniques to elucidate the vaporization nucleation process and boiling heat transfer properties of liquid hydrogen at the microscopic scale, examining the influence of different hydrogen thicknesses, surface temperatures, and surface wettability on nucleation. The findings reveal that varying hydrogen thicknesses notably modify the vaporization nucleation process, with nucleation occurring solely through evaporation when the hydrogen thickness is thin, and nucleation occurring beyond a critical thickness. The impact of different temperatures on nucleation speed is also evident, with higher temperatures facilitating earlier nucleation and lower wall thermal resistance. Surfaces with different wettability display distinct nucleation behaviors; hydrophobic surfaces exhibit nucleation at the wall, whereas hydrophilic surfaces demonstrate nucleation within the liquid hydrogen due to variations in intermolecular forces leading to boiling disparities. This paper provides a microscale perspective on the nucleation and boiling processes of liquid hydrogen, offering insights for phase transition studies in liquid hydrogen.

EFFECTS OF WALL WETTABILITY ON TWO-PHASE FLOW IN A CO_2 EJECTOR

Fang Liu
Shanghai University of Electric Power

ABSTRACT

Ejector can be used to enhance the efficiency of CO_2 heat pump. Normally, no slip velocity boundary conditions are imposed on ejector inner walls. In this preliminary study, effects of wall wettability on performances of a CO_2 ejector were investigated numerically by introducing slip velocity boundary conditions. The correlation between contact angle and CO_2 temperature was developed. With the motive nozzle inlet at subcritical, near-critical or supercritical conditions, it can be found that wettability of inner walls in mixing chamber and diffuser affect expansion angle of motive fluid and entrainment ratio of an ejector, while wettability of inner wall in motive nozzle doesn't affect performances of an ejector obviously. Superhydrophobic wall in mixing chamber (contact angle of 175°) leads to a decrease in expansion angle and an increase in entrainment ratio (by 15.8%). Hydrophilic wall in mixing chamber leads to an increase of energy loss, a decrease of pressure drop and entrainment ratio. Hydrophilic wall in diffuser leads to an increase in expansion angle, a higher energy loss and reflux. This causes a decrease in velocity in mixing chamber, and results in a lower entrainment ratio. In addition, based on the simulation data, a correlation between entrainment ratio and contact angle was developed. Moreover molecular dynamics study of wetting behavior of CO_2 droplets on solid surface in a high pressure system was carried out. This study is helpful to understand flow mechanisms inside a CO_2 ejector with different wetted wall boundary conditions, and improve optimal design of a CO_2 ejector.

BIOGRAPHY

Professor Fang Liu is the funding director of Advanced Energy Systems and Thermal Fluid Laboratory. She was honored as a Distinguished Professor of "High-end Talents" in Shanghai. She is the professional committee member for China Renewable Energy Society, Chinese Association of Refrigeration, and China Education Association of Machinery Industry. She has over 20 years of international academic and industrial experiences in multiphase flow, enhanced heat transfer, HVAC&R, thermal storages and integrated renewable energy system. She has lead in a dozen of projects funded by diverse funding agencies and industries including National Natural Science Foundation of China. She has published 100 peer-reviewed papers in high impact journals and referred conferences, and obtained a dozen of authorized invention patents. Her research in heat pump coupled with thermal storages has received "Excellent Exhibits Award" in the university and college exhibition area of the 22nd China International Industry Fair.

ENHANCEMENT OF INTERFACIAL THERMAL TRANSPORT BETWEEN EPOXY RESIN AND SILICON FILLER BY SELF ASSEMBLED MONOLAYER

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ABSTRACT

We employed both time-domain thermoreflectance (TDTR) and molecular dynamics (MD) simulations to systematically investigate the interfacial thermal conductivity at the interface between epoxy resin (EP) and silicon (Si). We introduced self-assembled monolayers (SAMs) capable of forming unilateral and bilateral covalent bonds at the EP/Si interface and compared the impact of the number of covalent bonds in a single molecular chain on interfacial thermal conductivity. Our findings indicate that the presence of bilateral covalent bonds significantly enhances interfacial thermal conductivity, whereas the formation of unilateral covalent bonds may even deteriorate heat transfer across the interface. Upon analysis, we attribute this to the improved vibrational mode matching between the EP and Si systems facilitated by the strong covalent bonding within the SAMs, which in turn, augments the interfacial heat transport.

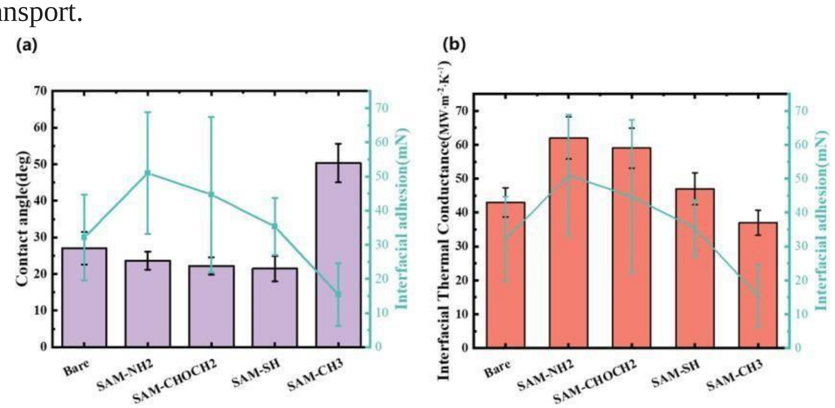

Fig. 1. (a) Relationship between interfacial adhesion and EP contact angle (b) Relationship between Interfacial thermal conductance and interfacial adhesion

BIOGRAPHY

Dr. Fangyuan Sun is an Associate Professor at the University of Science and Technology Beijing (USTB), holding a Ph.D. from the University of Chinese Academy of Sciences, and is a member of the Chinese Academy of Sciences Youth Innovation Promotion Association. His research interests encompass the theoretical analysis and experimental measurement of the thermal properties of micro and nanoscale materials, as well as heat transfer issues in micro and nanoscale materials related to aerospace, high-end equipment, new generation information technology, biomedical applications, and new energy fields. He has been engaged in the automation and integration of the femtosecond laser time-domain thermoreflectance (TDTR) system, developing automated control and data acquisition and analysis algorithms for the system, and has applied for over ten related invention patents. His research findings have been published in prestigious journals like Advanced Materials, ACS Nano, Nano Energy, and Advanced Functional Materials, with over 40 SCI-indexed papers to his credit.

Phonon Transport Physics in Two-Dimensional Systems

Jie Chen[1*]
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ABSTRACT

Two-dimensional (2D) systems exhibit peculiar thermal transport properties, and thus have attracted substantial recent interests. In this talk, I will present the recent advances in my group on the phonon transport physics in 2D systems from the following three aspects. First, I shall discuss the novel phonon transport mechanisms, including the phonon hydrodynamics, phonon coherence theory for heat conduction, and the phononic metagrating. Then, I will discuss the thermal transport properties of novel 2D systems, including moiré superlattice, carbon honeycomb structure, and the hydrogenated 2D borophene system. Finally, I will briefly discuss the advantages of atomic simulations combined with machine learning techniques for studying heat conduction in realistic materials.

BIOGRAPHY

Prof. Jie Chen is the full professor and vice dean for research in the School of Physics Science and Engineering at Tongji University. He obtained his Ph.D. degree in Physics from National University of Singapore in 2012, and completed his postdoctoral fellowship at ETH Zurich (2013-2015). He has been a faculty member at Tongji University since 2015. His research focuses on the nanoscale heat conduction, phononics, and thermal interface materials. He has won multiple recognitions, including the National Young Thousand Talent and Shanghai Youth May Fourth Medal. He has authored over 80 SCI-indexed peer-reviewed journal articles, 2 invited book chapters, and delivered 17 invited talks in international conferences. He has a total citation over 6300 and H-index of 43 in Google Scholar.

3D numerical modeling of laser-droplet interactions

Shucheng Pan, Jiaxi Song
Northwestern Polytechnical University

ABSTRACT

The problem of laser-droplet interaction plays an important role in the fields of extreme ultraviolet light sources, sessile drops, and biological matter, etc. Compared to other driven forces, the X-ray laser pulses induce direct and intense fragmentation dynamics of the droplets. In this study, a 3D numerical model of the droplet explosion induced by the X-ray laser pulses is developed by using a recently proposed compressible phase change model. Based on this model, a conservative sharp-interface method is formulated, which is used for high-resolution numerical simulations of such laser-droplet interaction problem. Compared with the experimental results, the numerical simulation results not only predict the precise evolution of the external interface of the droplet, but also statistically measure the evolution of the internal cavity, which is difficult to be measured experimentally. This provides a holistic understanding of the droplet explosion induced by the laser pulses. In addition, we have investigated the differences of droplet explosions at different pulse energies. With the increase of the pulse energy, the expansion rate of the internal cavity of the droplet becomes larger, and the fragmentation process of the droplet will be more intense.

BIOGRAPHY

Shucheng Pan is now a professor at the Department of Fluid Mechanics, Northwestern Polytechnical University. He received his bachelor and master degree from Northwestern Polytechnical University in 2010 and 2013, respectively. After that he finishes his PhD study at Chair of Aerodynamics and Fluid Mechanics, Technical University of Munich, with Summa Cum Laude. His current research interests include compressible multiphase flows, reacting flows, aerodynamics, and computational fluid mechanics.

Deep-potential enabled multiscale simulation of interfacial thermal transport in boron arsenide heterostructures

Guangzhao Qin
State Key Laboratory of Advanced Design and Manufacturing Technology for Vehicle, College of Mechanical and Vehicle Engineering, Hunan University, Changsha 410082, P. R. China

ABSTRACT

High thermal conductivity substrate plays a significant role for efficient heat dissipation of electronic devices, and it is urgent to optimize the interfacial thermal resistance. As a novel material with ultra-high thermal conductivity second only to diamond, boron arsenide (BAs) shows promising applications in electronics cooling. By adopting multi-scale simulation method driven by machine learning potential, we systematically study the thermal transport properties of boron arsenide, and further investigate the interfacial thermal transport in the GaN-BAs heterostructures. Ultrahigh interfacial thermal conductance of 260 MW $m^{-2}K^{-1}$ is achieved, which agrees well with experimental measurements, and the fundamental mechanism is found lying in the well-matched lattice vibrations of BAs and GaN. Moreover, the competition between grain size and boundary resistance was revealed with size increasing from 1 nm to 100 nm. The results are expected to lay theoretical foundation for the applications of BAs in advanced thermal management of electronic devices.

BIOGRAPHY

Guangzhao Qin is Professor of Mechanical Engineering at the Hunan University, China. He received the B.S. degree (2011) from Zhengzhou University, the M.Sc. degree (2015) from the University of Chinese Academy of Sciences, and the Ph.D. degree (2018) from RWTH Aachen University. Before joining the HNU, he worked at the University of South Carolina, USA as a Post-doctoral Fellow from 2018 to 2019. He was honored the Vebleo Fellow, the Outstanding Influence Award of 2021 China Rising Star of Emerging Technology, the "National Award for Outstanding Self-financed Chinese Students Abroad 2017", and the SUMMA CUM LAUDE with highest honors as the Outstanding Graduated Thesis at RWTH (Winners of the Borchers Plaque). His research interests are mainly in high-performance thermal management and energy transport and conversion at multi-time/-length scales, including fundamental physics and industrial/technical applications, together with the mechanical/electronic/optic/magnetic properties of advanced functional materials. He has published 3 book chapters, 2 software patents, and more than 120 SCI papers, with a current Google Scholar H-index of 31 with over 4100 citations.

Phonon transport in defective crystals

Ruiqiang Guo
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ABSTRACT

Defects are ubiquitous in solids and can strongly suppress thermal conductivity κ, especially at low temperatures or at high defect concentrations. Despite the remarkable progress in understanding phonon transport in perfect crystals, many questions remain regarding phonon transport in defective crystals, which is largely due to the difficulties in accurately predicting their phonon properties. In this talk, I will introduce our recent progress in understanding phonon transport in crystals containing point defects and grain boundaries using *ab initio* Green's function approach combined with machine learning. Particularly, our calculations reveal unusual phonon scattering behaviors induced by point defects beyond Rayleigh scattering, which can strongly affect thermal conductivity. I will also present our efforts in constructing machine learning interatomic potentials of defective crystals, which achieve a DFT-level accuracy in predicting their phonon transport properties with orders of magnitude reduced computational cost. These results deepen the fundamental understanding of phonon transport in defective crystals and will be helpful for tailoring the thermal properties of materials by defect engineering for relevant applications.

BIOGRAPHY

Dr. Ruiqiang Guo is a professor at Shandong Institute of Advanced Technology. He received his Ph.D. in Mechanical Engineering at the Hong Kong University of Science and Technology in 2015. After that, he worked as a postdoc at the Hong Kong University of Science and Technology, California Institute of Technology, and University of Pittsburgh. His main research interest is in nanoscale heat transfer and energy conversion, with a special focus on the fundamental understanding of transport and interaction processes of principle energy carriers, as well as the design and engineering of materials for thermal management, electronics, and clean energy.

Numerical Investigation of Thermal and Hydraulic Characteristics of Aviation Heat Exchanger Based on the Minimal Surface of Schwartz-D Structure

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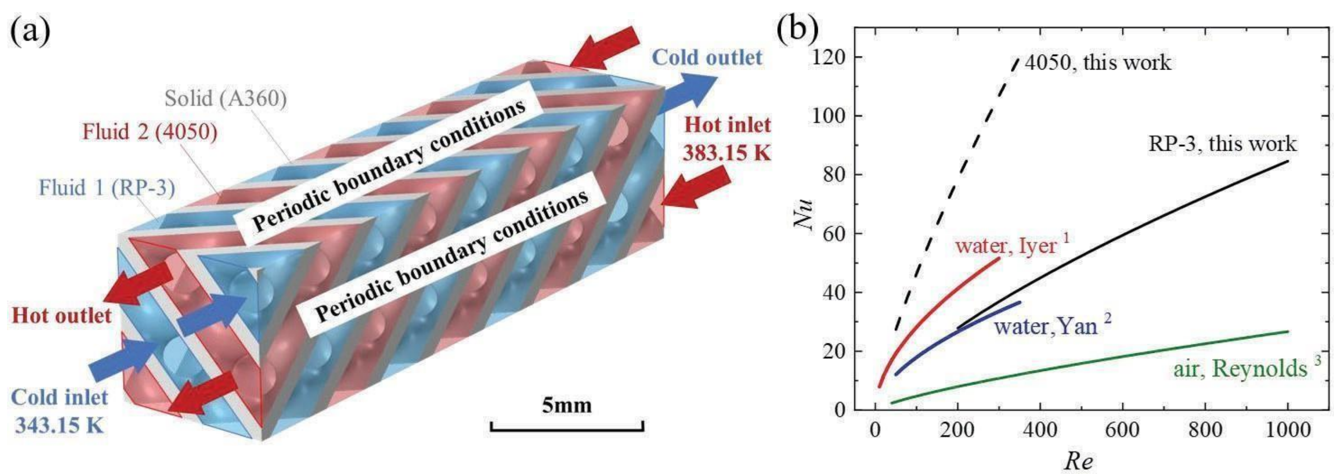
[2] School of Energy and Environment, Southeast University, China

ABSTRACT

The heat exchanger (HX) plays a crucial role in aviation thermal management systems. To meet the requirements of compactness, reduced weight, and high heat transfer performance, intricate internal flow paths within HXs are imperative. The Triply Periodic Minimal Surface (TPMS) HXs, a porous structure with microflow channels, have emerged as a popular solution to meet these requirements. Existing studies have demonstrated that the Schwartz-D type TPMS encompasses a relatively greater heat transfer performance compared to other TPMS structures. However, previous studies have primarily focused on water or air as working fluids. There is a considerable scarcity of research regarding Schwartz-D HXs addressing the working fluids employed in aviation applications. In this work, the numerical simulation method is used to systematically investigate the thermal and hydraulic characteristics of the Schwartz-D HX under typical aviation fuel-cooled oil cooler operating conditions. The 4050 lubricating oil and RP-3 aviation kerosene are selected as working fluids, which are commonly encountered in aviation areas. The influence of flow velocity, wall thickness, and hydraulic diameter on heat transfer and pressure drop are studied. When Re remains constant, reducing the wall thickness can greatly improve the mass average heat transfer coefficient while reducing the hydraulic diameter can greatly improve the volume average heat transfer coefficient. To further provide general guidance, the feature correlation between the Nusselt number and the Reynolds number is fitted based on the simulated results. This work provides a reference for designing a high- performance compact Schwartz-D type TPMS aviation heat exchanger.

ABSTRACT FIGURE (OPTIONAL)



(a) A schematic of the simulation model; (b) The curve of *Nu* with respect to *Re*.

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Completely Passive Capture of Carbon Dioxide from Air Using Solar Energy

Jian Zeng[1,2,3](Presenter), Hsinhan Tsai[2,4], Jeffrey R. Long[2,4], Ravi S. Prasher[3,5], and Sean Lubner[5,6]

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Abstract

In addition to reducing greenhouse gas emissions, it is now imperative that we implement direct air capture (DAC) of CO_2 from the atmosphere at a scale of hundreds of giga metric tons before the year 2100 to avoid catastrophic climate change[1, 2]. Development of a viable DACtechnology is still limited by the high cost[3] and high energy consumption[4, 5] that result from a low adsorbent capture capacity, requirements for expensive, cumbersome infrastructure for grid access or energy storage, and widespread societal acceptance challenges[6, 7]. In this work, we aim to address all three of these challenges and have designed and demonstrated a completely passive DAC device with a projected net CO_2 capture cost as low as 104 \$ t_{CO2}^{-1}, close to the 'Carbon Negative Shot' 2030 goal (100 \$ t_{CO2}^{-1})[8] and potentially profitable at 76 \$ t_{CO2}^{-1} with the 45Q carbon tax credit. It combines low-cost solar-thermal and low-risk photovoltaic technologies to facilitate the installation at different scales and runs with the diurnal cycle to avoid energy storage. The modular design and energy-autarkic operation of the system should enable deployment across broad geographic regions far from infrastructure centers, thereby enabling a distributed, self-powered solution to the problem of removing dilute CO_2 from the atmosphere.

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Prolate spheroids settling in a quiescent fluid: clustering, microstructures and collisions

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ABSTRACT

Particle sedimentation in the fluid flows is commonly encountered in nature and industry. In the present work, to better understand the effect of particle shape, we study the settling motion of prolate particles in a quiescent fluid with different particle volume fraction by using the particle-resolved direct numerical simulation (PR-DNS). First, we find that the flow field is disturbed due to the presence of particles, which are non-uniformly distributed (see Figure 1). Furthermore, we observe an non-monotonic variation of particle mean settling velocity with the increase of volume fraction, which is attributed by the tendency of particles to form clusters. In the very dilute suspensions, although the attraction of particle wakes results in the vertically aligned particle structures, the long distance between particles inhibits the growth of particle clusters. In the case of high particle volume fraction, the short particle-particle distance disrupts the wake of settling particles and weakens the hydrodynamic interactions among particles. The hindrance effect in this regime reduces the mean settling velocity of dispersed particles.

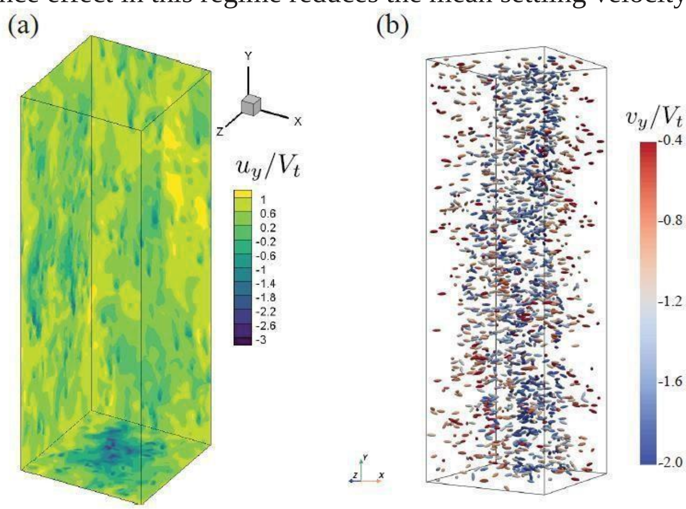

Figure 1: Snapshot of (a) the three-dimensional flow field and (b) the dispersed particles.

BIOGRAPHY

Lihao Zhao is a tenured Associate Professor in Fluid Mechanics at Tsinghua University. In 2012 he was selected as the finalist of "Da Vinci Award: Best European Doctoral Thesis on Flow, Turbulence and Combustion" sponsored by European Research Community on Flow, Turbulence and Combustion (ERCOFTAC), in 2016 awarded the "National Young Talents Program" and in 2023 received Zhou Peiyuan Award in Mechanics for Young Scholars. He has 80+ international journal publications, including Sci. Adv., PRL, JFM, on multiphase flow simulations and modelling with one JFM paper featured in a "*Focus on Fluids*" article of Journal of Fluid Mechanics. He serves as an Editorial Advisory Board Member in International Journal of Multiphase Flow, Acta Mechanica, Acta Mechanica Sinica.

A NOVEL MODEL FOR REACTIVE TRANSPORT PROCESSES IN CATALYST LAYER OF PEM FUEL CELLS

Li Chen

Key Laboratory of Thermo-Fluid Science and Engineering of MOE, School of Energy and *Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China*

ABSTRACT

Improving the performance of proton exchange membrane fuel cells (PEMFCs) requires deep understanding of the reactive transport processes inside the catalyst layers (CLs). In the literature, different models have been developed to study the reactive transport processes in CLs including thin-film model, homogeneous model, agglomerate model, and the single-particle model. Among the above models, the single-particle model is widely adopted due to its capacity to consider the local transport processes around the reactive sites. In this study, a particle-overlapping model is further developed for accurately describing the hierarchical structures and oxygen reactive transport processes in CLs. A multiscale model is developed by coupling the particle-overlapping model with cell-scale models, which is validated by comparing with the polarization curves and local current density distribution obtained in experiments. The relative error of local current density distribution is below 15% in the ohmic polarization region. Finally, the multiscale model is employed to explore effects of CL structural parameters including Pt loading, I/C, ionomer coverage and carbon particle radius on the cell performance as well as the phase-change-induced (PCI) flow and capillary-driven (CD) flow in CL. The multiscale model significantly contributes to a deep understanding of reactive transport and multiphase heat transfer processes inside PEMFCs.

BIOGRAPHY

Li Chen is a full Professor at Xi'an Jiaotong University (XJTU) China. He obtained his PH. D in Engineering Thermophysics at XJTU in 2013, followed by Director Postdoc at Loa Alamos National Lab from 2013.12 to 2015.12. His research focuses on transport phenomena in porous media with background of fuel cell, flow battery, CO2 storage and hydrocarbon resource exploitation. Particularly, he has developed an advanced pore-scale model based on the Lattice Boltzmann Method for coupled multiphase flow, heat and mass transfer, chemical reaction, solid precipitation-dissolution (melting- solidification) processes in porous media. Up to now, he has published 120 SCI papers in a variety of top journals, including Progress in Energy and Combustion Science, Small, Int. J. Heat and Mass Transfer, etc. Hies research has also resulted in over 40 conference presentations (15 keynote talks), 10 patents and 6 software copyrights. He serves as Editor and/or guest editor on several international journals.

AI-ASSISTED EXPLORATION AND ACTIVE DESIGN OF POLYMERS WITH HIGH INTRINSIC THERMAL CONDUCTIVITY

Shenghong Ju
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ABSTRACT

Designing polymers with high intrinsic thermal conductivity (TC) is critically important for the thermal management of organic electronics and photonics. However, this is a challenging task owing to the diversity of the chemical space and the barriers to advanced synthetic experiments/characterization techniques for polymers. In this Tutorial, the fundamentals and implementation of combining classical molecular dynamics simulation and machine learning (ML) for the development of polymers with high TC are comprehensively introduced. We begin by describing the core components of a universal ML framework, involving polymer datasets, property calculators, feature engineering and informatics algorithms. Then, the process of constructing interpretable regression algorithms for TC prediction is introduced, aiming to extract the underlying relationships between microstructures and TCs for polymers. We also explore the design of sequence-ordered polymers with high TC using lightweight and mainstream active learning algorithms. Lastly, we conclude by addressing the current limitations and suggesting potential avenues for future research on this topic.

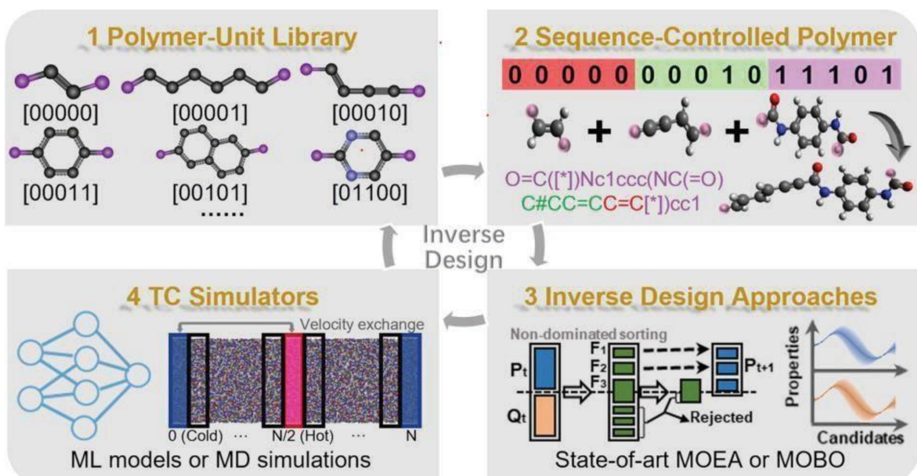


Figure 1. AI-assisted thermal conductive polymers design

BIOGRAPHY

Dr. Shenghong Ju is currently associate professor of China-UK Low Carbon College, Shanghai Jiao Tong University. He obtained his Ph.D. in Engineering Thermophysics from Tsinghua University in 2014, and conducted postdoctoral research in Ecole Centrale Paris and the University of Tokyo from 2014 to 2019. Dr. Ju's research interests mainly cover nanoscale thermal transport and AI-assisted design of thermal functional materials. He has published over 70 papers in peer-reviewed high quality journals including *Physical Review X*, *Journal of Materials Chemistry A*, *npj Computational Materials*, *Acta Materialia*, IJHMT, etc. Dr. Ju was awarded the Hangzhou Qingshanhu MGE Young Scientists Award in 2022, the Outstanding Young Researcher Award by The Heat Transfer Society of Japan in 2019. Dr. Ju also serves as the Youth Editorial Board Member of *Carbon Neutrality*, *Journal of Materials Informatics* and *MGE Advances*.

Scanning thermal microscopy characterization and enhancement mechanism analysis of local high thermal conductivity of composite phase change materials

Lin Qiu

We derived a formula for quantitative measurement of thermal conductivity using scanning thermal microscopy in open-loop mode, and combined it with a DMT model that uses nanoindentation to measure the reduced Young's modulus. We developed a novel scanning thermal microscopy method for in-situ characterization of thermal/mechanical properties, which can simultaneously achieve local in-situ characterization of thermal conductivity and reduced Young's modulus, with a spatial and thermal resolution of up to 100 nm. The local thermal conductivity and reduced Young's modulus of erythritol in three composite phase change materials (Ery@SiC, Ery@SiO_2, and Ery@Si_3N_4) were measured using scanning thermal microscopy. Molecular dynamics simulations were used to reveal the enhancement mechanism of the intrinsic thermal conductivity of erythritol in composite phase change materials. The results showed that as the measured location approached the interface, the thermal conductivity of erythritol gradually increased, reaching a maximum value of 1.13 $Wm^{-1}K^{-1}$ at the interface. The reduced Young's modulus and thermal conductivity had the same trend of change, and the two had a clear positive correlation. This is because an adsorbed layer composed of erythritol was formed around the nanoparticles, and the erythritol molecules in the adsorbed layer was more oriented, limiting the motion of erythritol molecules, thereby weakening phonon scattering and improving thermal conductivity. The maximum local thermal conductivity and the overall thermal conductivity renders the similar trend, that is Ery@SiO_2 < Ery@Si_3N_4 < Ery@SiC, suggesting that the increase in thermal conductivity of erythritol at the interface is the main reason for the increase in overall thermal conductivity of composite phase change materials. For different composite phase change materials, molecular dynamics simulations indicate that the increase in thermal conductivity and reduced Young's modulus of erythritol is attributed to the increase in interaction energy between erythritol and nanoparticles, as erythritol has a higher density at the interface and more erythritol phonon vibrations transform from localized mode to delocalized mode. These findings will provide new ideas for the design of phase change materials for energy storage.

Effect of the tilt angle on the melting process of PCM in a tilted square cavity

Zhenhua Xia*, Jin Hu
Zhejiang University, Hangzhou, China

ABSTRACT

An efficient modified enthalpy method for the phase-change melting problems utilizing dual time-steps is proposed. In contrast to the traditional enthalpy method, where the latent heat term was treated as an enthalpy source term that was implicitly solved iteratively, the enthalpy source term in the present method is coupled into the left-hand side of the energy equation through the Heaviside function. To overcome the limitations of the single-time-step approach caused by the characteristic time difference in thermal and viscous diffusion properties for very high or low Prandtl numbers, we have implemented two separate time steps for the momentum and enthalpy equations. This improves computational performance and reduces cost. Our enthalpy method is implemented using a direct numerical simulation solver called AFiD. This presentation will discuss our most recent findings regarding the impact of tilt angle on the melting process of phase change material (PCM) in a tilted square cavity, using the dual-time-step method that we have proposed.

BIOGRAPHY

Zhenhua XIA is currently a Tenured Associate Professor at the School of Aeronautics and Astronautics, Zhejiang University, China. He earned his bachelor's and Ph.D. degrees from Peking University, China. From Sep. 2007 to Sep. 2009, he visited Johns Hopkins University. Prior to joining Zhejiang University in July 2016, he worked as a postdoctoral fellow and research assistant at Peking University for five years. So far, he has published more than 70 journal papers in areas such as turbulence theory and numerical simulation, computational fluid dynamics and aerodynamics. These papers have been published in journals such as the Journal of Fluid Mechanics, Physical Review Fluids, and Acta Mechanica Sinica. Additionally, he has hosted four projects funded by the National Natural Science Foundation of China, including the Excellent Young Scientists Fund in 2018.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

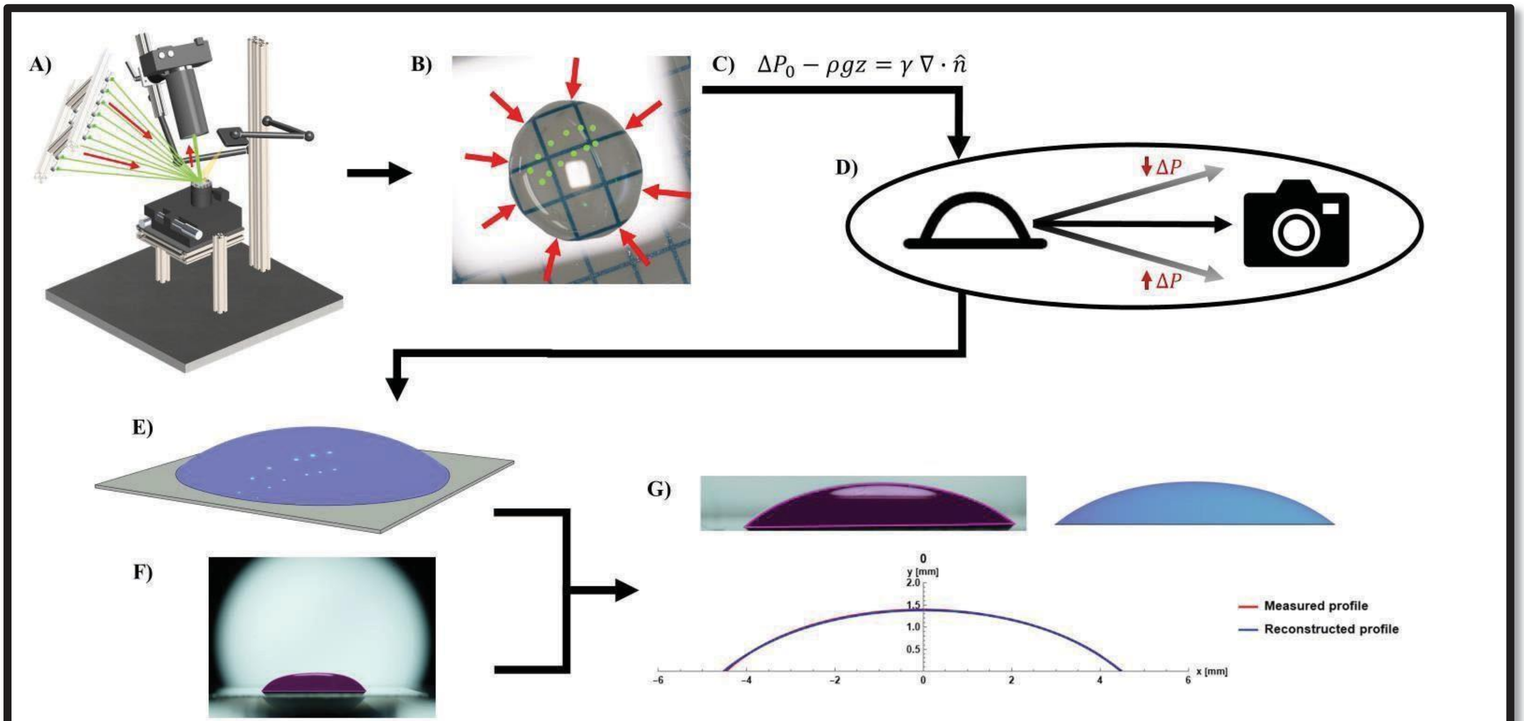
THE REVERSE CATCH LIGHT METHOD: A NOVEL AND ROBUST APPROACH FOR COMPLETE DROPLET RECONSTRUCTION IN THREE-DIMENSIONAL SPACE

Isaac Berk[1], Emilie Luong[1], and H. Jeremy Cho[1]
[1]*Department of mechanical engineering, University of Nevada, Las Vegas, USA*

ABSTRACT

Irregularly shaped droplets occur in many interfacial sciences, including those involving drop-wise condensation, mixed wettability textiles, and dew harvesting. However, characterizing three-dimensional (3D) droplet geometries is often challenging and requires a large number of images taken from many orientations. Here, we present an entirely new method of obtaining the *full 3D geometry of a droplet from a single image*, by back-calculating a droplet's shape from specular reflections. Using the known contact line as a boundary condition, we generate candidate droplet geometries by solving the Young-Laplace (YL) equation. Then, we ray-trace light that travels from known light sources and specularly reflects off the candidate droplet surface toward a known camera position. We compare the ray-traced reflections to the observed reflections, adjust a free parameter in the YL equation to generate a new candidate surface, and iterate until the ray-traced and observed reflections match, thereby reconstructing the full 3D droplet surface. This allows us to quantify phenomena such as local contact angle and contact line variations as well as droplet shape distortions, which are difficult or even impossible to quantify with traditional goniometry. Our analysis shows that our method is robust and insensitive to camera positioning and number of lights. Our method is validated by the strong qualitative and quantitative agreement with tradi- tional, multi-image goniometry where the average error in local contact angle is < 3°. Future work includes application to multi-droplet systems and video capture to analyze dynamically changing phenomena in realistic environments over long timescales.

ABSTRACT FIGURE



A) Using a camera and point source lights, we capture B) the contact line and specular reflections on a droplet. C) We then generate a candidate surface in three-dimensional (3D) space using the contact line as a boundary condition to solve the Young-Laplace (YL) equation. D) We compare ray-traced reflections from the generated surface to the observed reflections, adjust a free parameter in the YL equation to generate a new candidate surface, and iterate until the ray-traced and observed reflections match in order to E) reconstruct the 3D droplet surface. F) We validate our method by taking multiple goniometry images around the droplet and G) comparing them with the novel reconstructions.

A multi-physics pore-scale network modelling tool for the design of transport in device-scale porous media

Qingyang Lin
Zhejiang University

ABSTRACT

The design of transport in porous media to satisfy specific process requirement is crucial in many engineering applications but remains challenging. The complex porous structure at the device-scale contains a vast number of pores that create local heterogeneity, causing deviations in the heat and mass transport from the assumptions based on homogeneous pore structure. We aim to provide an approach based on pore-scale imaging and modelling to characterize and understand transport phenomena in complex pore structures and guide the design of transport in porous media. In terms of pore-scale imaging, we have developed a series of advanced image analysis algorithms to accurately characterize capillary forces and their spatial distribution, fluid interfaces, and thermodynamic properties such as wettability, which can be used as important inputs for the model. For pore-scale modelling, using actual porous media structures, we have developed a multi-physics network model framework to capture pore-scale heat and mass transport behaviors at the device-scale in three dimensions. We are also exploring the possibility ofusing the operator splitting and machine learning techniques to further improve computational efficiency in order to effectively couple reactions with heat and mass transport in long-period simulation.

BIOGRAPHY

Qingyang joined Zhejiang University in October 2020 as a Research Processor. Prior to this, he was a Research Associate at Imperial College London from 2015 to 2020. He holds PhD (2015) in earth science and engineering from Imperial College London. His research focuses on using pore-scale imaging and modelling to understand and guide the design of transport in porous media. This is achieved by using advanced X-ray imaging and synchrotron sources at micro and nano scales and developing pore-to-mesoscale numerical models. He has published more than 50 publications in peer-revi ewed journals such as Engineering, AIChE journal, Environmental Scienc e & Technology, Applied Energy, ACS Applied Materials & Interfaces, Ch emical Engineering Science, and Geophysical Research Letters, which have received over 2900 citations with an h-index of 32. His research can be applied to a wide range of engineering applications, particularly in reactor design, heterogeneous catalysis, electrochemical devices and geoscience.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
21 – 24 June 2024, Hong Kong

Numerical study of anti-frosting (anti-icing) mechanisms on superhydrophobic surface

Li-Zhi Zhang*, Shusheng Zhang

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Frost and/or ice formation are widespread phenomena in various engineering fields, such as power generation and transmission, aviation, air conditioning and refrigeration, and transportation. However, frost (ice) formation often affects the operational efficiency of industrial equipment and it could pose serious risks to people's safety. Therefore, mitigating the hazards posed by icing phenomena has become an urgent issue to address. In recent years, passive de-frosting/de-icing technologies based on superhydrophobic modifications of surfaces have gained widespread attention in the anti-frosting/anti-icing fields due to their low cost, lack of manual intervention requirement, and wide applicability. By applying superhydrophobic modification to the surfaces of industrial equipment, impacting droplets can rapidly detach from the surfaces, reducing heat transfer between the impacting droplets and solid surfaces, reducing ice adhesion and minimizing the condensation of ice crystals, and frost formation. To investigate the anti-icing mechanism of superhydrophobic surfaces, this presentation employs numerical simulation method to study the heat transfer of impacting droplets on solid surfaces, impact freezing of droplets on solid surfaces, macroscopic frost layer growth, and microscopic ice crystal nucleation and growth. The purposes of this study are to reveal the flow and heat/mass transfer mechanisms on superhydrophobic surfaces, and provide theoretical guidance for the design and optimization of anti-frosting/anti-icing superhydrophobic surfaces. The work in this presentation mainly consists of the following parts:

Firstly, a multiple distribution function phase-field lattice Boltzmann model was established based on the lattice Boltzmann method and phase-field model to investigate the dynamic behaviors and heat transfer characteristics of impacting droplets on micro-pillar arrayed and regularly distributed rough surfaces. The results indicate that the heat transfer performance between the bouncing droplets and textured superhydrophobic surface is affected by the synergistic effects of the contact time and contact area. A theoretical correlation was developed to predict the total transferred heat based on the identified droplet dynamics. Design principles for textured superhydrophobic surfaces for suppression heat transfer are given for two application scenarios. Subsequently, the dynamics behavior and heat transfer characteristics of droplets impacting randomly distributed micro structure rough superhydrophobic surfaces were simulated using a multi-distribution function phase-field lattice Boltzmann model. The study revealed the influences of the actual properties of random roughness on the wetting state and heat transfer characteristics of impacting droplet on the surfaces.The effect of random roughness on the rebound ability of impacting droplets and the total heat transfer was disclosed. Theoretical prediction formula for the total heat transfer of impacting droplets on random rough surfaces were proposed. The results show that the random rough surface with a smaller skewness, a kurtosis of 3.0, and a standard deviation of 0.3 μm could simultaneously promote the impacting droplets to rebound from the surface and to reduce the total transferred heat.

Secondly, a numerical model was proposed for droplet impacting and freezing on superhydrophobic surfaces of random roughness based on the lattice Boltzmann method coupled with phase-field model and enthalpy-porosity method. This model simulated the droplet supercooling effect by modifying the initial conditions of simulation. The effects of surface temperature, surface intrinsic contact angle, random roughness parameters, and supercooling on the droplet impacting and freezing process were analyzed. The study found that there were three dynamic states of droplet impacting and freezing on random rough surfaces: complete rebound, partial adhesion, and complete adhesion. The random rough surface with a larger contact angle, a smaller skewness, a kurtosis of 3.0, and a standard deviation of 0.3 μm could inhibit the icing phenomenon during droplet impacting on cold surfaces and the surface is suitable for anti-icing requirements in lower temperature environments.

Thirdly, to solve the problem of current macroscopic frost layer growth models in considering surface wettability, a novel lattice Boltzmann model for predicting frost formation and growth on surfaces of various wettabilities was proposed based on the heterogeneous nucleation and dendrite growth theories. It was experimental validated. Subsequent parameter analysis reveals that the intrinsic contact angles have little effects on frost layer thickness on smooth cold surfaces, however the frost layer density on hydrophobic surfaces is significantly lower than that on hydrophilic surfaces. Rough surfaces with larger skewness, smaller kurtosis, and smaller standard deviation could slow down the overall frost layer formation on the surface.

Finally, the nucleation and growth process of ice crystals from a relatively microscopic perspective were investigated. A numerical model for the nucleation and growth of ice crystals on solid surfaces was proposed based on the lattice Boltzmann method coupled with anisotropic phase-field model and Poisson seeding algorithm. The effects of surface contact angle, surface random roughness parameters, and forced convection properties on ice crystal nucleation and growth were discussed. The results indicate that the surface contact angle mainly affects the growth of near-wall dendrites, with less effect on the primary dendrites. Ice nuclei are fewer and the formed ice layer is looser on superhydrophobic surfaces. For the nucleation and growth process of ice crystals on surfaces of random roughness, the asymmetry caused by the random rough structures disrupts the competitions between ice crystals, leading to more gaps between ice phases on surfaces, which is reflected by a looser frost layer on the macroscopic scale. Furthermore, increasing the surface skewness, decreasing the surface kurtosis, and decreasing standard deviation could inhibit the nucleation and growth of ice crystals in some degree.

Keywords: Superhydrophobic, Anti-icing, Lattice Boltzmann method, Droplet impacting, Frosting

INTERFACIAL WELDING ENGINEERING OF CARBON NETWORKS

Qingbin Zheng
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ABSTRACT

Interfacial thermal and electrical resistance between individual carbon nanotube (CNT) significantly hinders the further improvement in thermal and electrical conductivity of CNT-reinforced nanocomposites. Herein, an interfacial welding strategy is reported to construct graphitic structure welded CNT (GS-w-CNT) networks. Notably, the obtained GS-w-CNT/polydimethylsiloxane (PDMS) nanocomposite not only shows a high thermal conductivity with a 410% enhancement as compared to a pure CNT/PDMS nanocompo-site, but also exhibits high electrical conductivity (>132 S m−1) and high stretchability (>150% strain) while ensuring long-term stability (1000 stretching-releasing cycles under 60% tensile strain). Molecular dynamics simulations are utilized to elucidate the effect of interfacial welding on the heat transfer behavior, revealing that the GS welding degree plays an important role in reducing both phonon scattering in the GS-w-CNT structure and interfacial thermal resistance at the interfaces between CNT. The unique welding strategy provides a new route to optimize the thermal and electrical transport performance in filler reinforced polymer nanocomposites, promoting their applications in next-generation wearable electronics.

BIOGRAPHY

Prof. Zheng received his Ph.D degree from Department of Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology (HKUST) in 2011. Prior to joining School of Science and Engineering (SSE), The Chinese University of Hong Kong, Shenzhen (CUHKSZ) as an Assistant Professor in 2019, he held various academic positions worldwide, including Research Assistant Professor of the Department of Mechanical and Aerospace Engineering at HKUST and Alexander von Humboldt Research Fellow at Leibniz Institute of Polymer Research Dresden, Germany. Prof Zheng has received many awards including National High-Level Young Talent, Research.com Best Materials Science Scientist, Stanford University World's Top 2% Scientist, Presidential Young Fellow of CUHKSZ, CUHKSZ-SSE Outstanding Faculty Research Award, Fellow of the International Association of Advanced Materials, Junior Fellow of the HKUST Jockey Club Institute for Advanced Study, and Alexander von Humboldt Fellowship of Germany.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
20 – 24 June 2024, Hong Kong

Numerical development on coupled moisture transfer and electrochemical reaction within porous catalyst layer of PEM electrolyte dehumidifier/vapor electrolyzors

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ABSTRACT

Electrolyte membrane dehumidification is a newly developed electrochemical dehumidification technology. It uses a multi-layer membrane electrode assembly to replace the traditional liquid or solid hygroscopic medium, and uses a direct electric field of about 3V for electrolysis to achieve air dehumidification. It has the advantages of compact size and wide range of humidity control, which is suitable for using in the fields of instrument cabinets, valuables or cultural relics storage with strict humidity requirements. The porous catalytic layer containing pores, polyelectrolytes and catalytic particles is the key to determin- ing the performance of membrane electrodes. This study developed a numerical method using the multi- ple-relaxation-time lattice Boltzmann method (MRT-LBM) to reproduce mesoscopic water vapor transport driven by both air flow and concentration gradient within CL, and its interaction with electro- chemical reaction. The ionomer coverage morphology and its influence on three-phase interfaces (TBIs) and pore structure were considered. Combined with the finite volume method, the operating current den- sity and dehumidification rate of PEM components can be predicted. The predicted dehumidificationrate closely matched the experimental results. This simulation enabled accurate visualization of the coupled mass transfer and electrochemical reaction process within porous CL, as well as its interaction with the PEM component. Thus, it can guide the morphology design and material selection of ionomers and cata- lysts, and also improve the mechanism understanding of electrolyte dehumidification and vapor/steam electrolyzors.

BIOGRAPHY

Dr. Ronghui QI received her Ph. D degree at the Hong Kong Polytechnic University, followed by postdoctoral research from 2013-2016. She then joined the South China University of Technology as an associate professor, and was promoted to full professor in Sep, 2019. Her main research interests are coupled heat and mass transfer mechanism and enhancement in porous media, membrane transport process and efficient energy conversion in the field of air-conditioning, dehumidification and humidity energy utilization. As the first or corresponding author, she has published more than 50 international SCI papers. She is currently on the editorial board of international journals <International Journal of Green Energy> and <Energy and AI>, and served as the guest editor of SCI journals <Heat Transfer Engineering> and <Polymers>.

HYDROGEN PRODUCTION OF STEAM-REFORMING USING NUCLEAR ENERGY FROM HIGH TEMPERATURE GAS-COOLED REACTOR: A FUNDAMENTAL VIEW OVER THE STEAM-REFORMING TUBE HEATED BY HELIUM GAS

Huang ZHANG

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ABSTRACT

(250 Words Max, optional to include figure/caption)

Hydrogen is an important raw material in industry as well as an efficient clean energy. Hydrogen production of steam reforming (e.g., methane-steam, methanol-steam reforming) using nuclear energy is the most promising technology of nuclear hydrogen production that could be fulfillment in the near future. In the steam-reforming system, steam-reforming tube is the key equipment which contains three zones, i.e., helium gas tube, catalyticbed, and center tube. In this work, the heat and mass transfer characteristics were systematically examined. First, the heat transfer model of the catalytic bed, which is a porous media in the form of pebble bed, was re-examined according to the derivation results of Zehner-Schlunder model. Second, a one-dimensional model was introduced to simulate the reaction flow in the reforming tube. Third, an experimental facility was built to measure the gas flow and temperature distribution in the reforming tube. The result shows that the equivalent heat transfer coefficient of the catalytic bed is mainly affected by heat conduction, convection and radiation of the process gas, catalyst particles and catalytic tube walls. And the one-dimensional mode is able to analyze the performance of the reforming tube. Finally, the experimental results of the reforming tube were presented. This study is helpful for better understanding the performance of the reforming tube heated by the helium gas from High Temperature Gas-cooled Reactor (HTGR).

BIOGRAPHY

(150 Words Max, optional to include photo/head-shot)

Dr. Huang Zhang got his master degree of computer science and Ph.D. of nuclear energy engineering both from Tsinghua University. Then, he came to the Department of Thermal Engineering at Tsinghua University as a postdoctoral fellow at 2015. From 2017 to 2021, Dr. Zhang worked as a research scientist in the Department of Energy, Environment and Chemical Engineering at Washington University in St. Louis. Dr. Zhang's research interest include 1) thermal-hydraulics of nuclear reactor; 2) hydrogen production using nuclear energy; 3) aerosol dynamics. He has published more than 40 articles on *Int. J. Heat & Mass Transf., Int. J. Multiphase Flow, Exp. Therm. Fluid and Sci., Nucl. Eng. & Des.*, etc., and been fundedby many projects, e.g., Ministry of R&D of China, National Science Foundation of China (NSFC), NSF Beijing, etc. His awards include Yong Talented Researcher of China National Nuclear Corporation (CNNC), Outstanding graduates of Tsinghua University, etc.

Theoretical Study of Reversing Coffee-Ring Effect Using Local Heating

Tao Wei[1,2] and Yu-Hwa Lo[3,4]

1. Biomedical Engineering Department, University of South Carolina, Columbia, South Carolina, 29208, United States.

2. Chemical Engineering Department, University of South Carolina, Columbia, South Carolina, 29208, United States

3. Electrical and Computer Engineering Department, University of California San Diego, La Jolla, California, 92093-0407, United States

4. Materials Science Program, University of California San Diego, La Jolla, California, 92093-0418, United States

ABSTRACT

The coffee-ring effect, commonly observed during the drying process of aqueous droplets, hinders the performance of various applications. These applications include the precipitation of particle suspensions in evaporating liquids on solid surfaces, such as liquid biopsy combinational analysis, microarray fabrication, and inkjet printing. Experiments showed that local heating can effectively reverse the coffee-ring effect, allowing for the enrichment and focused deposition of water-soluble molecules at the center rather than at the edge of a droplet. To complement the experimental design, in this study, using Stokesian hydrodynamics based on the Onsager principle, we conducted a theoretical investigation of the underlying physics that governs the evaporation process and drying patterns of solute precipitation at varying rates of local evaporation over a droplet. Our study showed that local heating introduced to a droplet can counteract the coffee-ring effect, altering the drying pattern and solution precipitation of particle suspensions. Our research provided not only a quantitative relationship for the effect of differential evaporation on the drying pattern but also experimental guidelines regarding laser power dependence on droplet size. These findings have the potential to substantially advance technologies in combinational liquid biopsy analysis, inkjet printing, and microarray fabrication.

BIOGRAPHY

Dr. Tao Wei is an associate professor of Biomedical Engineering and Chemical Engineering at the University of South Carolina, United States. Dr. Wei's research focuses on biomaterials and bionanotechnologies. To achieve optimal functional design, he combines multiscale simulation frameworks (quantum, atomistic, mesoscopic and continuum scales) and machine learning with experiments at the interface between chemistry, physics and biology.

Dr. Yu-Hwa Lo is a professor of Electrical and Computer Engineering at University of California at San Diego (UCSD), United States. Dr. Lo's research is focused on two areas, the first one being on condensed matter photonics and optoelectronic materials and devices with an emphasis on devices and novel physical mechanisms for ultrasensitive light detection with applications in imaging, LiDAR, and medical and bioimaging. The second area of focus is microfluidics, lab-on-a-chip devices, and biomedical and biophotonic devices for single cell analysis, diagnosis, and drug discovery.

A high-order scheme for the Navier-Stokes type equations and Saint Andrew's Cross

Zhan Wang
Institute of Mechanics, Chinese Academy of Sciences

ABSTRACT

A fundamental phenomenon in continuously density-stratified fluids is the so-called Saint Andrew's Cross, usually generated by a vertically oscillating circular cylinder in a uniformly stratified fluid in a controlled experiment. To better understand Saint Andrew's Cross and related phenomena, high-resolution numerical schemes are required to investigate the generation and propagation of internal wave beams. Since gravity provides a preferred direction, the pseudo-spectral method based on the fast Fourier transform algorithm is not applicable in the vertical direction, and high-order finite volume schemes become an appropriate choice. In this talk, we propose a high-resolution finite volume scheme for simulating density-stratified Boussinesq flows by generalizing the pressure Poisson equation method based on the Liu-Liu-Pego formulation. The scheme is of fourth-order accuracy in space and time and applies to two and three dimensions. Numerical experiments for Saint Andrew's Cross in uniformly/non-uniformly stratified fluids are carried out with various Brunt-Vaisala frequencies and compared with laboratory experiments.

BIOGRAPHY

Zhan Wang is Professor at the Institute of Mechanics (CAS), deputy director of the Academic Committee, and director of the CAS Key Laboratory for Mechanics in Fluid Solid Coupling Systems. He received a doctor's degree from the University of Wisconsin-Madison in Applied Mathematics and Fluid Mechanics. After graduation, he was appointed as a research assistant at the University College London and a lecturer at the University of Bath. He mainly engages in theoretical and applied research in hydrodynamics, environmental mechanics, nonlinear free-surface and interfacial waves, etc.

TITLE OF KEYNOTE/INVITED TALK

Efficient Numerical Model for Multicomponent Reacting Flows

Yu Lv
Institute of Mechanics, Chinese Academy of Sciences

ABSTRACT

(250 Words Max, optional to include figure/caption)

Numerical simulations of multicomponent reacting flows are often very computationally expensive. In this talk, the focus is on the tabulated chemistry technique commonly used in combustion modeling. The talk will first present the model formulations and then discuss the key algorithms for incorporating tabulated chemistry into incompressible and compressible flow solvers. After that, the LES techniques built upon the tabulated chemistry are presented and demonstrated in a few applications in modeling of turbulent flames. The talk will finish by outlining several modeling challenges and provide a outlook for future research.

BIOGRAPHY

(150 Words Max, optional to include photo/head-shot)

Dr. Yu Lv got his PhD degree from Stanford University in 2016. He spent one year at Center of Turbulence Research (CTR) before joining Mississippi State University as an Assistant Professor. He returned to China in 2021 and since then has been working at the Institute of Mechanics, Chinese Academy of Sciences, as an Associate Professor.

High-order numerical methods for compressible multiphase flows

Lin Fu[1,2,*]
[1]Department of Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology, Hong Kong, China
[2]Department of Mathematics, The Hong Kong University of Science and Technology, Hong Kong, China
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ABSTRACT

In this talk, we develop a family of high-order algorithms to simulate compressible multiphase flows by solving the quasi-conservative five-equation model. The general numerical framework utilizes targeted essentially non-oscillatory schemes with adaptive dissipation (TENOA) to boost the resolution of high-frequency waves, whereas the Tangent of Hyperbola for INterface Capturing (THINC) scheme is activated near the shock and contact discontinuities as well as material interfaces to maintain their sharpness, based on a novel indicator. Also, the newly derived THINC reconstruction scheme is both simpler and better at preserving the flow symmetry. Numerical results of the challenging one- and two-dimensional benchmark cases demonstrate the superiority of the proposed methods regarding oscillation-free, interface-sharpening, low-dissipation and robustness properties.

BIOGRAPHY

Prof. Lin Fu is an Assistant professor in the Department of Mathematics and the Department of Mechanical and Aerospace Engineering at The Hong Kong University of Science and Technology (HKUST). Before he joined HKUST, he was a postdoctoral fellow working with Prof. Parviz Moin at Center for Turbulence Research (CTR), Stanford University, for more than 3 years. And he also did postdoctoral research with Prof. Nikolaus Adams at Technical University of Munich, where he obtained his Ph.D. degree with a grade of Summa Cum Laude (passed with the highest distinction). His research is funded by the Research Grants Council (RGC) of Hong Kong with the recognition of Early Career Award. He has published more than 70 journal papers on PNAS, JFM, PRF, JCP, CMAME, etc.

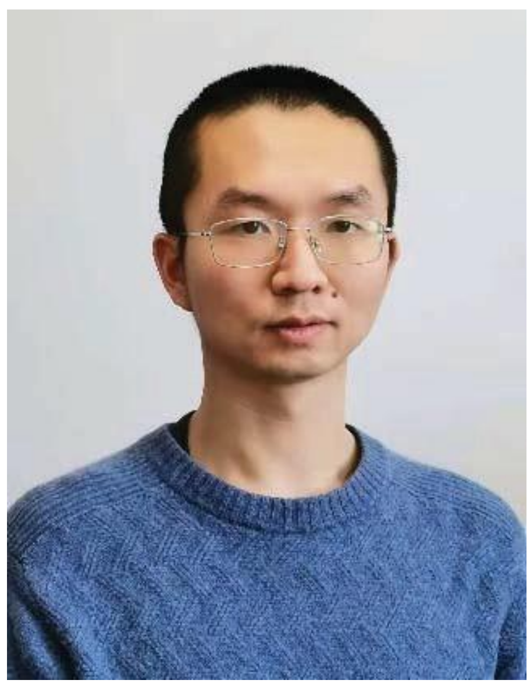
Photo:

Title: Numerical study of water jet plunging into a quiescent pool

Speaker: Zixuan Yang
Affiliation: Institute of Mechanics, Chinese Academy of Sciences / University of Chinese Academy of Sciences

Abstract:
Mixed-phase turbulence is a common phenomenon in nature and engineering applications. Water jet plunging acts as a key process causing interface breaking and generating mixed-phase turbulence. In the present study, we conducted high-resolution numerical simulations of the plunging of water jet into a quiescent pool to investigate the statistical properties of mixed-phase turbulence, with a special focus on the closure problem of the Reynolds-averaged equation. The simulation is conducted using an open-source code Computational Air-Sea Tank (CAS-Tank). The air–water interface is captured using a coupled level-set and volume-of-fluid method. It is discovered that the generation mechanism of the turbulence mass flux (TMF), which is an additional term in the Reynolds-averaged equation for mixed-phase turbulence, is highly correlated to the density gradient and turbulence kinetic energy. Based on this finding, a closure model for the production term of TMF is further proposed.

Biography:
Yang Zixuan, Ph.D., professor at the Institute of Mechanics, Chinese Academy of Sciences. He earned his undergraduate and graduate degrees from Tsinghua University and subsequently pursued postdoctoral research at the University of Manitoba in Canada and the University of Minnesota in the United States. His primary research focus lies in turbulence and two-phase flows. Dr. Yang has proposed an approximation-synchronization algorithm for density evolution, which significantly enhances the stability of large-eddy simulation of high-density ratio two- phase turbulent flows. Based on the viscous- potential flow decomposition, he further proposed new methods for reducing the numerical dissipation, which improves the numerical accuracy for wave propagation and evaporation problems. Building upon these methods, he has led his team in the development of the Computational Air-Sea Tank (CAS-Tank), a high-fidelity two-phase flow simulation platform designed for high- resolution simulation and mechanistic studies of two-phase turbulence. He has authored over 50 SCI-indexed papers, including 10 in the Journal of Fluid Mechanics (JFM) and 3in the Journal of Computational Physics (JCP).



Modeling Electron-Phonon Interaction and Spin-Lattice Coupling in Energy Materials

Bolin Liao
Department of Mechanical Engineering, University of California Santa Barbara

ABSTRACT

Interactions among fundamental energy carriers, such as electrons, phonons, and magnons, are critical for energy transport and conversion materials and devices. In this talk, I will discuss our recent progress in understanding electron-phonon interaction and spin-lattice coupling in solid-state materials using first-principles simulations and machine learning. First, I will discuss how nonequilibrium coupling between electrons and phonons ("drag effect") can significantly modify both electrical and thermal transport properties in wide-bandgap semiconductors and 2D materials. In particular, I will address key factors contributing to a strong drag contribution in general. Secondly, I will describe the impact of spin-lattice coupling on magnetocaloric and thermal transport properties of magnetic materials in 3D and 2D. Specifically, I will show that indirect RKKY-type magnetic exchange interaction can lead to long-range spin-lattice coupling and a large lattice entropy change during magnetic phase transition, with important implications in magnetic cooling applications. Furthermore, I will discuss our effort of using large language models and machine learning to discover new magnetic cooling materials. These findings contribute to our fundamental understanding of coupled energy transport phenomena in technologically relevant materials.

BIOGRAPHY

Bolin Liao is an associate professor of mechanical engineering at UCSB. He received his Ph.D. in mechanical engineering from MIT in 2016 and was a Kavli postdoc scholar at Caltech from 2016 to 2017. His current research focuses on the fundamental understanding of microscopic energy transport mediated by phonons, electrons and spins in emerging quantum and energy materials and their potential application in next-generation energy and electronic systems. His research has been recognized by an outstanding Ph.D. thesis award from MIT, a Kavli prize postdoctoral fellowship in nanoscience from Caltech and an NSF CAREER award.

DATA ASSIMILATION OF TURBULENT FLOWS

Ying Zheng Liu
School of Mechanical Engineering, Shanghai Jiao Tong University

ABSTRACT

The spatial and temporal variations of turbulent flow and pressure fields are important features in a wide variety of applications, such as industrial aerodynamics and architectural engineering. Having access to exhaustive spatial–temporal flow information, which is critical for analysis including flow-induced vibration, acoustic noise emission and optimal flow control is still difficult even for academic purposes despite the rapid development in computational power and measurement techniques. High-frequency signals can be indeed collected pointwisely by probes, but with the missing of timely spatial information. Although the state-of-the-art high speed cameras enable the time-resolved flow field acquisition using particle image velocimetry (PIV) it strongly relies on the frequency and power of laser illumination, which is costly or even prohibited for measurement of a high-speed flow in wind tunnels. Consequentially, the development of a reliable method for reconstruction of the high-frequency and high-resolution flow fields from limited measurement data, based on which the pressure fields are determined, would play an important role in turbulence analysis and is thus highly desirable.

Data assimilation is an important data augmentation method for increasing the data reach in measurement techniques and understanding turbulence dynamics. This talk focuses on recent progress of data assimilation of turbulent flows: 1) global velocity and pressure fields recovery over a NACA0012 aerofoil using the adjoint based sequential data assimilation (DA) approach; 2) a data assimilation (DA) strategy based on weak-constraint four-dimensional variation to conduct an STR reconstruction in a turbulent jet beyond the Nyquist limit from given low-sampling-rate observations. 3) a compressible continuous adjoint data assimilation (C2ADA) approach for reproducing a complete mean flow from sparse wall pressure observations.

BIOGRAPHY

Professor Yingzheng Liu received Ph.D. from Shanghai Jiao Tong University in the year 2000. He is currently working as distinguished professor and head for the Institute of Turbomachinery, Shanghai Jiao Tong University. His research subjects are mostly related to 1) Turbulent flows, vortex dynamics and flow control; 2) Data assimilation or measurement coupled turbulence modeling; 3) Machine learning in fluid-mechanics; 4) Fluid-structure interaction and flow-acoustics resonance; 5) Development of 4D Tomo-PIV, i-PSP and Phosphor-based measurement techniques (pressure, temperature, heat flux, strain...)

COUPLED FLUID-STRUCTURE-ELECTRIC MODELING OF A PIEZOHYDROELASTIC FLAG FOR ENERGY HARVESTING

Hui Tang
Department of Mechanical Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong

ABSTRACT

We develop a high-fidelity multi-physics model and, by using it, study the energy conversion process of a piezohydroelastic flag. Instead of a regular flag with a clamped upstream leading edge, we use an inverted flag to make the best of fluid elastic instability for energy harvesting. Moreover, different from many previous studies where a resistor–capacitor (RC) circuit is usually used, we adopt a resistor–inductor–capacitor (RLC) circuit for electricity generation. The influences of several key parameters associated with fluid, structure and electric dynamics are studied. Significantly different response modes are identified, among which the symmetric- and asymmetric-flutter modes are most suitable for sustainable energy harvesting, both emerging with moderate bending stiffness. If only deploying the RC circuit, increasing the resistance makes the flag more stable. By adding an inductor to turn the RC circuit into an RLC one, we observe the occurrence of 'lock-in' between the flag frequency and the circuit frequency. This phenomenon can significantly enhance the energy output, but it only happens when the circuit resistance is sufficiently large. From a derivation based on dynamic mode decomposition analysis, we further identify an optimal condition for maximizing the energy output, which can serve as a guideline to determine whether deploying an inductor can boost the performance, and, if yes, the required inductance. The findings from this study can better guide the design of flow-induced-vibration-based piezoelectric energy harvesters for microelectronic devices.

BIOGRAPHY

Dr. Hui Tang is Associate Professor, Director of Consortium for Multiphysics Fluid Dynamics, and Associate Head (Research) of Department of Mechanical Engineering, The Hong Kong Polytechnic University. He specializes in various areas of fluid mechanics, including aero/hydrodynamics, active flow control, fluid-structure interaction, and heat and mass transfer, with both fundamental investigations and real-world applications. He has published 100+ papers in top-tier journals and has been ranked among the world's top 2% most-cited scientists since 2023. He is now an executive committee member of Hong Kong Society of Theoretical and Applied Mechanics and is serving in editorial board for several journals including Actuators, Fluid and Structure, and Frontiers in Bioengineering and Biotechnology.

EXPERIMENTAL INVESTIGATION ON RISING BUBBLES WITH/WITHOUT LIQUID CROSSFLOW

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ABSTRACT

Bubble flow has attracted significant attention from both industry and academia. It can be generated by injecting air into a liquid and has various practical applications, such as in mass transfer enhancement, underwater environment changing, etc. In this talk, we will present some experimental studies on rising bubbles both with and without liquid crossflow. In the experiments without crossflow, we used both planar PIV and Tomographic PIV to quantitatively acquire the bubble morphology and induced flow fields. Both the effects of gas flow rate (GFR) and orifice spacing on rising bubbles have been investigated and discussed, with special attention paid on the mechanisms of path instability of rising bubble. It was found that the bubble-induced wake shedding plays a key role in triggering the path instability. In addition, the bubble deflection direction caused by the path instability is closely related to the sequence of wake vortices shedding: bubbles turn left with a clockwise vortex shedding first and right with a counterclockwise one. In experiments with crossflow, we examined how crossflow velocity and GFR influence the bubble formation and rising behavior. An increase in GFR results in a larger bubble diameter and faster rising speed. Conversely, an increase in crossflow velocity causes bubbles to detach earlier from the orifice, leading to a reduced bubble diameter and slower rising speed. A theoretical model based on dynamic force equilibrium had been developed to explain these experimental observation. It is believed that our findings could provide some foundational references for modeling two-phase flows and also provide some guidance for the practical application of bubbles.

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BIOGRAPHY

Prof. Xu Yang received his B.S. in Engineering Mechanics from Beihang University in 2011, and his Ph.D. in Fluid Mechanics from Beihang University in 2017. From 2015 to 2016, he conducted the joint PhD project in George Washington University, and worked as a visiting scholar in Pusan National University in 2018. Since 2024, he was promoted as the full professor in Beihang University.

His research interests included technique developments for experimental fluid mechanics, bubble & bubbly flow, vortex dynamics, heat transfer using impinging jets. He won the National Postdoctoral Program for Innovative Talents in China in 2017 and the Excellent Youth Project of Natural Science Foundation of China in 2023. In recent 5 years, he has published more 20 journal papers in such as JFM, Exp. Fluids, etc. He servers as deputy secretary general of Beijing Mechanics Society and the fellow of visualization committee of Chinese Aerodynamics Society. He is also the editorial board member of FDMP, and youth editor of Aerodynamic Research & Experiment.

MOLECULAR UNDERSTANDING OF IN-SITU LUBRICANT INFUSED SURFACE FORMATION BY ADDING AROMA MOLECULES IN THE VAPOR PHASE

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ABSTRACT

Thin lubricant film adhering to the solid-vapor interface of Lubricant Infused Surfaces (LIS) reduces the sliding drag be- tween water droplets and surface and facilitates faster water drainage. Accordingly, LIS is extensively used in domains of self-cleaning surfaces, biomedical devices, water harvesting, among others. LIS is conventionally prepared by adding lub- ricant over fabricated hydrophobic-oleophilic surfaces. These fabrication methods are costly, and the lubricant eventually drains out when it is continuously applied. In this study, we discuss a new method of LIS formation over non-coated hy- drophilic surfaces by resupplying the lubricants from the vapor phase. Here, we focus on aroma molecules like linalool and geraniol, which are practically immiscible in water and fully wet over metallic surfaces. Additionally, these oily liquids are volatile surfactants, exhibit anti-corrosion characteristics, and remain unexplored as potential lubricants for LIS. We first present experimental evidence of LIS formation by adding a water droplet over a copper surface wetted by linalool. We then perform molecular dynamics simulations to investigate the possibility of LIS formation using the abovementioned methodology. In our simulations, we supply linalool molecules in the vapor phase near a water droplet over a hydrophilic surface. We observe that linalool molecules first adsorb onto the three-phase contact line and experience an energy barrier. Eventually, these molecules replace the water molecules from the water-solid interface and form a lubricant layer. Subse- quently, the droplet spreads over the new lubricant layer. We believe these molecular-level insights will help plan suitable experiments to realize the in-situ LIS formation in practical applications.

ACKNOWLEDGEMENT

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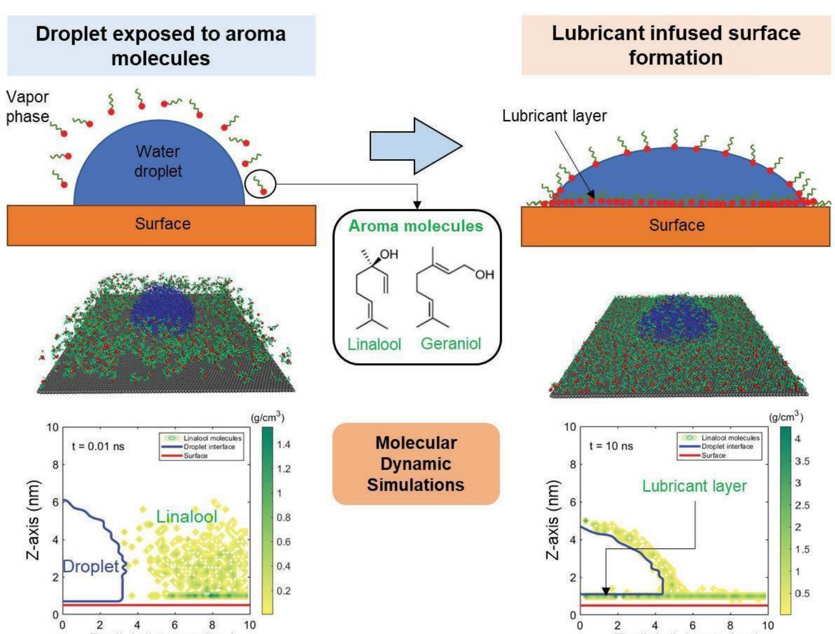
ABSTRACT FIGURE



Thermal Transport Spectroscopy across Interfaces: Algorithm and Applications

Abstract

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When the scale of materials goes down to a tiny scale, i.e., nanometer scale which is a billionth of a meter, the thermal properties of the materials become quite unusual due to the quantum and size effects. As a result, nanotechnologies have often served as tools for design of highly functional engineered materials & structures with potential applications in energy and thermal related areas. In this talk, I will introduce our developed methodology to handle the detailed thermal transport process in nonequilibrium molecular dynamics simulations, propose a strategy based on nonequilibrium molecular dynamics to quantify the scattering process in across interfaces, and its application in quantitatively characterizing thermal transport across interfaces between porous crystals and substrates.

Biography

Dr. Yanguang Zhou received his Ph.D. degree with “Ausgezeichnet” in the Mechanical Engineering Department at RWTH-Aachen University. He worked as a postdoc research associate and an assistant visiting project scientist at the University of California, Los Angeles (UCLA) before joining Hong Kong University of Science and Technology (HKUST) as an assistant professor. Dr. Zhou’s group at HKUST designs advanced materials & structures, i.e., thermoelectric materials, magnetic materials and nanocomposites, via using nanotechnologies (both experimental and theoretical methods), with applications in water harvesting and thermal management. His research has been published in *Nature Communications*, *Advanced Sciences*, *Nano Letters*, *International Journal of Heat and Mass Transfer* and *Physical Review B*. Dr. Zhou is a receipt of AICES Fellowship, Chinese Government Award for Outstanding Self-financed Students Abroad, Borchers-Plakette at RWTH-Aachen University and Hong Kong SciTech Pioneers Award.

Mechanisms of Bubble Nucleation on Hydrophilic-hydrophobic Surfaces: Molecular Dynamics Perspective

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ABSTRACT

Researchers have extensively studied the nucleation mechanism of gas bubbles on pure wetting surfaces. However, the complexity associated with hybrid wetting surfaces warrants further investigation. It has been observed that bubbles tend to nucleate preferentially at the hydrophilic-hydrophobic interface, but this phenomenon is difficult to explain using existing theories. Therefore, the purpose of this paper is to elucidate the mechanism of nucleation on hybrid wetting surfaces. Through molecular dynamics simulations, this study elucidates the microscopic mechanism of bubble formation at the hydrophilic-hydrophobic interface and attributes it to the combined advantages of low nucleation energy and elevated liquid temperature. Additionally, vaporization nucleation at different surface temperatures is also investigated. The research results show that high surface temperatures lead to similar heating rates for liquids on different surfaces, which weakens the advantage of hybrid wetting surfaces. This paper provides valuable reference for researchers studying boiling heat transfer on hybrid surfaces.

ABSTRACT FIGURE

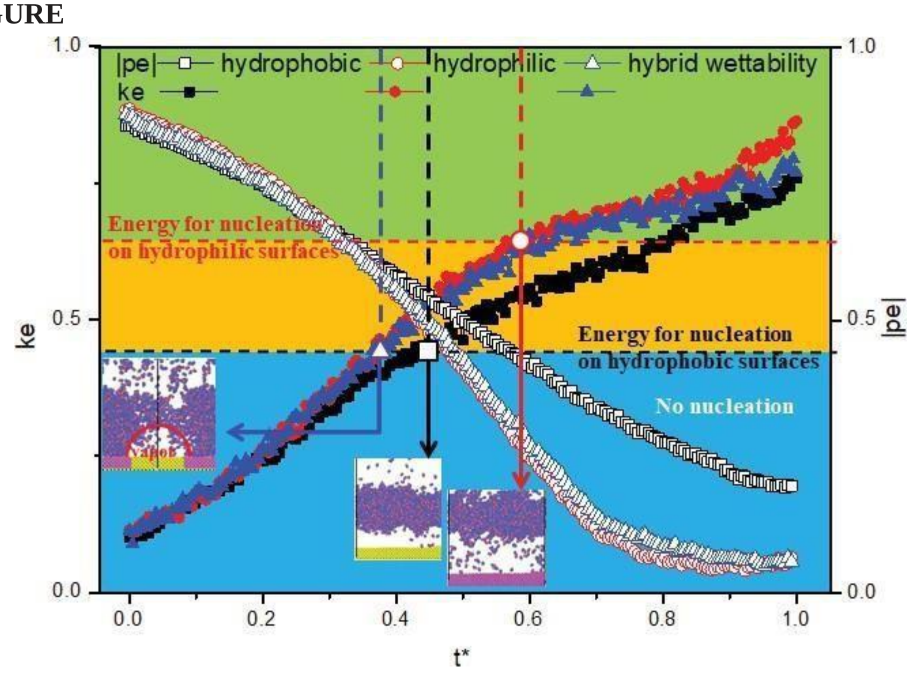

Fig. 1 The temporal variations of the kinetic and potential energies of the liquid film.

4th Conference on Micro Flow and Interfacial Phenomena (μFIP)
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MOLECULAR DYNAMICS SIMULATION OF ION CONCENTRATION POLARIZATION IN MICROFLUIDIC SYSTEMS

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ABSTRACT

In biosensing applications, sample concentrations are often below the limit of detection. Ion Concentration Polarization (ICP) as nonlinear electrokinetic phenomenon offers an efficient approach to increase the target sample concentration within a microfluidic channel. Our research interest is to understand the role of a cation-ion selective Poly(2-Acrylamido-2-Methylpropanesulfonic Acid) (PAMPS) membrane under an electric field during ICP. Molecular dynamics (MD) simulation was used to study its role in the ICP depletion zone formation within a nanochannel. The simulated nanochannel had a dimension of 6 nm (height) x 20 nm (length) x 20 nm (width) at an electric field of 0.5 V/nm. The deriding force field was used for all the components of the system. PAMPS was crosslinked using 800 AMPS molecules and 400 MBAA molecules as crosslinking agent. SPC model was used with water solvation which resulted in 75321 water molecules. 79 Na^+ and 79 Cl^- ions were added to provide 50 mM concentration in an overall electrically neutral system. Our simulation results showed a shift in the density profile of sodium ions, chloride ions, and RNA molecules within the channel after applying a voltage across the channel as shown in Fig. 1. The depletion region was formed inside and around the PAMPS membrane at the bottom of the nanochannel. At the same time, an ion concentration zone was observed next to the depletion zone. In sum, the MD simulation proved the role of the cation-selective membrane for initiating ICP and showed the possibilities to improve the preconcentration of samples.

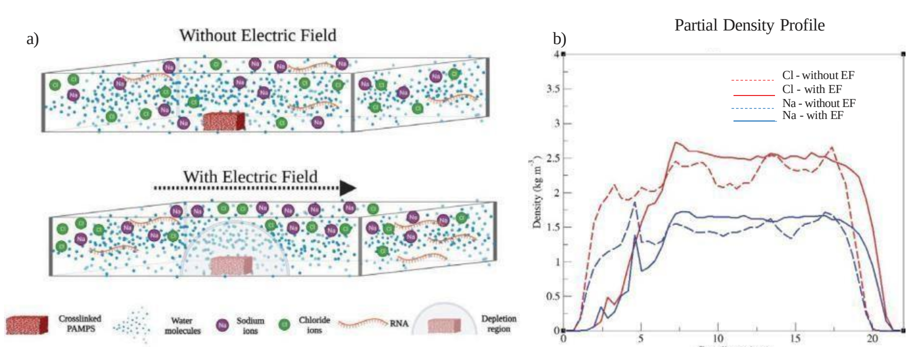
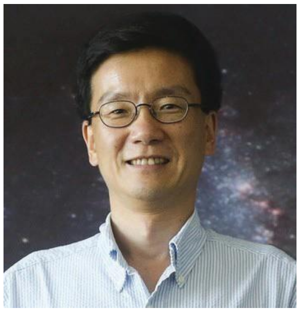


Figure 1: MD simulation results. a) Schematic of the simulation to study the effect of electric field and PAMPS on ICP, b) Partial density profile of the ions before and after applying electric field. GROMACS was used for the MD simulations. Each simulation was performed using 4 nodes, 128 core each.

BIOGRAPHY



Yong-Ak (Rafael) Song received MEng degree in Mechanical Engineering from the RWTH Aachen University of Technology in 1993, and Ph.D. degree from the School of Mechanical Engineering, RWTH Aachen University in 1996. He was a senior research scientist at Korea Institute of Science and Technology (KIST) until 2001. He moved to Boston and worked at MIT until 2012. He is currently an associate professor in the Division of Engineering, New York University in Abu Dhabi (NYUAD) and holds a joint appointment in the Department of Chemical and Biomolecular Engineering, as well as in the Department Biomedical Engineering at New York University. He is also the program head of the Bioengineering Program at NYUAD. His main research interests are on various aspects of micro- and nanoscale bioengineering including biosensors, point-of-care diagnostics, organ/organoid on a chip and biomimetics.

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Machine Learning for Nanoscale Thermal Transport

Tengfei Luo
University of Notre Dame

ABSTRACT

Nanoscale thermal transport features the phenomena of non-diffusive phonon transport as the characteristic lengths of de- vice become comparable to or smaller than phonon mean free path. The phonon Boltzmann transport equation (pBTE) has been proved to be capable of precisely predicting heat conduction in this region. However, numerically solving pBTE is still com- putationally costly due to its high dimensionality. In this study, we use physics-informed neural networks (PINNs) to solve pBTE for multiscale non-equilibrium thermal transport problems both efficiently and accurately. In particular, a PINN frame- work is devised to predict phonon energy distribution by minimizing the residuals of governing equations, boundary conditions, and initial conditions without the need for any labeled training data. With phonon energy distribution predicted by the PINN, temperature and heat flux can be obtained thereby. In addition, geometric parameters, such as characteristic length scale, are also considered as a part of the input to PINN, which makes our model capable of predicting heat distribution in different length scales. Besides pBTE, we have also extended the applicability of the PINN framework for modeling coupled electron-phonon (e-ph) transport. *e-ph* coupling and transport are ubiquitous in modern electronic devices. The coupled electron and phonon Boltzmann transport equations (BTEs) hold great potential for the simulation of thermal transport in metal and semiconductor systems.

BIOGRAPHY

Dr. Tengfei Luo is the Dorini Family Professor and Associate Chair in the Department of Aerospace and Mechanical En- gineering (AME) with a concurrent appointment in the Department of Chemical and Biomolecular Engineering (CBE) at the University of Notre Dame (UND). Before joining UND, he was a postdoctoral associate at the Massachusetts Institute of Technology (2009-2011) after obtaining his PhD from Michigan State University (2009). At UND, Dr. Luo focuses on na- noscale thermal transport, electronics thermal management, novel material design and manufacturing, and water treatment. Since joining UND in 2012, he has won many awards as an independent researcher, such as the DuPont Young Professor Award (2016), the DARPA Young Faculty Award (2015), and the ASME Fellow.

Pore-scale study of multiphase flows and evaporation

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ABSTRACT

Evaporation in porous media is ubiquitously observed in nature, daily life and engineering fields, such as soil drying, food preservation, seawater desalination, etc. It is a multi-physical process coupling multi-phase flow, phase change, heat and mass transfer. The complex pore structure at micro-scale makes its investigation more challenging. In this talk, I first present the pore-scale multi-physical modeling framework that we have been working on, which is constructed by coupling lattice Boltzmann method, pore network model and discrete element method. It is capable of modeling isothermal liquid-gas interfacial flows, liquid-gas-particle three-phase flow, non-isothermal drying of liquid and colloidal suspension in porous media, etc. Afterwards, I present the pore-scale study of liquid evaporation in porous media. We found that, the competition/collaboration between capillary flow and local evaporation is responsible for various drying patterns. Air convections is found to significantly increase drying rate, while the contact angle hysteresis influences the interfacial receding/advancing and leads to slow drying. Inspired by capillary drying, we designed a self-driven multiplex reaction device, which significantly promotes the efficiency of chemical degradation. Finally, I present the study of colloid drying in porous media. We proposed the control method to achieve directional transport and quantitative deposition of nanoparticles, by designing the pore size/distribution and surface wettability, respectively. For application, we designed a micropore structure located between different layers of 3D chip stacks, and found it could increase the heat release around threefold.

BIOGRAPHY

Feifei Qin, Associate Professor of Northwestern Polytechnical University (NPU). Dr. Qin obtained his PhD degree from ETH Zurich in 2020, and worked as a post-doctor in ETH Zurich until 2022. Dr. Qin's research focuses on multiphase flows, flow in porous media, phase change, heat and mass transfer. He has published over 30 SCI journal articles, including 18 published as first/corresponding author (4 JFM papers including 1 ESI highly-cited paper). He has been selected into the Sanqin Tanlent Introduction Program of Shaanxi Province, and selected as Aoxiang Overseas Scholar of NPU. He is now hosting the NSFC-Youth Project, and serving as the editorial board member of Journal of Hydrodynamics.

Direct numerical simulation of liquid ammonia near-wall inhomogeneous nucleation phenomenon in thetransitional atomisation regime

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ABSTRACT

As a promising carbon-free fuel, ammonia has attracted attentions to replace fossil fuels in gas turbines. However, liquid ammonia has a relatively high saturation pressure, which features it completely different atomisation characteristics, e.g., flash boiling. Compared to the non-flashing sprays, the flash boiling generates fine droplets and introduces significant mass transfer. The heat transfer during phase change is also important as ammonia has a large latent heat of evaporation. To investigate the dynamics of the spray flashing in the transitional regime, we perform direct numerical simulation of a slot nozzle and quantify the two-way coupling between boundary layer formation and bubble growth/collapse. The coupled level set and volume-of-fluid method is adopted to shed light on the role of the wall roughness. Evolution of the turbulence flows, bubbles, heat and mass transfers were investigated. It was found that the emergence of roughness structures introduces pressure fluctuation in the boundary layer. The pressure fluctuation downstream the roughness structure is a key to the inhomogeneous near wall nucleation, which is sensitive to the flow rates due to the relative values of the inertial force and the viscous force. A large pressure loss triggers the homogeneous nucleation and the flashing inception, which dramatically increases the volume of ammonia vapor in the nozzle, further enlarges the pressure loss, and eventually leads to the transition. The competition and the interaction between inhomogeneous near wall nucleation and homogeneous nucleation is regarded as the underlying mechanism of the transition from aerodynamic atomisation to the thermodynamic atomization.

Key words: flashing; transitional atomisation; ammonia; direct numerical simulation; volume of fluid.

Multiscale Modelling of Non-Equilibrium Transport Phenomena

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ABSTRACT

By simultaneously considering models at different scales, multiscale modelling offers an approach to describing mass and heat transport problems in which the multiscale character is the dominant issue, and the traditional physical laws lose their validity. For instance, gas flows in porous media and heat dissipation in semiconductor materials at nano-/micro-scales. In this talk, I will introduce my works on the multiscale modelling of non-equilibrium gas and phonon transport, which are based on a hybrid of macroscopic equations, which resolve flows in terms of macroscopic quantities, and Boltzmann kinetic equations that describe the variation of the distribution functions of the mass or energy carriers. Combined with advanced numerical techniques, the developed schemes can accurately and efficiently simulate multiscale transport phenomena involved in complex engineering geometries.

BIOGRAPHY

Dr Wei Su is an Assistant Professor in the Division of Emerging Interdisciplinary Areas and the Department of Mathematics at the Hong Kong University of Science and Technology. Her research interests include multiscale computation, physics of transport phenomena, high-order discontinuous Galerkin finite element methods, and practical engineering-design simulation.

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Wall Roughness effects on compressible turbulent boundary layers

Zhenxun Gao
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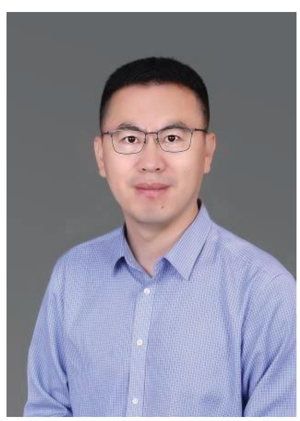
ABSTRACT

Compressible turbulent boundary layers over zero-pressure gradient flat plate with three-dimensional sinusoidal roughness are simulated by direct numerical simulation (DNS). The roughness effects on surface drag, velocity transformation, and turbulence fluctuation characteristics are analyzed in a wide range of Mach numbers (Ma_∞=2.25–7.25) and different ratios of wall-to-recovery temperature (T_w/T_{aw}=0.43 and 0.84) conditions. It is found that the roughness causes a significant increase in surface drag coefficient, which is attributed to the extra pressure drag induced by roughness, and the relative increment increases by 31.1% when the Ma_∞ changes from 2.25 to 7.25. The logarithmic region of velocity profiles obtained by current compressible velocity transformations cannot be independent of T_w/T_{aw} condition for rough cases. This is attributed to the fact that these transformations fail to account for the wall heat transfer effect in the region below the roughness peak. Hence, a new velocity transformation (denoted as $U_{\rho t}^{+}$) is proposed in present study by considering the variation of density due to the wall heat transfer effect in the region below the roughness peak to make the logarithmic regions of $U_{\rho t}^{+}$ profiles collapse under different Ma_∞ and T_w/T_{aw} conditions. The newly proposed velocity transformation enables the downward shift of velocity profiles in logarithmic region ($\Delta U_{\rho t}^{+}$) to be solely determined by the roughness height. Further numerical experiments validate that, in the hypersonic boundary layers, the relation between $\Delta U_{\rho t}^{+}$ and the equivalent sand-grain roughness height Reynolds number (k_s^{+}) still satisfies the roughness function proposed in previous studies for incompressible flows.

BIOGRAPHY

Zhenxun Gao is a professor in School of Aeronautic Science and Engineering of Beihang University in China. He obtained his Bachelor and PhD degrees in fluid dynamics from Beihang University in 2005 and 2011, respectively. Now his research interests are mainly in the area of CFD, tuebulence/transition modeling, turbulent combustion. He has published more than 50 SCI papers as the first or corresponding author in many journals including Journal of Fluid Mechanics, Journal of Computational Physics, Physics of Fluids, AIAA Journal, Combustion and Flame.



DEEP LEARNING POTENTIAL FOR MAGNETIC MATERIALS

Ben Xu
Graduate School of China Academy of Engineering Physics

ABSTRACT

Atomistic simulations hold significant value in clarifying crucial phenomena such as phase transitions and energy transport in materials science. Their success stems from the presence of potential energy functions capable of accurately depicting the relationship between system energy and lattice changes. In magnetic materials, two atomic scale degrees of freedom come into play: the lattice and the spin. However, accurately tracing the simultaneous evolution of both lattice and spin in magnetic materials at an atomic scale is a substantial challenge. Addressing this deficit, we present DeltaSPIN, and DeepSPIN, a versatile framework that generates high-precision training data of energy, atomic forces, magnetic torque and therefore the high-accuracy predictive models for them in magnetic systems. This is achieved by integrating our in-house first-principles calculations of magnetic excited states with deep learning techniques via "pseudo atom" descriptor and active learning. We also demonstrate that this model also has advantage in achieving the cooperative ground states including both spin and lattice. Our technique adeptly connects first-principles computations and atomic-scale simulations of magnetic materials. This synergy presents opportunities to utilize these calculations in devising and tackling theoretical and practical obstacles concerning magnetic materials.

BIOGRAPHY

Ben Xu, associate Professor, he received his B.S. degree from Central South University and Master degree from Tsinghua University, and Ph.D. degree from University of Antwerp, Belgium. After, he did postdoc at CNRS France and worked as an assistant professor at the School of Materials, Tsinghua University till 2021. He is mainly engaged in the cutting-edge research of computational materials science algorithms and applications, and is committed to the development of multi-scale computational methods.