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Nature-Inspired Surface Engineering

NISE 2026

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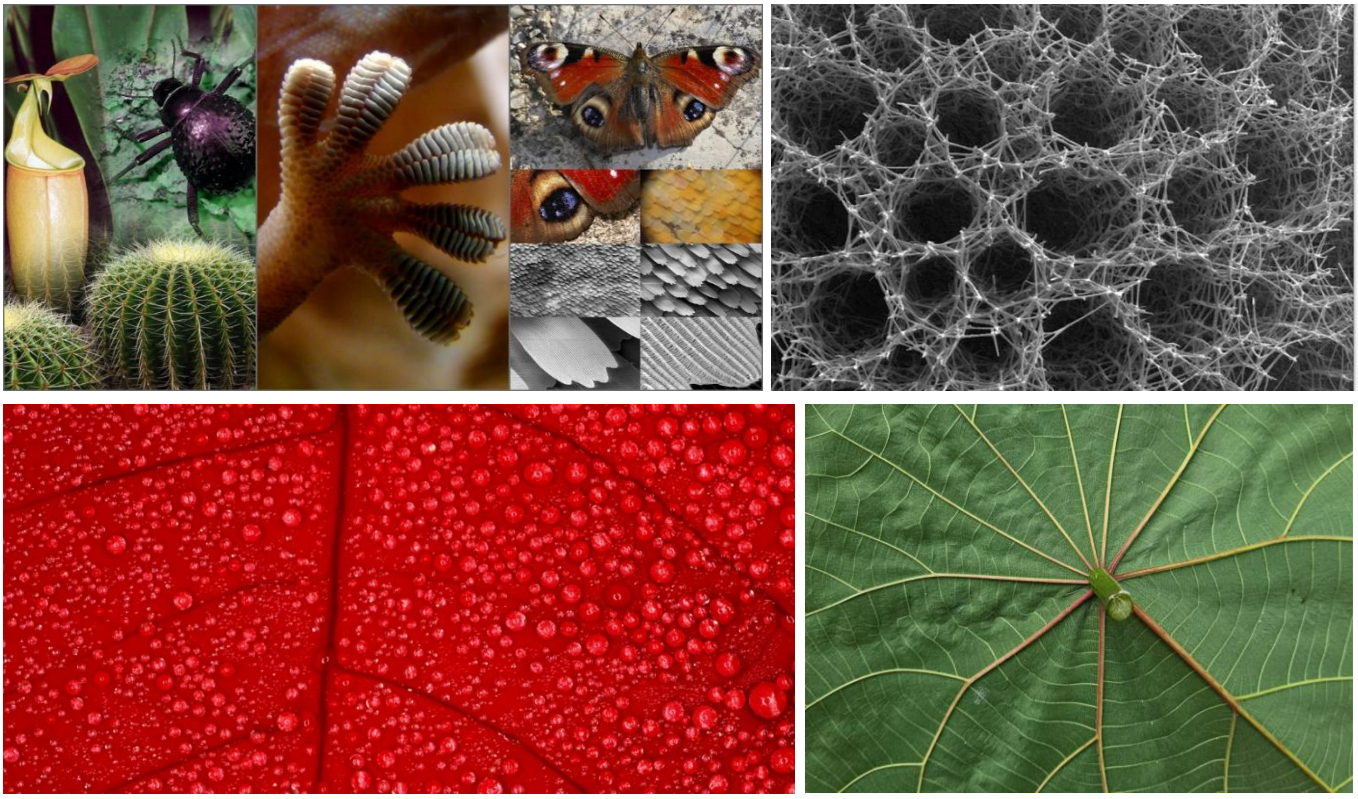

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Oral Presentations - Day 1

KEYNOTE

The physics of droplet freezing on nanoarchitected surfaces

Dimos Poulikakos

Professor em. Laboratory of Thermodynamics in Emerging Technologies,
Mechanical and Process Engineering Department
ETH Zurich, Zurich, Switzerland
dpoulikakos@ethz.ch, www.ltnt.ethz.ch

Keywords: Surface architecting, physics driven, anti-icing, anti-frosting, recalescence

In this lecture I will focus on the fundamental physics of droplet freezing on surfaces and the physics-driven nanoarchitecting of such surfaces, to intrinsically combat icing. I will discuss the phenomenon of recalescent freezing of sessile droplets, leading to simultaneous emergence of evaporation, condensation and freezing in the droplet region, directly affecting the ability of the surface to resist or propagate icing. To this end, I will discuss the local thermodynamic conditions generated in the droplet neighbourhood, and the ensuing local pressure differences, that can drastically accelerate icing through surprising phenomena, such as various manifestations of ice bridging, or the development of freezing cascades, affecting large groups of droplets. I will then present fascinating physical phenomena manifesting themselves during the freezing of supercooled droplets on superhydrophobic surfaces at low environmental pressures. I will define the surface characteristics necessary to induce spontaneous (intrinsic), ice expulsion behaviour, a phenomenon driven by the explosive latent heat release upon freezing. Concurrently, I will identify distinct mechanisms through which the surface ice repellence ability fails. Further, I will provide experimental evidence, a theoretical model and effective surface design solutions to rationalize and mitigate against these failure mechanisms.

Biomimetic Hydration-Stabilized Polymer Brush Interfaces for Ultra-Low Ice Adhesion

Guojun Liu

The State Key Laboratory for Bio-Inspired Interfacial Materials Research, *Suzhou Institute for Advanced Research, University of Science and Technology of China, Suzhou 215123, China*

Keywords: Polymer Brush, Freezing Point Depression, Ice Adhesion Reduction

In biological systems, ice adhesion is often suppressed not by intrinsic ice repellency but by stabilization of confined hydration layers that remain liquid under sub-zero conditions. Inspired by this strategy, we investigate hygroscopic polymer brush monolayers that stabilize nanoconfined, non-freezing water to create biomimetic anti-icing interfaces. Surface-grafted polymer brushes were prepared on glass substrates via surface-initiated atom transfer radical polymerization, producing hydration-rich layers that mechanically decouple ice from the underlying solid through strong polymer–water interactions and osmotic stabilization.

By introducing a novel initiator system that independently controls initiator density and polymer grafting density,[1] we systematically varied monolayer thickness, chain length, and grafting density and developed an innovative method to quantify the swollen layer thickness. An optimal hygroscopic monolayer formulation was identified that reduces ice adhesion strength by 33 ± 4 times at –20 °C, representing unprecedented performance for hygroscopic polymer monolayers.

To rationalize these observations,[2] ice adhesion was modeled using a Couette-type shear framework in which the apparent viscosity and thickness of the swollen layer are governed by the polymer volume fraction. A key postulate is that the monolayer partially dehydrates upon subzero cooling to maintain equilibrium with bulk ice, consistent with classical freezing-point depression thermodynamics. Coupling polymer solution theory with mean-field thermodynamics reveals how grafting density, chain length, polymer–water interactions, and monomer size collectively dictate ice adhesion. Together, the experimental and theoretical results establish a biomimetic, hydration-mediated design principle for high-performance ice-shedding interfaces.

References

[1] Lai, Z. R.; Wang, J.; Benmeddour, A.; Song, N. H.; Liu, G. J. Hygroscopic Polymer Monolayers with Ultralow Ice Adhesion Strength: Investigating Factors Influencing Ice Shedding Performance. *ACS Appl. Mater. Interfaces* **2025**, *17*, 30044

[2] Ji, J.J.; Liu, G.J. Theoretical Investigation of Factors Governing the Ice-Shedding Performance of Hygroscopic Polymer Monolayers *ACS Appl. Mater. Interfaces* **2026**, *18*, 70039.

Invited: Novel Ice-Shedding Surfaces

Anish TUTEJA
Department of Materials Science and Engineering,
University of Michigan, USA.

Keywords: Ice-shedding, Icephobic, Surface Texture

Ice accretion has a negative impact on critical infrastructure, as well as a range of commercial and residential activities. Icephobic surfaces are defined by an ice adhesion strength $\tau_{ice} < 100$ kPa. However, the passive removal of ice requires much lower values of τ_{ice}, such as on airplane wings or power lines ($\tau_{ice} < 20$ kPa). Such low τ_{ice} values are rarely reported, and robust coatings that maintain them have not been reported previously. In the first part of the talk, I will discuss how, irrespective of material chemistry, by tailoring the crosslink density of different elastomeric coatings and by enabling interfacial slippage, it is possible to systematically design coatings with extremely low ice-adhesion ($\tau_{ice} < 0.2$ kPa). By utilizing these mechanisms, we fabricate extremely durable coatings that maintain $\tau_{ice} < 10$ kPa after severe mechanical abrasion, acid/base exposure, 100 icing/de-icing cycles, thermal cycling, accelerated corrosion, and exposure to Michigan wintery conditions over several months.

In the second portion of the talk, I will discuss how the force required to remove ice from a surface is typically assumed to scale with the area of the ice. This imparts a scalability limit to the use of icephobic coatings for structures with large surface areas, such as power lines or ship hulls. I will then describe a class of materials that exhibit a low interfacial toughness with ice, resulting in systems for which the forces required to remove large areas of ice (a few cm^2 or greater) are both low and independent of the iced area. Coatings made of such materials allow ice to be shed readily from large areas (~1 m^2) solely by self-weight. Finally, I will discuss our efforts to develop standardized, high-throughput, quantitative, and reproducible assays for ice nucleation, propagation, and adhesion.

Antibiofilm Efficacy of Bio-inspired Slippery Surfaces in Dynamic and Static Culture Conditions

Jinju CHEN *,[1] Yufeng ZHU[1,2], Glen McHALE [3], Hernán BARRIO-ZHANG,[3] Rui HAN[1], Gary WELLS,[3] Rodrigo LEDESMA-AGUILAR,[3] Jack Dawson[1], Hongzhong LIU[4], Waldemar VOLLMER[5,6], Nicholas JAKUBOVICS[5]

[1]Loughborough University, Loughborough, UK; [1]Shanghai JiaoTong University, China
[3]The University of Edinburgh, Edinburgh, UK; [4]Xi'an JiaoTong University, China; [5]Newcastle University, UK; [6]The University of Queensland, Australia

Keywords: Contact angle hysteresis, liquid-like surfaces, antibiofilm

Microbial biofilms cost the global economy over $5 trillion annually. [1]. This study explores the antibiofilm potential of slippery covalently attached liquid-like surfaces, revealing their remarkable ability to inhibit biofilm formation over extended periods, regardless of their hydrophobic or hydrophilic nature. We engineered permanently bound liquid-like solid surfaces with exceptional slipperiness, defined by ultralow contact angle hysteresis, and assessed their effectiveness against two nosocomial pathogens, *P.aeruginosa* and *S. epidermidis*. These surfaces achieved a 3–5 log reduction in biofilm formation compared to polydimethylsiloxane (PDMS) under both static and dynamic culture conditions over 14 days [2]. Notably, both hydrophobic and hydrophilic variants outperformed traditional silver-based coatings and emerging liquid-infused surfaces in long-term dynamic trials [2]. We demonstrate that ultralow liquid–solid friction is a critical predictor of sustained performance, even in challenging environments like artificial urine [3]. This work establishes the design principles for next-generation antifouling coatings.

Acknowledgment: UK EPSRC (Grant Nos. EP/V049348/1, EP/V049615/1, and EP/V049615/2) and UK BBSRC (BB/R012415/1–04POC21-309) via NBIC.

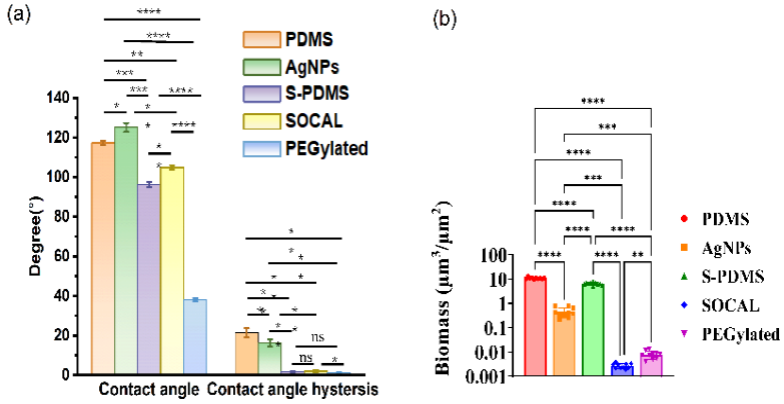

Fig. 1. Slippery liquid-like surfaces resist *P. aeruginosa* colonization. (a) Wetting characterization of different surfaces. (b) Biofilm biomass reduction after 14 days of dynamic culture, correlates low liquid–solid friction with sustained antibiofilm resistance.

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Invited: Bioinspired Multiscale Pore/Channel Systems

Xu HOU*,[1,2,3]
[1]*State Key Laboratory of Physical Chemistry of Solid Surfaces, Xiamen University, Xiamen, China;*
[2]*College of Chemistry and Chemical Engineering, Xiamen University, Xiamen, China;*
[3]*College of Physical Science and Technology, Xiamen University, Xiamen, China*

Keywords: Liquid Gating Technology, Bioinspired Nanofluidic Iontronics

"Pore" and "Channel" are everywhere, e.g., from small biological ion channels to large oil pipelines. Both “Pore” and “Channel” have a wide range of significant applications on different scales. For nanoscale 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. For microscale systems, another example 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.

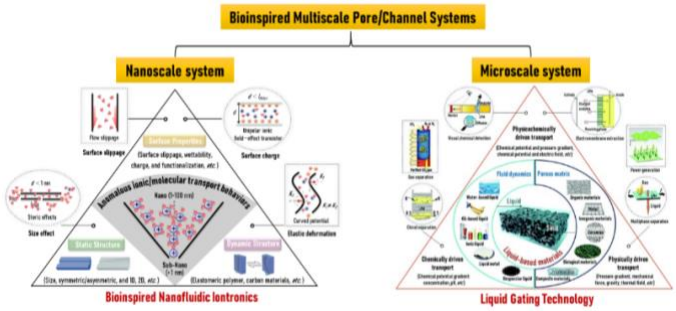

Fig. 1: Bioinspired multiscale pore/channel systems

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Controlled attachment of responsive nano-assemblies induces functionality on hybrid membrane surfaces

Cornelia G. PALIVAN*[1]

[1]*Chemistry Department, University of Basel, Mattenstr. 22 BPR1096, Basel, Switzerland;*
[2]*Swiss Nanoscience Institute, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland*

Keywords: active surfaces, soft polymer membranes, micro-domains, peptide nanoparticles, biomimicry

Abstract: The intrinsic patch-based architecture of cell membranes is central to how biological surfaces regulate transport, maintain barrier function, and orchestrate dynamic responses to environmental cues. Reproducing such spatially organized functionality in synthetic materials remains a major challenge in active surface engineering. Active surfaces, capable of adapting their chemical, mechanical, or structural properties in response to environmental stimuli, offer a promising route toward biomimetic behavior.

Here, we introduce active surfaces with stimuli-responsive functionality by self-patterning hybrid membranes that enable spatially selective immobilization of thermoresponsive peptide nanoparticles with an inner architecture as multicompartment micelles (MCMs), resulting in programmable interfaces with desired functionality. We selected triblock copolymers with dissimilar properties because the immiscibility between blocks or between different copolymers is driving the formation of segregated regions with sharp boundaries as nano and micron-scale domains [1]. The segregated domains of the hybrid membranes exhibit contrasting topography and properties in addition to specifically exposing chemical groups that serve for the covalent attachment of the MCMs. Loading of cargos in MCMs does not affect their inner architecture, which remains stable upon immobilization on the chemically complementary domains of the hybrid membranes. Only upon heating to 37 °C, the attached MCMs undergo disassembly and release their cargo, inducing temperature-triggered functionality of the active soft surfaces [2]. The advantages of such hybrid planar membranes are the spatial cargo localization and release at micrometer scale together with the time precision of the resulting functionality, both essential for rapid response of functional surfaces. This strategy provides a versatile route to engineering active surfaces without lithography or templating, and thus represents a significant conceptual advance in the design of adaptive, bioinspired active surfaces for applications as controlled and localized delivery systems or biosensing platforms

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Invited: Biomimetic Reconstruction of Plant Cell Wall–Inspired All-Lignocellulosic Composite Membranes via Sustainable Protonic Ionic Liquid Processing

Long Zhang, Lifeng Yan*
State Key Laboratory of Precision and Intelligent Chemistry, School of Chemistry and Material Science, University of Science and Technology of China, Hefei, Jinzhai Road 96, 230026, Anhui, China;

Keywords: biomass, biomimetic, film.

Renewable lignocellulosic biomass represents Nature's most abundant hierarchical structural material, where cellulose microfibrils, hemicellulose, and lignin are intricately organized to form plant secondary cell walls with exceptional mechanical robustness, environmental stability, and multifunctionality. However, the natural growth-confined geometry of lignocellulose severely restricts its direct deployment in advanced membrane technologies.

Here, inspired by the hierarchical reconstruction principle of plant cell walls and wood secondary wall architectures, we report a sustainable disassembly-reassembly strategy to fabricate artificial plant-cell-wall-like composite membranes entirely from native lignocellulosic biomass. A malonic acid-DBU-based protonic ionic liquid was employed as a green and efficient biomass deconstruction medium, enabling the complete dissolution of a wide spectrum of natural biomass feedstocks with a high dissolution capacity of 10.2 wt%. Systematic correlation between lignocellulosic composition and dissolution behavior was established through comparative analysis of eleven representative biomass sources, revealing fundamental structure-solubility relationships critical for biomass reconstruction engineering.

Subsequent biomimetic regeneration via coagulation-induced self-organization and hot-press-directed densification enabled the re-assembly of cellulose, hemicellulose, and lignin into plant-cell-wall-inspired laminated composite membranes. Benefitting from the nacre-like polysaccharide-lignin structural synergy and the UV-screening function of aromatic lignin, the resulting all-biomass membranes exhibit a unique combination of high tensile strength (107 MPa), excellent ultraviolet shielding (up to 99% rejection), robust water stability, satisfactory thermal resistance, and intrinsic biodegradability.

Notably, this biomimetic reconstruction strategy preserves the native multifunctionality of lignocellulose while overcoming the geometric limitations imposed by natural growth, offering a scalable route toward artificial wood-like membranes for sustainable separation, protection, and structural applications.

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Invited: Biomimetic Catechol Binders as Interfacial Anchors in Batteries

Dong Woog LEE*,[1]

[1]*School of Energy and Chemical Engineering, Ulsan National Institute of Science and Technology (UNIST), Ulsan, Republic of Korea*

Keywords : Catechol-functionalized binder; Interfacial engineering; Bio-inspired adhesion

Polymeric binders play a critical yet often underestimated role in determining the structural and electrochemical stability of battery electrodes, particularly under harsh operating conditions involving large volume changes or aqueous environments. Here, we present a unified study on catechol-functionalized polymer binders as a versatile interfacial engineering strategy for advanced battery systems. Inspired by mussel adhesion chemistry, catechol moieties enable strong and multifunctional interactions with diverse electrode components, including active materials, conductive additives, catalysts, and current collectors.

In silicon-based lithium-ion battery anodes, catechol-containing binders form robust chemical anchoring through hydrogen bonding and metal coordination, effectively suppressing particle migration and mechanical degradation induced by repeated lithiation and delithiation. Operando and in situ analyses across nano- to microscale regimes reveal significantly mitigated structural evolution, leading to markedly improved cycling stability and rate capability [1]. Beyond non-aqueous systems, the same catechol chemistry is shown to be highly effective in aqueous sodium–air batteries, where strong underwater adhesion is essential to stabilize the catalyst–current collector interface. Quantitative adhesion measurements combined with theoretical calculations demonstrate that catechol groups substantially enhance interfacial energetics, preventing catalyst detachment and maintaining stable triple-phase boundaries during prolonged cycling [2, 3].

Collectively, these results establish catechol-functionalized binders as chemistry-driven, system-agnostic interfacial stabilizers that bridge mechanical integrity, interfacial adhesion, and ionic transport. This work highlights the potential of bio-inspired catechol chemistry as a general design principle for next-generation polymer binders across a broad range of battery chemistries.

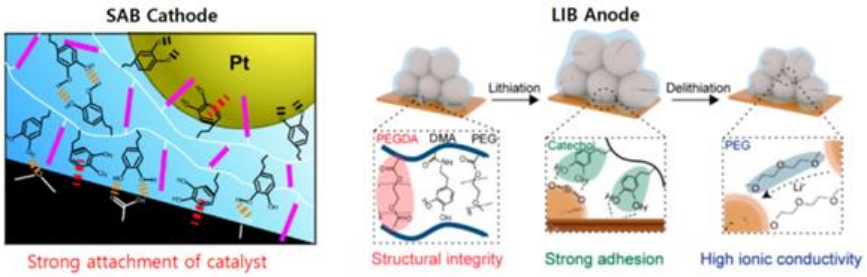

Fig. 1: Multifunctional catecholic binder for batteries.

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Bioinspired cascade photocatalysis for upclying plastics into vinegar under sunlight

Yimin A. WU,[1*] Wei WEI,[1]
)

1Waterloo Institute for Nanotechnology, University of Waterloo, Waterloo, Canada;
[*]yimin.wu@uwaterloo.ca

Keywords: Bioinspired, plastics upcycling, photocatalysis, microplastics, vinegar

Microplastic waste imposes a critical threat to the environment ecosystems, and human health. Inspired by phanerochaete chrysosporium microbal, we developed a bifunctional cascade photocatalyst for both Fenton-like and CO_2 reduction reactions. We can convert common plastics, like PP, PET, PE, PP, plastic bottles, into acetic acid (vinegar) under the natural sunlight without CO_2 emissions. The photon transport and utilization enhances the yield of the process.

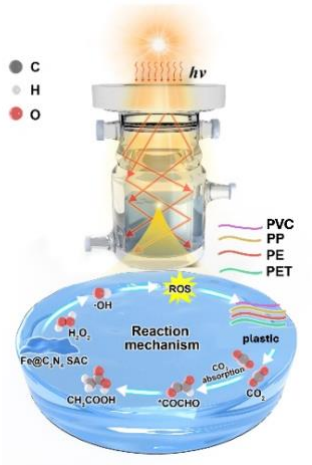

Fig. 1: Fungi inspired cascade photocatalysis

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Invited: Making and measuring the most slippery water-repellent surfaces

Robin RAS

Aalto University, Espoo, Finland

Keywords: Contact angle hysteresis, surface modifications, wetting characterization

Water-repellent surfaces have the attractive property of staying dry, and find applications in self-cleaning, anti-icing, anti-fogging and much more. These surfaces stay dry because water droplets experience low friction and slide off easily at low tilt angles.[1]
Surface heterogeneity is generally acknowledged as the major cause of contact angle hysteresis and friction of droplets. Here we evaluate this long-standing premise for chemical heterogeneity at the molecular length scale. It is often assumed that achieving low sliding angles on water-repellent surfaces requires hydrophobicity, in other words high water contact angle like for example teflon. We challenge this assumption and demonstrate a hydrophilic alkyltrichlorosilane self-assembled monolayer featuring the unusual combination of low sliding angle and low contact angle. By coating a nanotextured surface with hydrophobic self-assembled monolayer, we obtain extraordinarily low droplet friction.[2]
Finally, because contact angle goniometry has inherent limitations in accuracy [3], we have developed highly sensitive methods to study droplet friction and adhesion.[4,5]

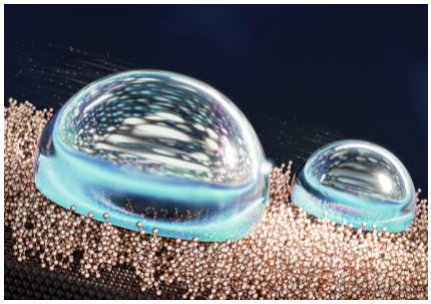

Fig. 1: Cartoon of droplets sliding on a self-assembled monolayer

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Engineering Wettability to Control Gas Dynamics in Electrochemical Energy Devices

Jungki RYU*,[1] Dong Woog LEE *,[1]

[1]*Ulsan National Institute of Science and Technology (UNIST), Ulsan, Republic of Korea*

Keywords: electrochemistry, gas evolution reactions, water electrolysis, gas consuming reactions, CO2RR

Electrochemical systems that involve gaseous reactants or products—such as hydrogen and oxygen evolution, or CO_2 and N_2 reduction—critically rely on how efficiently gases are generated, detached, and transported at solid–liquid interfaces [1]. Beyond catalyst design, the control of interfacial wettability emerges as a decisive factor in governing reaction efficiency, gas crossover, and long-term durability. In this presentation, I will discuss our recent progress on manipulating electrode and cell wettability to achieve efficient and stable water electrolysis. Specifically, we developed a superaerophobic hydrogel coating that universally promotes gas bubble detachment irrespective of electrolyte type or catalyst composition, leading to improved efficiency and stability in both acidic and alkaline electrolyzers [2,3]. Furthermore, I will present strategies for locally tuning hydrophobicity in porous transport layers (PTLs) to enhance mass transport in AEM cells [4], and hydrogel-modified diaphragms that effectively suppress H_2/O_2 crossover in alkaline systems. Together, these approaches demonstrate how rational wettability engineering across electrolyzer interfaces can offer a unified framework for advanced gas management in diverse electrochemical environments.

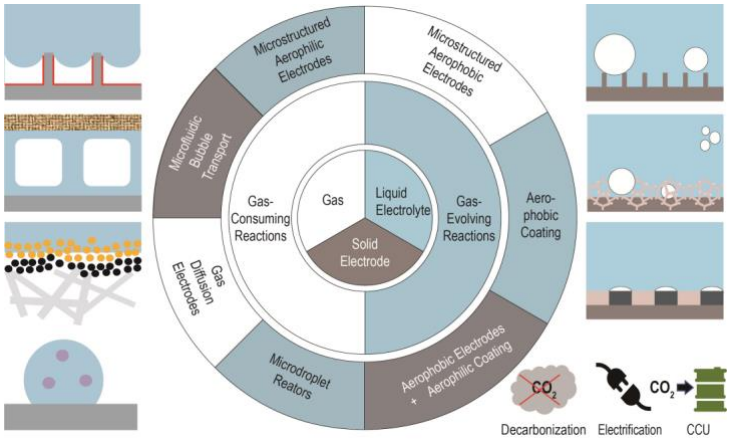

Fig. 1: Schematic illustration of wettability engineering strategies across electrochemical interfaces for gas-evolving and gas-consuming reactions.

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Invited: Optical diffusers inspired by *Morpho* butterfly's optical properties

Akira SAITO*,[1,2] Kazuma YAMASHITA,[1] Takuma HATTORI,[1] Yuji KUWAHARA[1,2]

[1]*Department of Precision Engineering, The Univ. of Osaka, Suita, Osaka, Japan;*
[2]*RIKEN SPring-8 Center, Sayo-gun, Hyogo, Japan*

Keywords: *Morpho* butterfly, optical diffuser, diffraction, disorder, multi-function

Optical diffusers are essential optical devices, which can spread the incident light and create a uniform illumination. This function leads to various applications such as daylight window, liquid crystal display, LEDs, photography lighting, etc. Therefore, optical diffusers are required to have multi-functions such as i) high transmittance, ii) wide-angle diffusion, iii) low color dispersion. However, conventional diffusers can hardly achieve these conditions simultaneously. This is because their principles to diffuse the incident light are based on "multiple scattering" or "refraction", which makes the above properties fall into trade-off relationship. Recently, we have been inspired by the optical properties of *Morpho* butterflies (Fig. 1(a)).
This butterfly's brilliant blue is known as a typical structural color caused by interference, whereas its single color in wide angular range contradicts the interference. This mystery is attributed to specific nanostructures on their wing having both narrow widths to produce the wide spread and disorder to prevent the color dispersion [1] (Fig. 1(b)(c)). To simultaneously satisfy the above-mentioned three conditions, the *Morpho*-principles, i.e. narrow width and nano-disorder are helpful. Also, the diffraction only at an incident interface without multiple scattering can give high transmittance [2] (Fig. 1(d)). Moreover, from viewpoint of fabrication, we designed a feasible nanostructure using 2D-3D conversion principle [2] obtained from our reflection studies [1].
Finally, a novel *Morpho*-type diffuser was successfully fabricated using nanoimprint technique, of which properties were verified [2,3]. Moreover, our diffuser could provide additional functions to control the diffused light-shape and anti-fouling [3].

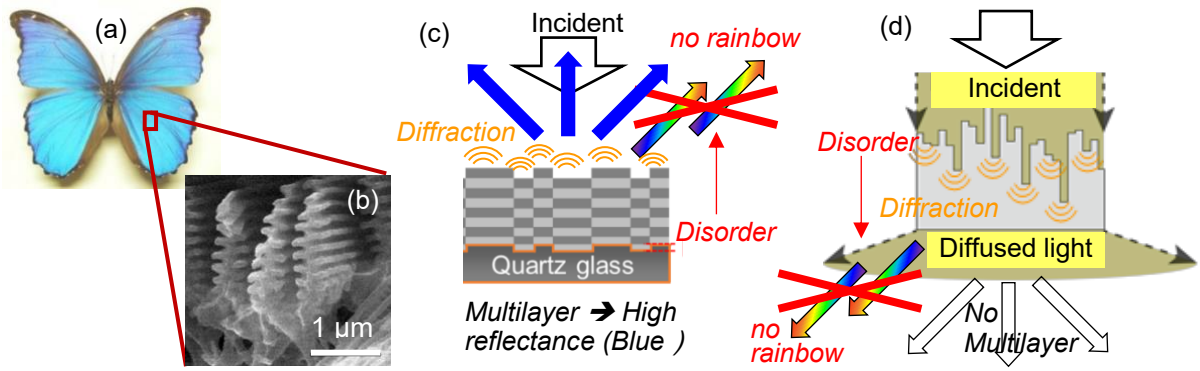

Fig. 1: (a) Photograph of a male *Morpho Didius* (b) cross-sectional SEM image of its wing scale's nanostructure. Schematic of the concept of transfer from reflection (c) to transmission (d) in *Morpho*-models. Common principles between them are diffraction spread, disorder to prevent the multicolor [2].

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Taming Crystallisation for Regenerating Functional Epicuticular Interfaces

Sepideh KHODAPARAST*[1]
[1]*University of Leeds, Leeds, UK*

Keywords: Epicuticular wax, Crystallisation, Interfaces, Structured surface.

Epicuticular waxes form the outermost interfaces of many terrestrial organisms, where they constitute the primary boundary between living tissue and the environment. Although chemically composed of relatively simple long-chain aliphatic compounds, these waxes assemble into diverse micro/nanostructured surface architectures[1] that underpin key functions, including suppression of non-stomatal water loss, protection against environmental stress, modulation of wettability, adhesion, and friction, ultraviolet screening and optical effects such as light scattering and reflectance. This combination of chemical simplicity, structural complexity, and multifunctionality defines epicuticular waxes as a distinctive class of natural functional interfaces.[1,2]

A central yet often under-emphasised feature of epicuticular waxes is that their structural diversity arises predominantly from crystalline or semi-crystalline organisation. Upon emergence at the surface, wax molecules undergo phase change and crystallise under interfacial confinement, producing anisotropic morphologies such as platelets, rods, tubules, and films.[1] These morphologies are emergent outcomes of specific nucleation and growth pathways governed by molecular composition, thermal history, and interfacial boundary conditions. Consequently, crystallisation acts as a unifying mechanism linking wax chemistry to surface structure and interfacial function, including wettability,[2,3] optical response, and ultraviolet attenuation.

In this talk, I will present a crystallisation-driven approach to regenerating functional epicuticular interfaces by deliberately controlling wax phase change at solid-air interfaces.[3] By translating principles of natural epicuticular wax emergence into experimentally accessible model systems, nucleation density, growth anisotropy, and polymorphic selection are tuned through thermal protocols, confinement, and processing history. This strategy enables reproducible formation of micro- and nanostructured wax morphologies that closely resemble those found in natural functional epicuticular systems.

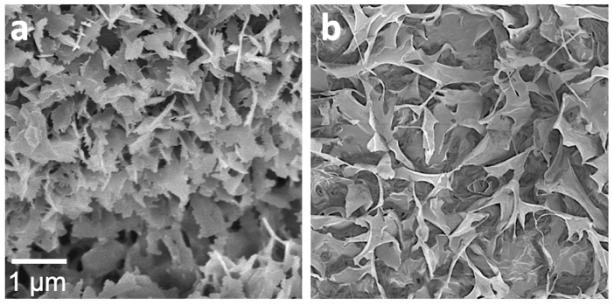

Fig. 1: natural (a) and regenerated (b) interfacial wax structures.

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Bio-inspired Transparent Superhydrophilic Coatings Exhibiting Rapid and Repeatable Self-healing Properties

Kim Hyeonjin and Atsushi Hozumi*

National Institute for Advanced Industrial Science and Technology (AIST)

Sakurazaka, Moriyama-ku, Nagoya 463-8560, Japan
a.hozumi@aist.go.jp

Keywords: Self-healing, (Super)hydrophilicity, Anti-fogging, Underwater superoleophobicity

Superhydrophilic coatings that artificially mimic biological surfaces, such as fish skins and snail shells, have attracted much attention across a wide range of engineering fields. Despite their promise, conventional biomimetic coatings have limited durability because they lack the intrinsic self-healing properties found in living organisms. In this talk, we will introduce an environmentally friendly strategy for fabricating transparent superhydrophilic hydrogel (HG)–based coatings that not only exhibit rapid and multiple self-healing properties under physical damages but also demonstrate a series of multifunctional surface properties. Remarkably, self-healing is autonomously activated by moisture alone. In addition to their self-healing, our coatings displayed excellent anti-fouling performance, underwater superoleophobicity, and durable anti-fogging properties. Our transparent superhydrophilic HG-based coatings [1-3], inspired by the surface multiple functionalities of fish bodies, were prepared based on an integral blend method, which has been widely employed in the industry. A water-based mixture of nanoscale clay particles, polyvinylpyrrolidone, waterborne aminosilane, and metal ions (*e.g.*, aluminum or magnesium) was spin-cast and then heated to form coatings. The resulting coatings were highly transparent. When exposed to hot steam at 80 °C, surface scratches up to approximately 30 μm in width were completely repaired for several times within just 10 sec due to the addition of metal ions. Furthermore, our coatings exhibited durable anti-fogging performance for more than six weeks (ongoing) under high-humidity environments exceeding 80% relative humidity. They also maintained stable underwater superoleophobicity. Overall, this nature-inspired and moisture-responsive approach offers a sustainable pathway toward multifunctional self-healable biomimetic coatings, and holds significant potential for applications in diverse engineering and industrial fields.

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Invited: Water–Hydrophobe Interfaces: From Debunking Myths to Enabling Global Food–Water–Climate Resilience

Himanshu MISHRA*, Adair Gallo, Batool Albar, Bob Vernooij, Kenendy Odokonyero, Ramona Marasco, Muzzamil Eatoo

King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

Keywords: capillarity; superhydrophobicity; desert agriculture; biochar; microdroplet chemistry

First, I will present our work on overcoming the physical constraints that make desert agriculture inherently inefficient. Sandy soils are alkaline and inherently poor at retaining water and nutrients; also, intense heat drives significant evaporative losses. In response, we developed Superhydrophobic Sand (SHS)1, a plastic-free, bio-inspired mulch that suppresses evaporative losses by ~80% when applied as a 1 cm-thick layer. Complementarily, we developed CarboSoil2, an engineered biochar that restructures pore-scale water and nutrient retention in sandy soils, increasing biomass growth and yields by up to 70%. I will trace the path from gram-scale materials synthesis to ton-scale pilot production and multi-year field trials with food crops and native and non-native plants. Terraxy, the company I co-founded, is now scaling CarboSoil production to ~6,000 tons/yr to support large-scale desert rehabilitation initiatives. In the second part, I will draw attention to the controversy surrounding the claims of spontaneously H2O2 formation at the air–water interface of microdroplets without external energy or catalyst or co-solvent3. If correct, this claim would overturn foundational principles of physical chemistry and have ramifications across fields where water plays a central role, including biology, environmental science, atmospheric chemistry, and green synthesis. Through systematic experiments, we have demonstrated that H_2O_2 does not originate from microdroplet geometry or the air–water interface. Instead, it arises from oxygen reduction at solid–water interfaces4. Under oxygen-free conditions, no H2O2 was detected within a 50 nM limit. These findings restore mechanistic consistency and underscore the importance of distinguishing true interfacial phenomena from experimental artifacts.

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Invited: Structural colors from multi-reflection interference in microstructures

Lauren ZARZAR*[1]

[1]*The Pennsylvania State University, University Park, PA 16802, USA*

Keywords: structural color, optical interference, microfabrication, interfaces

Many of the colors found in nature, such as those of iridescent, color-shifting organisms like beetles, butterflies, and birds, are structural colors. Structural coloration is often generated by optical interference occurring within nanoscale periodic structures, like diffraction gratings, photonic crystals, or thin films. In these cases, the periodicity of the structure is similar to the wavelength of the visible light undergoing interference. However, I will describe the interesting observation and mechanism behind how optical interference and iridescent color can be generated by light interacting within much larger, microstructure structures[1-5]. In this mechanism, light reflecting multiple times (such as by total internal reflection or a mirrored surface) and traveling along different paths within a single microstructure[5] can optically interfere. This effect happens in materials as simple as water droplets[1], but it can also be harnessed within far more complex 3D polymeric geometries[2-3] to customize the interference. Ray tracing simulations coupled with color visualization and spectral analysis techniques can be used to model, examine, and rationalize the iridescence generated for a range of micro-geometries, including hemicylinders, hemispheres, truncated hemispheres, and other irregular structures under varying illumination conditions[3]. Microstructure arrays patterned on surfaces with varying orientation and size lead to unique color-traveling optical effects and highlight opportunities for how multibounce reflection interference can be used to create customizable colored appearances. The findings provide a conceptual framework for rationalizing the multibounce interference mechanism and establish approaches for characterizing and tailoring the optical and iridescent properties of microstructured surfaces.

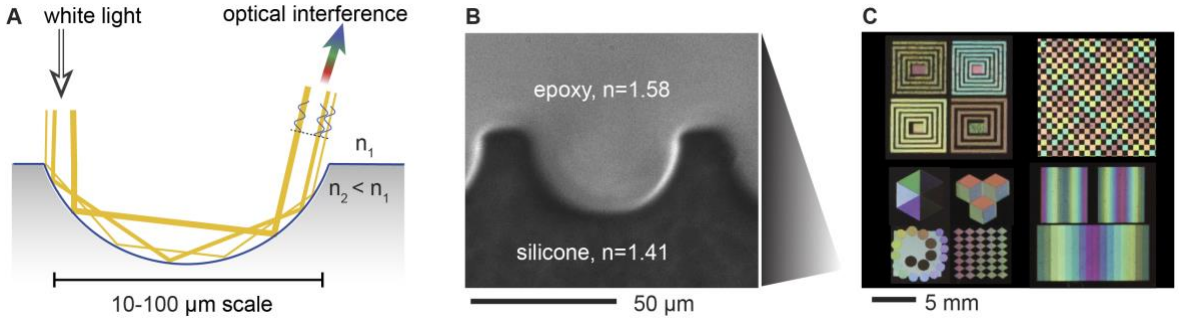

Fig. 1: A, schematic of the multi-reflection optical interference mechanism. **B**, cross-section of a single microstructure from a polymer film exhibiting structural color, with examples shown in **C**.

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Oral Presentations - Day 2

KEYNOTE

From Gecko Feet to Coral Reefs: Bioadhesion Mechanisms as a Design Principle for Soft Matter Engineering

Boxin Zhao

Department of Chemical Engineering, Waterloo Institute for Nanotechnology,
Centre for Bioengineering and Biotechnology, Waterloo Institute for Polymer Research
University of Waterloo, Canada, Email: zhaob@uwaterloo.ca

Keywords: bioadhesion, polymer nanotechnology, soft matter engineering

Natural adhesion systems provide valuable design principles for soft matter engineering, enabling the development of polymers, gels, biomedical devices and functional interfaces with adaptive surface and interfacial properties. Translating these principles into engineered interfaces with smart adhesion, sensing, and actuation capabilities requires a fundamental understanding of bioadhesion mechanisms across the macro, micro, and nano length scales, along with interdisciplinary collaboration to integrate individual components into scalable high-performance technologies. In this talk, I will present our research progress in the science and engineering of bioadhesion and bio-inspired systems, including gecko inspired switchable dry adhesion using structured micro/nano fibrillar surfaces, and our latest exploration of coral mucus adhesion that passively captures microplastics from seawater, with direct implications for marine conservation and environmental remediation. I will also discuss the design of smart polymer based "active" material systems, including a hybrid material that reversibly switches between two stable solid states, asymmetric Janus biogels for human machine interfaces, multi thermoresponsive double network hydrogels for 3D printed medical applications, and a gecko and inchworm inspired untethered soft robot capable of climbing walls and ceilings, illustrating how bio-inspired and smart polymers can lead to adaptive, multifunctional, and more sustainable soft matter systems.

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Static and Kinetic Droplet Friction on Liquid-like Surfaces

Glen McHALE*,[1] Gary WELLS,[1] Rodrigo LEDESMA-AGUILAR,[1] Vasileios KOUTSOS,[1]
Hernán BARRIO-ZHANG,[1] Jinju CHEN,[2] Ahlam ABDALJALIL,[1] Yaofeng WANG[1], Sara JANAHI[1]

[1]*The University of Edinburgh, Edinburgh, UK*
[2]*Loughborough University, Loughborough, UK*

Keywords: Contact angle, liquid-like surfaces, contact-line friction

The Furmidge equation can be rewritten in an Amontons'-like form using a coefficient of friction, which classifies surfaces by the liquid-solid adhesive force and the surface heterogeneity [1,2]. Here we show the experimentally determined Furmidge shape-factor for superhydrophobic, slippery covalently-attached liquid-like, and high contact angle hysteresis surfaces is k=p/4 and the coefficient of static friction is $m_s=k\mathrm{D}q_{fb}/\mathrm{p}$, where $\mathrm{D}q_{fb}$ is the difference in front and back contact angles during the tilting of a substrate through a range of angles, a [3]. We further show that droplets sliding on high (SOCAL) and low (c50-SOCAL) contact line friction liquid-like surfaces have a coefficient of kinetic friction $m_k=k\mathrm{D}q_{fb}/\mathrm{p}$, where $\mathrm{D}q_{fb}$ depends on the speed [4]. We derive a molecular-kinetic theory model that provides an excellent description of the motion.

Acknowledgment. UK EPSRC (Grant Nos. EP/V049348/1, No. EP/V049615/1, and No. EP/V049615/2) and Y. W. acknowledges a PhD studentship from the UK EPSRC.

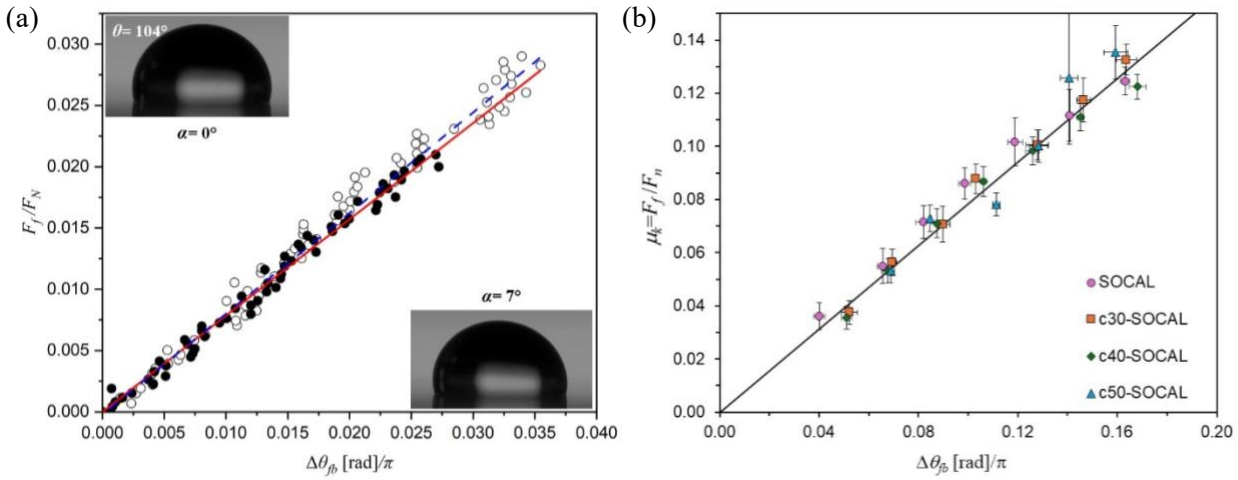

Fig. 1: (a) Furmidge factor (statics) and (b) coefficient of kinetic friction (dynamics)

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Invited: Beyond the Lotus Effect: Exploring Self-Cleaning Superhydrophilic Structures inspired by Fish-Scales

María J. MOSQUERA*, Rafael ZARZUELA, Manuel LUNA, Alfonso B. MOSQUERA

TEP-243 Nanomaterials Group, Department of Physical-Chemistry, Faculty of Sciences, University of Cadiz, 11510 Puerto Real (Spain)
IMEYMAT, Institute of Electron Microscopy and Materials, University of Cadiz, 11510 Puerto Real (Spain)

Keywords: superhydrophobia; superhydrophilia; self-cleaning; buildings

Nowadays, superhydrophobic coatings are employed to promote simultaneously protection from water and self-cleaning performance on buildings. Superhydrophobic surfaces, mimicking natural structures such as the lotus leaf, are characterized by a high static contact angle, which prevents water ingress and a low sliding angle, promoting repellence [1].

In the case of pollutants with a non-polar nature (oils, aerosols, soot), superhydrophobic coatings produce a limited self-cleaning performance because pollutants have a very low affinity with water due to their different polarity, which hinders their removal by the water droplets. Biological decay agents have similar behavior, as the presence of non-polar domains in cell walls and extracellular matrices promote their adhesion to the surface and prevents their removal.

The use of superhydrophilic coatings, instead of superhydrophobic solutions, is a promising strategy to promote effective self-cleaning performance. In the case of porous substrates, such as building materials, it would be considered counterproductive because water related to their main decay processes, either directly or as vehicle of other agents. We develop [2] a coating combining photoinduced superhydrophilic activity on the surface, which facilitated removal of polar and oily contaminants, whereas hydrophobic performance is maintained inside the pore structure in order to prevent water ingress. These treatments show remarkably better performance compared to their superhydrophobic counterparts in terms of resistance to organic (soot, oily dust) and biologic contamination, while maintaining a good resistance to polar stains. Thus, the results show the potential of this disruptive strategy for producing solutions optimized for buildings protection.

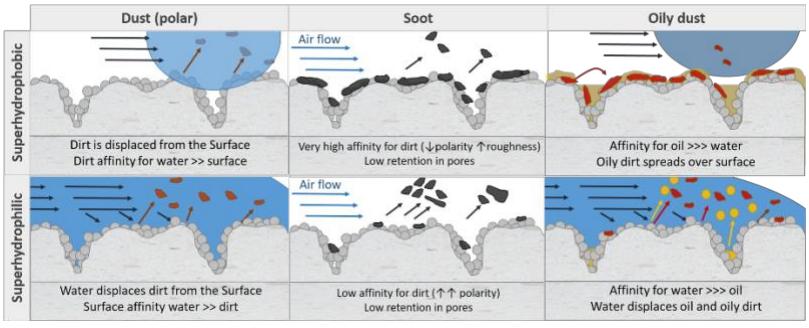

Fig. 1: Schematic representation of the self-cleaning phenomena

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Invited: Grafted polydimethylsiloxane chains as a replacement for perfluoroalkyl substances

Kevin GOLOVIN *,[1]

[1]*University of Toronto, Toronto, Canada*

Keywords: omniphobic, polymer brushes, PDMS, oleophobic, liquidlike surfaces

The use of perfluoroalkyl substances (PFAS) in engineered surfaces has been commonplace for many decades. However, recent evidence of their long-term toxicity has reignited the search for low surface energy materials, but ones safe for the environment and human health. Grafted linear chains of polydimethylsiloxane (PDMS) have shown promise as a potential replacement for PFAS in certain applications. The unique morphology of grafted PDMS chains imparts many interesting properties that crosslinked PDMS, commonly known as silicone rubber, does not exhibit. The purpose of this talk is to give an overview of some of the more interesting and anomalous properties of grafted PDMS chains that have been discovered over the last decade. These include (1) the ability to achieve extremely low contact angle hysteresis with low surface tension fluids, (2) autophobicity, or the ability to repel droplets of chemically identical silicone oil, (3) the sliding of adhered foulants such as ice during shear, and (4) contact line velocities that can be tuned several orders of magnitude through engineering of chain termination. Applications of such surfaces include highly liquid repellent surfaces, both dense materials like glass and porous ones like fabrics; ice-phobic coatings; anti-microbial materials where protein-laden residue spontaneously delaminates upon drying; and surface treatments that prevent the release of microplastics.

Surface-Coating Decoupling for New Superhydrophobic Surfaces

Youhua JIANG*,[1,2] Chuanqi WEI,[1,2] Oleg GENDELMAN,[2]

[1]Department of Mechanical Engineering Guangdong Technion – Israel Institute of Technology, Shantou, China; [2]Faculty of Mechanical Engineering, Technion – Israel Institute of Technology, Haifa, Israel

Keywords: Superhydrophobic, Droplet, Smart Structures, Robust

Armor-like metal frames, which prevent direct contact between the abrasion source and the superhydrophobic coatings housed in frame pockets, improves the mechanical robustness of a superhydrophobic surface. However, the water repellency fails after moderate abrasion because the intrinsically hydrophilic surfaces of the metal frames are exposed to pin droplets. Here, we present a new design concept for superhydrophobic surfaces, where the metal frames serving for mechanical robustness and the superhydrophobic coatings serving for liquid repellency, are decoupled and can be assembled or separated in an on-demand manner. Inclined magnetoresponsive superhydrophobic microwires are site-specifically fabricated on the bottom of a grooved metal surface. When facing mechanical damage, the microwires are controlled by a magnetic field to lay down horizontally on the groove so that the abrasion contacts only the frame top walls. When needing water repellency, the superhydrophobic microwires are reconfigured to cover the abraded metal frames, providing water repellency. This surface-coating decoupling allows the preservation of surface superhydrophobicity even when 90% of frame materials have been removed – a state-of-art performance that paves the way for the next-generation superhydrophobic surfaces.

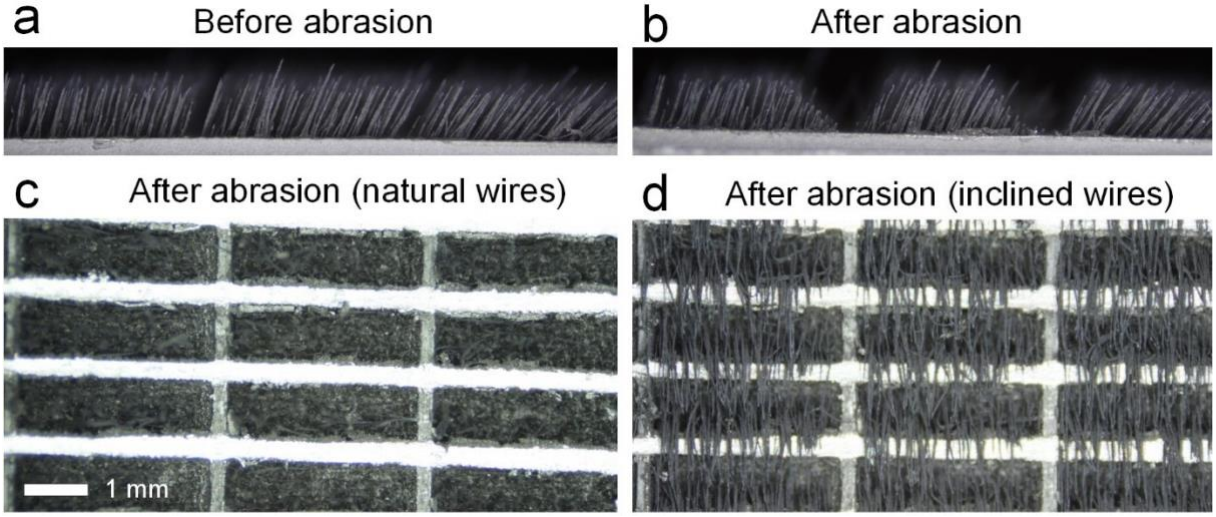

Fig. 1: (a - c) Surface morphology before and after abrasion. (d) Abraded surface covered by wires.

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Invited: Robust superhydrophobic coatings and their applications

Junping ZHANG*,[1]

[1] *Research Center of Resource Chemistry and Energy Materials, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, 730000 Lanzhou, P. R. China*

Keywords: Superhydrophobic, Superamphiphobic, Silanes, Wettability

Bioinspired superhydrophobic surfaces represent an interdisciplinary research frontier, spanning biomimetics, wettability theory, fabrication techniques, and diverse applications. Despite significant advancements over the past two decades, the practical deployment of superhydrophobic surfaces has been hindered by persistent challenges, such as limited stability (e.g., mechanical durability, pressure and weather resistance) and complex, costly fabrication methods.

To overcome these obstacles, we focus on the fundamental scientific issues that contribute to these technological bottlenecks. Utilizing silanes, silicates, and polymer/inorganic nanocomposites, we have developed a series of superhydrophobic coatings with exceptional performance. These coatings have demonstrated successful applications for prevention of rain attenuation of 5G/weather radomes[1], as well as anti-icing solutions of new energy facilities[2, 3]. Furthermore, we have explored their potential in lithium battery separators, solid-state electrolytes, and solar-driven interfacial evaporation[4]. Our research addresses both the scientific challenges and the path to industrialization and practical application of superhydrophobic coatings[5].

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Invited: Three-dimensional shaping of gas-liquid interfaces

Pavel A. Levkin[1]

[1]*Institute of Biological and Chemical Systems-Functional Molecular Systems (IBCS-FMS), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344, Eggenstein-Leopoldshafen, Germany*

Keywords: Gas-liquid interfaces, Liquid manipulation, Superhydrophobicity, Surface engineering, 3D printing, Porous structure

Three-dimensional control over liquid-gas interfaces is central to processes ranging from mass transfer and catalysis to sensing and microfluidics. While superhydrophobic and slippery surfaces have enabled powerful strategies for droplet manipulation, their functionality has largely remained limited to planar or quasi-two-dimensional geometries. In this talk, I will present our recent advances in extending superhydrophobicity, liquid repellency, and porosity into fully three-dimensional polymer architectures fabricated by 3D printing.

In particular, we introduce superhydrophobic open frameworks (3D-SOFs) that combine designed lattice geometries with intrinsic nanoscale porosity, enabling stable shaping and dynamic reconfiguration of liquid–gas interfaces in open space. These structures allow droplets in air and bubbles under water to be suspended, merged, split, and reshaped with minimum solid-liquid contact, governed instead by interfacial curvature and Laplace pressure. Beyond static confinement, 3D-SOFs enable reconfigurable open microfluidic networks assembled from suspended droplets, as well as long-lived, shape-defined gas cavities under liquid.

Placing these results in a broader context, I will also discuss complementary work on 3D-printed superhydrophobic, slippery, and porous polymer structures, illustrating how material chemistry, surface topology, and architecture can be combined to achieve ultra-low adhesion, enhanced gas–liquid exchange, and spatially programmed interfacial processes. Together, these studies establish a versatile platform for three-dimensional interfacial engineering with opportunities in open fluidics, sensing, catalysis, and bioinspired systems.

The main work for this project was performed by Mr. Sida Liu

Biomimetic Omniphobic Reentrant Structures Processed by Femtosecond Laser Machining

Yuhan LIU,[1] Anne-Maire KIETZIG *,[1]

[1]*McGill University, Montreal, Canada.*

Keywords: Springtail, Reentrant Structures, Hydrophobicity, Omniphobicity, Femtosecond Laser.

Springtails are one of the most widespread species in the world, found in wet habitats where water is contaminated by organic species. Moreover, they take in oxygen through their skin. The physiological structure and the living conditions drove springtails to develop unique reentrant structures, featuring extraordinary hydrophobicity and omniphobicity. [1] These microstructures are characterized by narrow pores and relatively large cavities underneath. Such structural arrangements give rise to inversely tapered cavity walls, significantly elevating the apparent contact angle at the edge of the cuticle, therefore enhancing the pressure resisting liquid penetration.

However, the fabrication of reentrant structures has long been a challenge. Existing complicated methods, such as multistep lithography and micro-molding combined followed by metal deposition, pose a production bottleneck, necessitating a more streamlined fabrication process that has potential for industrial scalability. [2-3] Laser machining stands out, with its high-precision and large-scale production capabilities, as a versatile and efficient option, though it is still relatively unexplored for alike complex fabrication tasks.

Utilizing a multiaxial laser machining setup, we have successfully developed a single-step process to fabricate microscale biomimetic reentrant structures via 3-dimensional femtosecond laser machining on stainless steel and polytetrafluoroethylene (PTFE) surfaces. Taking inspiration from the omniphobicity of springtail cuticles, we processed square pillars with overhanging walls to augment the Laplace pressure against liquid penetration. With these laser-processed reentrant structures, surfaces of both materials exhibit excellent hydrophobicity, with average static contact angles above 145° and advancing contact angles exceeding 150°. Furthermore, both stainless steel and PTFE surfaces manifest omniphobicity, repelling organic solutions with surface tensions as low as 36 mN/m and 33.5 mN/m, respectively. The effects of structural parameters and the presence of nanostructures, were investigated. The results indicate that high taper angle and narrow spacing between pillars are the dominant factors for better omniphobicity. While nanostructure enhances hydrophobicity, their tendency to redeposit and replenish cavities effectively limits spacing to a minimum of 50 μm. At which scale, organic solutions can readily penetrate nanoparticle deposits, therefore facilitating liquid penetration in microscales.

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Invited: Assembly and Processes along All-Aqueous Interfaces

Anderson Ho Cheung SHUM*[1,2]

[1]*Department of Biomedical Engineering & Department of Chemistry, City University of Hong Kong, Hong Kong*
[2]*Advanced Biomedical Instrumentation Center, Hong Kong Science Park, Shatin, New Territories, Hong Kong*

Keywords: All-aqueous interfaces, Self-assembly, Phase separation

All-aqueous interfaces provide a versatile and biocompatible platform for guiding assembly, transport, and reactions. This talk highlights recent advances in understanding and engineering assembly and processes at such interfaces, spanning colloidal self-assembly [1], AI-guided microfluidic flow programming [2], and phase separation-driven biomolecular enrichment [3]. By coupling flow programming with interfacial thermodynamics, we achieve controlled formation of anisotropic structures and hierarchical compartments [4], while uncovering fundamental size-scaling principles in condensates [5]. These results establish all-aqueous interfaces as a powerful platform for materials engineering, synthetic biology, and diagnostics.

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Key to wetting studies: chemical and morphological variability at the nanoscale as visualized by Atomic Force Microscopy

Jaime Colchero,[1] *

[1]*Department of Physics, University of Murcia, Murcia, 30100*

Keywords: Nanoscale Wetting, Atomic Force Microscopy, nanoscale Contact Angle

Understanding wetting goes well beyond biological applications, since even in Material Science two characteristic wetting behaviors have names from prominent surfaces prepared by Nature: the Lotus and the Rose Petal effect. While macroscopic wetting behavior has been extensively studied [1], nano-scale wetting studies have been more limited due to the challenges of measuring wetting on a nanometer scale. Here, we demonstrate that non-contact Dynamic Atomic Force Microscopy (nc-DAFM) is a valuable tool for characterizing the wetting at the nano-scale. In humid conditions tip-sample interaction is caused by the spontaneous condensation of liquid water necks when the AFM tip is close to the surface [2], resulting in an attractive capillary interaction that depends on the nano-scale contact angle of water with the surface. We will discuss how to use nc-DAFM to simultaneously measure nanoscale topography and chemistry of a variety of surfaces. While high roughness is generally accepted to be the origin of peculiar wetting (super-hydrophobicity) the role of nanoscale chemical variability is generally discussed much less; most probably because -up to now- this variability could not be "seen" due to lack of experimental techniques. In addition, we propose to model the combination of topographic and chemical variability with a single nanoscale wetting parameter $w(x,y)=\cos(\vartheta_{chem})/\cos(\vartheta_{nano})$, where $\cos(\vartheta_{chem})$ is essentially the (chemical) contribution to wettability of a (flat) surface of a material, and $1/\cos(\vartheta_{nano})$ is the (local) increase of (nanoscale) surface area due to tilting (=roughness) of the surface normal. Our model can be considered a nanoscale extension of plotting the effective contact angle ϑ_{eff} of a rough surface vs. the contact angle ϑ_{chem} of a flat surface of the same material [2]; more precisely plotting: $\cos(\vartheta_{eff})$ vs. $\cos(\vartheta_{chem})$. The combined effect of roughness and chemical (nanoscale) wetting properties can induce a very high effective nanoscale contact angle, which naturally explains the surprising wetting properties of many plant surfaces, as observed on Rose Petals [3] well as Lettuce and Olive leaves [4,5].

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Invited: Nature-Inspired Microstructured Nonwetting Architectures for Transparent Antifogging Surfaces

Hyomin Lee*,[1]

[1]*Department of Chemical Engineering, Pohang University of Science and Technology (POSTECH), Pohang, South Korea*

Keywords antifogging, superhydrophobic, transparent, self-cleaning, hydrogel

Transparent optical surfaces such as lenses, displays, sensors, solar cells, and medical devices readily fog when water vapor condenses into light-scattering microdroplets; therefore, coatings must preserve clarity in humid environments while remaining self-cleaning and durable. Yet conventional hydrophilic antifogging coatings can saturate and foul, whereas purely superhydrophobic textures often suffer early-stage droplet pinning that temporarily degrades visibility. Herein, we describe an architectural design path from mosquito-eye-inspired "dry-style" microtextures to a wet-style, microstructured nonwetting architecture that decouples condensation management from surface repellency. A hygroscopic reservoir preemptively captures water vapor, while a low-surface-energy microtexture maintains high apparent contact angles, droplet mobility, and contaminant removal. We highlight three implementations: (i) a wet-style superhydrophobic antifogging coating for optical sensors that couples microstructured nonwetting features with a hydrophilic reservoir layer [1]; (ii) a scalable, deformable wet-style antifogging tape integrating monolithic PDMS micropillars with inkjet-printed hydrogel micropatterns for robust use on flat and curved substrates [2]; and (iii) a simplified transparent platform based on low-surface-energy-capped hydrogel micropillar arrays, where hygroscopic sidewalls suppress fog nucleation while capped tops sustain superhydrophobic, self-cleaning behavior [3]. Together, these platforms articulate practical design guidelines for transparent antifogging surfaces that maintain optical performance under prolonged humidity, contamination, and mechanical deformation.

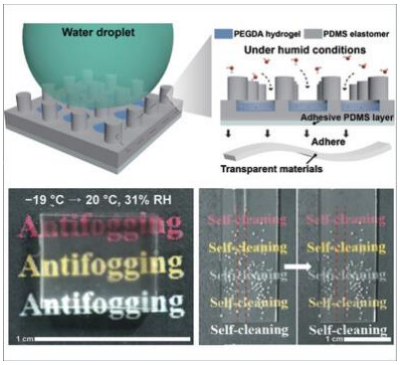

Fig. 1: Micropatterned Hydrogel-Elastomer Hybrids for Superhydrophobic Antifogging Tapes

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Invited: Complex Droplet Wetting and Impact on Structured Surfaces

Peichun Amy TSAI*,[1] Ahmed ALDHAEAI,[1] Lihui LIU,[1] Lap AU-YEUNG[1]

[1]*Mechanical Engineering, University of Alberta, Edmonton, Canada*

Keywords: wetting, surfactant-laden drop, drop impact, superhydrophobic surfaces

Droplet wetting, evaporation, and impact govern many processes in thermal management, coating technologies, and microfluidics. While classical studies largely focus on pure liquids, real droplets often contain surfactants that dynamically modify interfacial tension and wetting behavior. In this talk, I present recent experimental studies on the multiphysics dynamics of surfactant-laden droplets interacting with micro- and nanostructured surfaces.

We examine how surfactant transport, surface microstructure, and thermal conditions influence droplet spreading, wetting transitions, evaporation dynamics, and impact behavior. Our studies show that surfactants significantly modify wetting on superhydrophobic surfaces and influence Cassie–Wenzel transitions [1, 2]. Evaporation of surfactant-laden droplets exhibits concentration-dependent wetting dynamics and transition [3], while droplet impact on heated nanostructures reveals complex spreading and thermal effects [4]. We further demonstrate how machine learning can predict impact outcomes and spreading behavior on heated surfaces [5]. These studies highlight the interplay between interfacial chemistry, surface structure, evaporation, and thermal effects governing complex droplet dynamics.

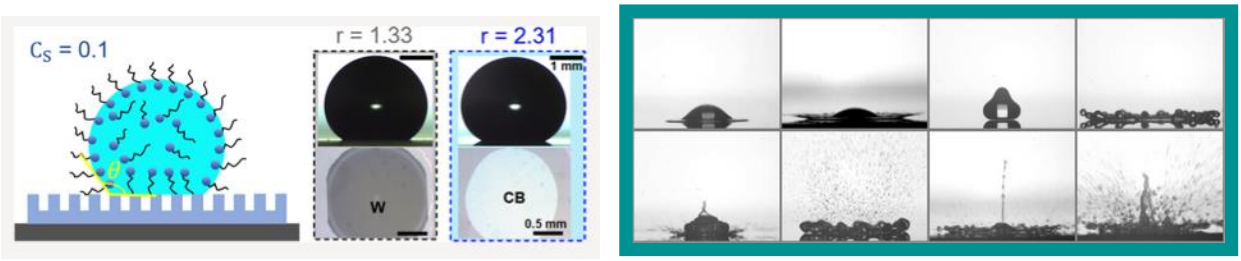

Fig. 1: Surfactant concentration modifies droplet wetting on microstructured surfaces (left), while thermal effects alter droplet impact dynamics on heated nanostructures (right).

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Directional Wetting Via Femtosecond Laser Machined Nepenthes-Inspired Microstructures

Gregory BROCK[1] and Anne-Marie KIETZIG*[1]

[1]*McGill University, Montreal, Canada*

Keywords: Nepenthes, directional wetting, hydrophilicity, laser machining

The *Nepenthes* is an often-cited source of bioinspiration for directionally wetting surfaces. Its hydrophilic peristome features a hierarchy of structures, including 450 μm wide, ~100 μm deep mesochannels patterned with rows of ~50 μm wide, overlapping microcavities. The arc-shaped microcavities leverage Laplace pressure gradients to drive water outward and Gibb's criterion to prevent flow inward. [1] Many surfaces have been thus inspired, but research using single-step techniques like laser inscription is largely confined to directional wetting with structures larger than the *Nepenthes*, limiting their utility in fields like microfluidics. [2] Two research goals were identified – first was microcavity production via laser machining at the *Nepenthes* scale to simplify conventional fabrication pathways. Next, these microcavities were patterned across mesoscale structures to determine the wettability of a hierarchical structure analogous to the *Nepenthes.*

With angled femtosecond laser machining we addressed these goals. The intrinsic shape of a focused laser beam was used to produce biomimetic microcavities on a stainless-steel surface smaller than those of the *Nepenthes*, at ~ 15 μm wide. These structures were optimized across machining angle (55° and 70°) and laser polarization (s- and p), with the microcavities produced at a 55° angle using s-polarization (s-55° microcavities) exhibiting the greatest directional wetting, in **Fig. 1A**. The 55° angle let the microcavities be more tightly spaced, improving wicking. The spolarization also produced nanoridges aligned parallel to the direction of the microcavities which produced sharper edges at microcavity overlaps, reducing wetting in the unfavoured direction.

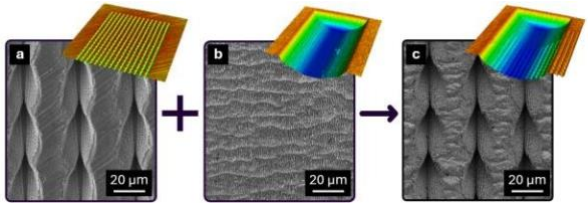

Fig. 1: S-55° microcavities (A), mesochannel (B), overlaid mesochannel and s-55° microcavities (C)

A biomimetic analog to the mesochannels was laser-inscribed on stainless steel to elucidate the role of different scales on *Nepenthes* wicking in **Fig. 1B**. On one mesochannel surface, s-55° microcavities were overlaid, in **Fig. 1C**. The bare mesochannel wicked modestly and nondirectionally, whereas overlaying with the s-55° microcavities induced directionality and greater wicking on the surface, indicating that the mesochannel structure augments microcavity wetting.

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A concept and proof-of-principle for a microstuctured surface converting a vertical temperature into horizontal fluid motion

Clarissa SCHÖNECKER*,[1,2] Jan-Niklas SCHÄFER,[2] Tillmann CARL,[2]

[1]*University of Applied Sciences Darmstadt/European University of Technology, Darmstadt, Germany;*
[2]*RPTU University Kaiserslatuern-Landau, Kaiserslautern, Germany*

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Keywords: superhydrophobic, Marangoni, pumping

Waste heat occurs in many technical systems. Especially in electronic devices this heat needs to be removed or presents a source of unproductively spent energy. We present a concept for a microstructured surface that can convert a vertical heat supply into a fluid motion parallel to the surface. It is based on a superhydrophobic surface. Temperature gradients at the fluid-fluid interfaces of the superhydrophobic surface give rise to Marangoni stresses, a phenomenon caused by the temperature dependence of the surface tension. Consequently, these stresses induce a fluid flow. Similar concepts have previously been examined to propel micron-sized particles, or to drive flow in microfluidic systems. A key disadvantage of existing pumping concepts is the requirement that the temperature gradient has to be applied horizontally along the surface. Often, this is not trivial to be technically implemented and furthermore limits the achievable length along which a fluid can be pumped as well as the direction of pumping in such systems. The presented concept overcomes these disadvantages and enables length-independent pumping with vertical instead of horizontal heat supply.
Furthermore, we present a proof-of-concept experimental implementation of the concept and show its functionality.
The experimental observations agree well with numerical model that solves the coupled fluid dynamics-heat transfer occurring at the surface. The numerical model also indicates potential further developments and optimizations of the surface design.

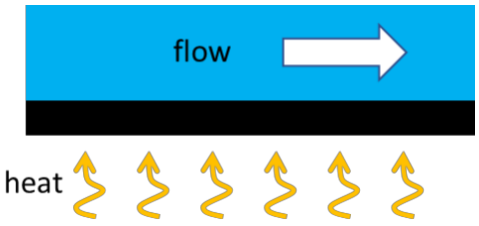

Fig. 1: Schematic: converting vertical heat supply into horizontal motion

Oral Presentations - Day 3

Invited: From the Sea to Sustainability: Development of Next Generation Adhesives

Jonathan WILKER

Department of Chemistry, Purdue University, West Lafayette, IN, 47907-2084, USA

Keywords: Adhesion, biomimicry, marine biology, polymers, sustainability

Imagine trying to live at the beach, constantly being pounded by waves. Nature has developed intriguing classes of adhesives for allowing mussels, barnacles, and oysters to stay in place. By contrast, consider all of the adhesives that you can buy at the hardware store. None function well in water. How do these animals stick in such an environment? What can we do with this technology once we understand it? We are working to uncover these secrets of how shellfish stick. These insights are then used for the development of biomimetic materials. In doing so we have created one of the strongest underwater adhesives seen to date. Current industrial adhesives hold together our electronics, furniture, and packaging. These petroleum-based glues prevent material separation and recycling. Ongoing efforts include using biomimetic chemistry to develop fully sustainable adhesive systems. Bio-based, high-performance adhesives may help us bring about a future generation of carbon negative materials.

Fig. 1: Mussels, oysters, barnacles, and kelp making adhesives for staying in place.

Mussel-Inspired Surface Engineering of Multifunctional Catechol Polymers for Health and Sustainability

Belén PEPIÓ-TÁRREGA,[1] José D. BOLAÑOS-CARDET,[1] Daniel RUIZ-MOLINA,[1] Víctor J. YUSTE,[2] Salvio SUÁREZ-GARCÍA*,[1]

[1]Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Campus UAB, Bellaterra, 08193 Barcelona, Spain
[2] Cell Death, Senescence and Survival Group, Departament de Bioquímica i Biologia Molecular and Institut de Neurociències, Facultat de Medicina, Campus de Bellaterra, Universitat Autònoma de Barcelona, Bellaterra, Spain

Keywords: bioinspired surfaces, catechol, antimicrobial, biomedicine, environment

Inspired by the catechol-rich adhesion proteins of marine mussels, we have developed a versatile platform of bioinspired materials using naturally occurring polyphenols. Through an eco-friendly, water-based synthesis, we exploit their redox chemistry to engineer adaptable, smart materials (**Fig. 1**). This approach allows us to design universal conformal coatings as well as robust, substrate-independent free-standing films. In the biomedical sector, these platforms are engineered at the nanoscale to solve specific clinical challenges. Our free-standing films can be structurally modulated into Janus configurations for complex biological environments. Furthermore, these catechol-based materials act as powerful intrinsic antimicrobial agents, generating reactive oxygen species to prevent biofilm formation.[1] Currently in preclinical studies, we apply these interactive platforms to safely deliver cells, modulate oxidative stress, accelerate tissue regeneration, manage complex wounds, and deliver targeted cancer therapies for glioblastoma.[2] Beyond healthcare, this technology offers efficient environmental solutions. Coated substrates function as active water and air filters to capture heavy metals, effluents, pathogens and CO_2. In this talk, I will share how translating these fundamental, nature-inspired surface principles into scalable, multifunctional technologies addresses pressing global clinical and environmental challenges.

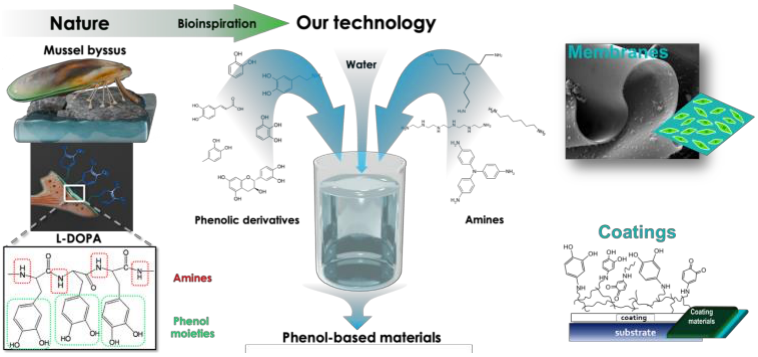

Fig. 1: Schematic overview of our bioinspired technology.

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When and how particles are removed by drops

Abhinav NAGA,[1*] Franziska SABATH,[2] Doris VOLLMER,[2*] Halim KUSUMAATMAJA[1*]

[1]*Institute for Multiscale Thermofluids, School of Engineering, University of Edinburgh, Edinburgh, UK*
[2]*Physics at Interfaces Group, Max Planck Institute for Polymer Research, Mainz, Germany*

Keywords: Wetting, friction, surface cleaning, particles, self-cleaning

Particulate contaminants decrease the power output of solar panels, the transparency of windows, and are detrimental to microelectronics, where even a single particle can induce a short circuit. Despite significant research on particle adhesion and self-cleaning, it remains unclear when and how a drop can remove a particle from a surface, thus efficiently cleaning the surface. Here, by combining lattice Boltzmann simulations [1] and confocal microscopy experiments [2], we show that at least six different scenarios (Fig. 1) arise from the complex interplay between capillary and friction forces when a drop collides with a particle. Notably, the capillary force plays a dual role in particle removal: while its tangential component always drives removal, its normal component can also hinder it. By introducing a dimensionless capillary capture parameter, we can predict particle removal across a wide range of particle and surface properties [3]. These results provide quantitative design principles for easy-to-clean surfaces that minimize water and chemical usage.

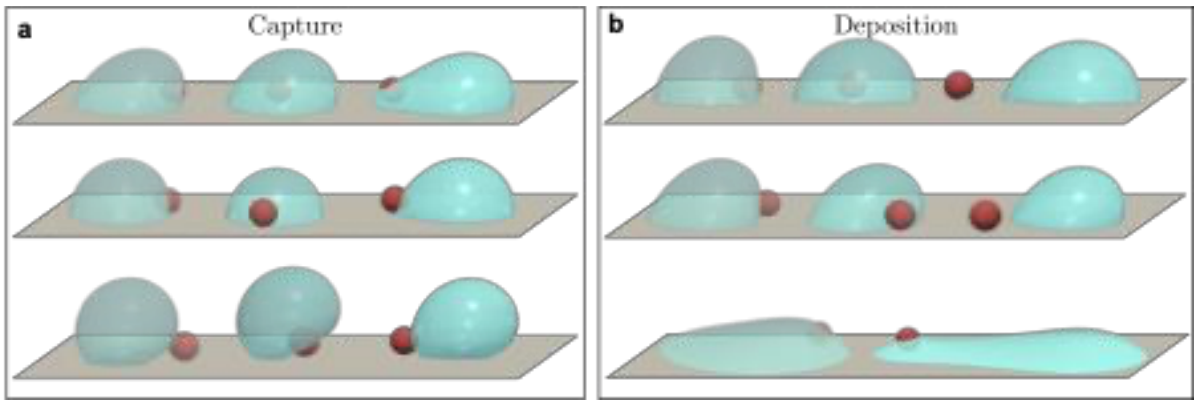

Fig. 1: Six possible scenarios when a drop collides with a particle on a surface. The particle can either be captured and transported by the drop (a) or get deposited on the surface (b). We introduce a capillary capture parameter to predict the outcomes by accounting for the complex interplay between the capillary force between the drop and the particle and the friction force between the particle and the surface.

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Invited: Bio-inspired Self-reporting and Self-healing Composite Coatings for Advanced Corrosion Protection

Sakeena Arshad[1,3,] Sehrish Habib[1], Abdul Rehman Sadiq Butt[1], Ramazan Kahraman[2], Elsadig Mahdi Ahmed[3], R.A. Shakoor[1,3,*]

[1]*Center for Advanced Materials (CAM), Qatar University, 2713 Doha, Qatar.*

[2]*Department of Chemical Engineering, Qatar University, 2713 Doha, Qatar.*

[3]*Department of Mechanical and Industrial Engineering, Qatar University, 2713 Doha, Qatar.*

Keywords: Self-healing; Corrosion Sensing; Smart Nanocarriers; Stimuli Responsive surface; Corrosion Protection

Nature-inspired surface engineering often seeks to replicate the adaptive and self-healing capabilities found in biological systems. In this work, we present an intelligent, stimuli-responsive epoxy-based composite coating designed to mimic biological "sensing-and-response" mechanisms to combat localized corrosion. The system utilizes engineered hollow cerium oxide microspheres (Ceria-MS) synthesized via a carbon-templating approach. These microspheres serve as "smart containers" for 4-methylumbelliferone (4-MUF), a dual-function molecule acting as both a corrosion inhibitor and a fluorescent sensor. Drawing inspiration from adaptive materials, the Ceria@4-MUF architecture exhibits a pH-responsive release of 4-MUF from ceria microsphere; UV–Vis spectroscopy confirms accelerated release at acidic pH levels typically found at incipient corrosion sites. Furthermore, the system demonstrates a sophisticated self-reporting capability of 4-MUF via Fe^{3+}-responsive fluorescence quenching, supported by Density Functional Theory (DFT) analysis indicating a photoinduced electron transfer (PET) process. Electrochemical Impedance Spectroscopy (EIS) reveals that the modified surface significantly outperforms traditional coatings, with charge transfer resistance (R_{ct}) reaching 11.9 $G\Omega \cdot cm^2$. Potentiodynamic polarization and Raman spectroscopy further confirm a dual inhibition mechanism involving $Ce(OH)_3$ passivation and Fe–MUF complexation. By integrating localized activation and real-time response to corrosion, this research offers a robust, nature-inspired solution for developing self-healing and self-reporting multifunctional surfaces in aggressive industrial and marine environments.

Invited: Autonomous Patterning and Transformation: Nature-Inspired Routes to Functional Surfaces

Willem Noorduin,*,[1],[2]

[1]*AMOLF, Amsterdam, The Netherlands;*
[2]*University of Amsterdam, Amsterdam, The Netherlands*

Keywords: Reaction-diffusion patterning, structural color, photoluminescence, ion-exchange

Nature routinely fabricates complex, functional surfaces through self-organization rather than top-down design. Reaction–diffusion (RD) processes [1], central to biological morphogenesis, offer a powerful route to autonomous pattern formation, yet their use in surface engineering has been limited by challenges in control and scalability. In this talk, we show how RD dynamics and chemical transformations can be harnessed as versatile design principles for nature-inspired surface engineering.

We demonstrate that sequential RD processes can be autonomously generated and superposed into complex periodic surface topographies. Their surfaces exhibit vivid structural coloration and well-defined diffraction behavior, comparable to engineered optical gratings, while remaining uniform over centimeter-scale areas. We further extend this bioinspired approach to fossilization-like chemical transformations that enable preserving of the topographies. Using this strategy, mineralized RD architectures can be converted into functional semiconductors, and toxic lead can be transformed into photoluminescent perovskite nanocrystals for rapid and sensitive lead detection [2]. This method is now used worldwide by citizens, health professionals, law enforcement, and environmental scientists, illustrating how bioinspired surface engineering can translate fundamental self-organization principles into real-world impact.

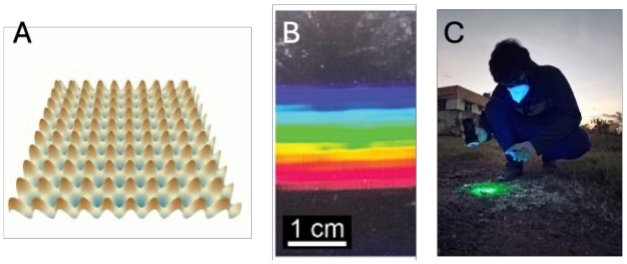

Fig. 1: Bioinspired pattering and transformation of surfaces.
(A) Schematic, and (B) experimental realization of RD patterned surface with structural color.
(C) Fossilization-inspired photoluminescent lead detection.

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Mass Transfer Enhancement in Continually Replenished Bio-Inspired Aerophilic Surfaces

Omar Nemir,[1] Rawad Refai[1], Ralph Rodrigues[1], Campbell Tiffin[2], Natasia Fisher[1], Lorenzo Yao-Bate,[1] Sami Khan*,[1]

[1]*School of Sustainable Energy Engineering, Simon Fraser University, Surrey, Canada;*
[2]*Department of Chemical Engineering, University of Canterbury, Christchurch, New Zealand*

Keywords: aerophilic surfaces, CO_2 capture, superhydrophobic, mass transfer

The ever-growing global carbon dioxide (CO_2) emissions are driving irreversible climate change. In 2024, nearly 40 billion tons of CO_2 were emitted globally [1], and emissions continue to rise. Carbon capture, utilization, and storage (CCUS) offers a potential pathway, especially for hard-to-decarbonize sectors [2] but deployment remains limited. More broadly, gas absorption into liquids underpins technologies from environmental remediation to bioreactors, yet performance is often bottlenecked by sluggish transport across the gas-liquid interface. Continually-replenished aerophilic surfaces can address this limitation. Inspired by the diving-bell spider in nature, they are designed to sustain an underwater trapped-gas layer (a plastron) on hierarchical micro/nanotextures, analogous in concept to superhydrophobic surfaces. Using laser ablation, aerophilic substrates can be fabricated with microcapsule-like features, nanoscopic pinning points, and tunable inter-feature spacing; when tested for CO_2 uptake in potassium hydroxide near neutral pH, these surfaces can reach roughly 80% of saturation within one hour, compared to about 20% for diffusion from an overhead CO_2 atmosphere. Colorimetric measurements (bromothymol blue) indicate around a 20-fold increase in mass transfer rate relative to a planar interface of the same projected area, with the improvement arising not from added interfacial area but from a large increase in the liquid-side mass transfer coefficient, consistent with reduced resistance across the plastron interface. Microscopy observations of pinned, hemispherical gas caps and corresponding area estimates support this mechanism, underscoring the promise of dynamically replenished aerophilic surfaces for overcoming mass-transport limits in multiphase gas-liquid systems relevant to carbon capture and sustainable energy.

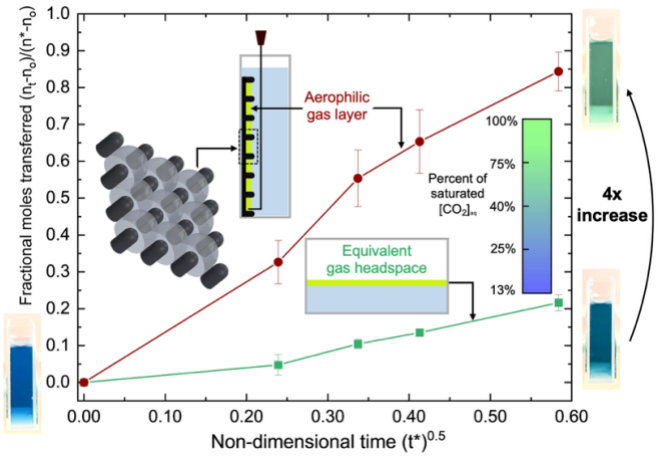

Fig. 1: Comparing mass transfer from aerophilic surfaces with an equivalent flat headspace

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Poster Presentations

Preparation of MgO-CaO-P_2O_5 glasses for biomedical applications via liquid phase method

Sungho Lee*,[1,2] Akiko Obata,[3] Benjamin Hatton,[2]

[1]*National Institute of Advanced Industrial Science and Technology (AIST), Nagoya, Japan;*
[2]*University of Toronto, Toronto, Canada;*
[3]*Nagoya Institute of Technology, Nagoya, Japan*

Keywords: bioactive glass, phosphate glass, Magnesium ion, glass structure, cell behavior

Phosphate invert glasses consist of short phosphate units such as orthophosphate (Q_P^0) and pyrophosphate (Q_P^1) [1]. Magnesium (Mg), classified as an intermediate oxide despite being an alkaline earth metal, enhances glass-forming ability and ion release in invert glasses, and also promotes cell adhesion and bone formation [2, 3]. The liquid phase method used in this work is a simple, energy-efficient process that enables glass synthesis at ambient temperature and pressure. Our group has previously controlled the chemical durability of phosphate glasses prepared by this method using transition metals such as Ti, Nb, and Ta, finding that durability depends on the amount of chain structures formed by bridging phosphate units with intermediate oxides [4, 5]. In this work, the structural analysis and cell behavior of Mg-containing phosphate invert glasses synthesized by the liquid phase method. Glasses were prepared by adding $CaCl_2$/$MgCl_2$ mixed solutions (Mg content: 0 ~ 100%) to $K_4P_2O_7$ solution, followed by filtration, washing, and drying at 200 °C. XRD confirmed amorphous phases for all samples, with partial crystallization observed at high Mg contents (90 ~ 100%). Composition analysis showed constant P_2O_5 (30 mol%) and increasing MgO with decreasing CaO, though Mg incorporation was lower than the nominal ratio. Raman and ^{31}P MAS-NMR indicated structures composed of Q_P^0 and Q_P^1 units, with sharp Q_P^1 peaks in partially crystallized samples. From the NMR result, Q_P^0 and Q_P^1 (including $Q_P^1{}_{\_crystal}$) of the samples were approximately 30 and 60%, respectively, while the samples with Mg content of 90 ~ 100% contained approximately 30% of crystalline phase. Cell proliferation tests using MC3T3-E1 cells showed that samples with Mg content 25 ~ 90% showed larger cell numbers compared to the control and 0%, whereas 100% sample inhibited cell proliferation.

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Droplet Pinning on Slippery Biphilic Surfaces

Gary G. WELLS,[1] Ruiheng HU,[1] Glen McHALE*,[1]
Hernán BARRIO-ZHANG,[1] Chiara NETO,[2] Huiling ONG[1]

[1]*The University of Edinburgh, Edinburgh, UK;*
[2]*The University of Sydney, Sydney, Australia*

Keywords: Contact angle hysteresis, liquid-like surfaces, defects.

Droplet pinning on superhydrophobic surfaces can be modelled as arising from dilute strong solid defects within a perfectly slippery completely hydrophobic background of air [1,2]. Recently, it has become possible to create perfectly smooth flat hydrophobic and hydrophilic surfaces with extremely small contact angle hysteresis (CAH) below 3°. Here we present a smooth micropatterned biphilic surface, which retains its low CAH in each individual component [3]. We show that a dilute defects model using Cassie area fractions can describe the increase in droplet pinning as either the hydrophobic or hydrophilic density is increased within an almost perfectly slippery hydrophilic or hydrophobic background surface. We compare our results to droplet pinning on a molecularly-mixed biphilic surface created using ultra-low contact angle hysteresis components [4] and to literature data on superhydrophobic surfaces, and discuss the importance of the receding contact angle of the defect coatings in determining the strength of the pinning.

Acknowledgements: UK Engineering & Physical Sciences Research Council (EPSRC EP/V049348/1), The Leverhulme Trust (Research Project Grants RPG-2022-140 and RPG-2024-339), Chinese Scholarship Council (CSC) and the Australian Research Council (DP230100555).

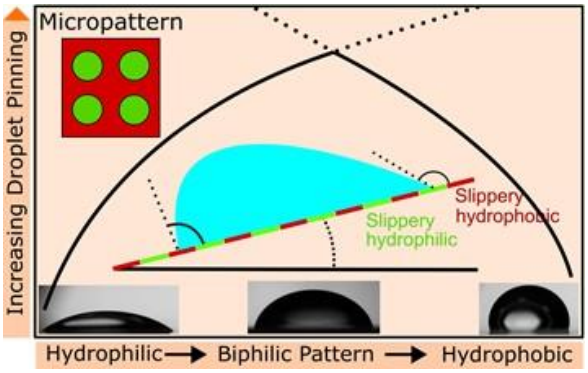

Fig. 1: Droplet pinning on biphilic surfaces composed of two ultra-low pinning coatings

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Rechargeable and compostable slippery liquid infused porous surfaces

Adya KARTHIKEYAN,[1] Wendell RAPHAEL,[2] William SIMON, [2] Marie-Josee Dumont,[3] Jason R TAVARES*[2]

University of Ottawa[1], Ottawa, Canada
Polytechnique Montreal[2], Montreal, Canada
University of Laval[3], Quebec City, Canada

Keywords: SLIPS, compostable, polymer, rechargeable

Slippery Liquid-Infused Porous Surfaces (SLIPS) are biomimetic innovation inspired by the peristome of the Nepenthes pitcher plant, whose micro structured surface filled with wax crystals that act as a lubricant, forms a continuous slippery surface that causes insects to slide into the pitcher. SLIPS are primarily developed on non-biodegradable polymer substrates. As an attempt to combat plastic pollution, we present a novel scalable simple process to create durable SLIPS on a biodegradable substrate, polylactic acid (PLA). The two-step surface recrystallization process transforms PLA into a porous high surface area, low energy surface [1,2]. This allows for good hold up of non-polar hydrophobic lubricants as silicone oil, with oil loading up to 0.28±0.01g oil/g PLA. The water sliding angle on the thus infused modified PLA surface is found to be 1.8 ± 0.6°. The durability of this novel surface was tested by submerging it in deionized and simulated sea water (of salt concentration 36 g/L)- the sliding angle remained at an average of 1.58 ± 0.2°, and 1.9 ± 0.22°, respectively in both conditions, for up to 37 days. Rechargeability of the discs were tested by re-applying silicone oil on the discs after the first durability test. It was observed that the discs performed the same as the initially prepared surface and exhibited durability for 37 days in both DI water and simulated sea water. Additionally, it was ensured that silicone oil can be removed up to less than 3% traces, by washing in isopropanol, thus preventing any interference with the compostability of the PLA polymer.

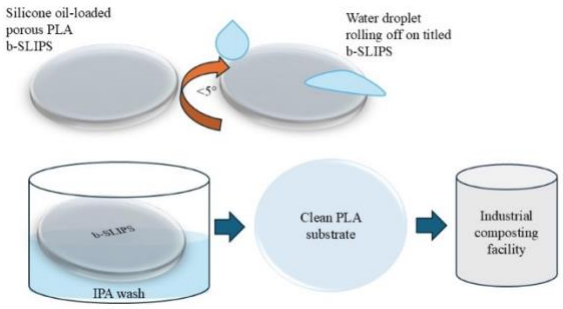

Figure 1: Graphical abstract

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Determining the Ingression and Breakthrough Pressure of Micromeshes

Seamus LILLEY,[1] Giovanni ACANFORA,[2,3] Sebastian ANZINGER,[2] Marc FUELDNER,[2] Hutomo Suryo WASISTO,[2] Gary WELLS,[1] Glen MCHALE,[1] Halim KUSUMAATMAJA *,[1]

[1]Institute for Multiscale Thermofluids, School of Engineering, University of Edinburgh, Edinburgh, United Kingdom; [2]Infineon Technologies AG, Neubiberg, Germany; [3]Institute of Semiconductor Technology, Technische Universität Braunschweig, Braunschweig, Germany

Keywords: Superwettability, Laplace Pressure, Meshes, MEMS

Many insects and spiders rely on their rough, hairy exteriors to support a thin air layer (plastron) around themselves when submerged underwater, allowing them to respire indefinitely. Their setae (hairs) adopt a series of inverted L-shapes to form a hydrophobic lattice, which is capable of minimizing the Laplace pressure, to prevent the collapse of the plastron [1]. Inspired by their geometry, we investigate liquid interactions with meshed surfaces using a combination of phase-field simulations, experiments, and analytical modelling. Computationally, we simulate the pressure required for a liquid to ingress and subsequently break through a mesh of varying geometry and wettability. Experimentally, meshes of different shapes and materials are manufactured via laser-induced deep etching or photolithography to determine the hydrostatic pressure required to induce the breakthrough transition. The experiments demonstrate that the simulations can accurately predict the ingression and breakthrough pressures of different micromeshes. Both the experimental and simulation data are well-captured by a compact theoretical approximation for the ingression and breakthrough critical pressures. These results help inform engineering design principles for sustaining an air layer under the mesh. This can be used to protect microelectromechanical systems (MEMS) devices from contaminants brought about by water breakthrough, which is key to their long-term, real-world performance [2].

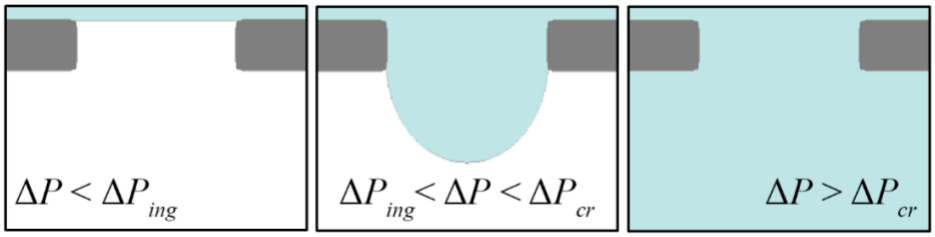

Fig 1: The stages of ingression and critical breakthrough as increasing pressure is applied to a hydrophobic mesh.

Acknowledgements: The authors would like to thank EPSRC for funding SL through studentship 2937215 and HK with EP/V034154/2

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Nature-Inspired Vibration-Induced Separation of Pinned Droplets for Capture of Surface-Buried Particulates

Jinhyung KIM,[1] Gui Won HWANG,[1] Changrok PARK,[1] Changhyun PANG *,[1,2]

[1]*School of Chemical Engineering, Sungkyunkwan University (SKKU), Suwon, Republic of Korea;*
[2]*Samsung Advanced Institute for Health Science & Technology (SAIHST), Sungkyunkwan University (SKKU), Suwon, Republic of Korea*

Keywords: Vibration-assisted cleaning, Hydrophobic interfacial film, Biomimetics, Wettability control, Particulate removal

Nature has evolved resourceful strategies to sustain hygiene by enabling organisms to dislodge contaminants through the synergy of water-repellent integuments and kinetic compensatory mechanisms. [1-3] In this study, we present an efficient vibration-driven surface cleaning platform for pinned droplet separation inspired by the natural behavioural strategies of avian feathers with kinetic compensatory movements. Counterintuitively, unlike superhydrophobic surfaces that hinder droplet–contaminant interaction, our feather-like hydrophobic films are shown to promote such interaction and facilitate droplet release through vibration for efficient cleaning. To quantify the vibrations required to separate droplets on hydrophobic surfaces, we established a fluid dynamics model treating the droplet as an elastic body, and an energy-based framework to analyse how vibration and gravity affect interfacial adhesion and to define separation criteria across surface wettabilities. Our surface technology exhibits promising performance in removing fine particulates embedded within surface multiscale asperities and suggests potential relevance to applications where consistent surface cleanliness and visibility maintenance are critical.

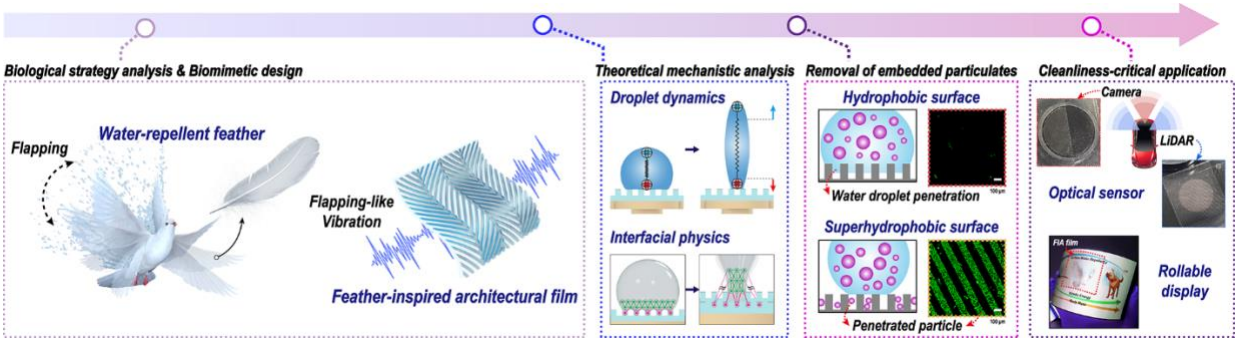

Fig. 1: Schematic of vibration-induced droplet separation strategy and particulate removal.

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Rapid Synthesis of Nano- and Micro-Porous Copper Surfaces Driven by Selective Dealloying of Micrometer-Sized Cu-Al Powder

Aleksandra NASTIC *[1] and Yomna ELSAHLI[1]

[1]*University of Ottawa, Ottawa, Canada*

Keywords: dealloying, surface engineering, nano-structures, coatings, cold gas dynamic spray

Metal surfaces engineered with hierarchically porous architectures are rapidly redefining functional and transformative materials, enabled by their exceptionally high surface-to-volume ratios, tunable three-dimensional ligament network and complex geometries. These features reveal enhanced mass transport, increased reactivity and improved mechanical stability making nano- and micro- porous metals compelling structures for next-generation catalysis, energy storage, sensing, thermal management and filtration systems.

In this work, a novel manufacturing route for hierarchical porous surfaces is developed combining cold spray additive manufacturing (CSAM) and powder dealloying, enabling the fabrication of complex multiscale networks. The CSAM process uniquely preserves the metastable features formed during dealloying of the precursor powders while also enabling the fabrication of surfaces with geometries that evolve into highly complex morphologies, previously inaccessible in the fabrication of hierarchical nano- and micro-ligaments. This combination between deposition-mediated microstructure and gas atomized powder chemical dissolution offers a novel level of architectural control, providing a versatile and scalable route for surface engineering.

This study investigates the effects of precursor powder starting microstructure on dealloying kinetics and porous network evolution, as well as the influence of etching solution composition and concentration on reaction kinetics and surface chemistry. Figure 1 shows the dealloyed $Cu_{60}Al_{40}$ precursor and the resulting complex nano- and micro- porous surface features after CSAM. Production-scale dealloying is addressed, including control step for the exothermic reaction and thermal runaway, alongside an evaluation of CSAM process parameters influence on deposition efficiency and surface morphology. Lastly, the oxidation kinetics of dealloyed $Cu_{60}Al_{40}$ powder are presented, and surface oxide control strategies are evaluated for their impact on CSAM deposition efficiency, particle deformation behavior and resulting surface porous network.

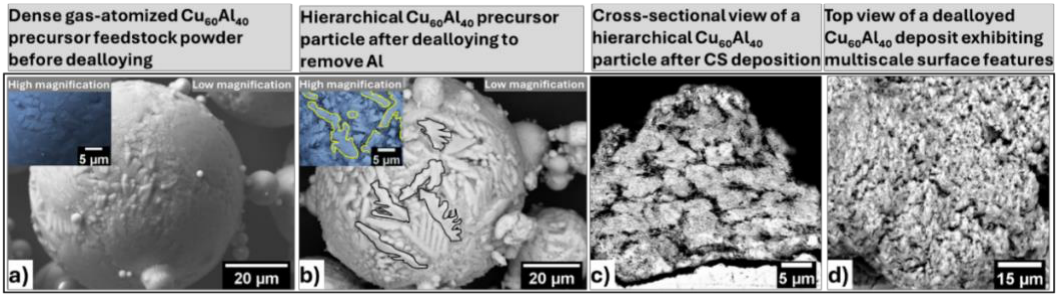

Fig. 1: $Cu_{60}Al_{40}$ precursor powder (a) before and (b) after dealloying. CSAM deposited dealloyed precursor (c) cross-section and (d) top surface.

Eco-friendly hydrophobic slippery coatings for enhanced protection against marine corrosion and biofouling

Rakesh Choubey[1], Sriharitha Rowthu*[1]
[1]Materials Engineering Department, Indian Institute of Technology (IIT) Gandhinagar, 382055-Gandhinagar, Gujarat, India
*Email: sriharitha.rowthu@iitgn.ac.in

Keywords: Slippery coatings, eco-friendly, anti-corrosion, anti-fouling, AA 5083

Marine corrosion is a serious challenge for the shipping industry and is responsible for ~90% of ship failures [1]. This issue is particularly severe for aluminium alloy (AA 5083), which is widely used for ship hulls but is highly prone to pitting and intergranular corrosion when exposed to marine environments [2]. In addition to corrosion, biofouling on ship hulls increases hydrodynamic drag, leading to higher fuel consumption and causing annual economic losses of ~USD 60 billion [3]. Recent research has aimed to mitigate these challenges by developing superhydrophobic and liquid-infused surfaces on AA 5083. However, superhydrophobic surfaces often lose their performance after long-term exposure to seawater, while liquid-infused slippery surfaces suffer from limited durability due to lubricant loss. In our study, we also observed that PDMS-based liquid coatings lost their slippery properties within 7 days of immersion in a 3.5 wt.% NaCl solution. To address these limitations, we developed an environmentally friendly and durable solid slippery surface on AA 5083 by applying polydimethylsiloxane (PDMS) and a PDMS-based composite coating on polished AA 5083 [4]. The coated surfaces demonstrated strong saltwater repellency, with static contact angles >90° and slide-off angles <25°, in contrast to the hydrophilic polished alloy surface. Notably, the coatings retained their slippery properties for over one month during continuous immersion in a 3.5 wt.% NaCl solution. The PDMS-based composite coating also showed good mechanical durability, retaining slide-off angles below 40° even after more than 30 tape peeling cycles. Electrochemical tests indicated improved corrosion protection, as the PDMS-based composite coating and PDMS coating lowered the corrosion current density by 7 and 3 orders of magnitude, compared to bare AA 5083. In addition, the PDMS-based composite coating effectively reduced the adhesion and growth of bacteria and algae, while bare AA 5083 promoted the formation of large bacterial colonies. These findings demonstrate that the developed coating has strong potential for developing durable, anti-corrosion, and anti-fouling solid slippery surfaces for marine applications.

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From Natural to Synthetic Melanosomes: Shape-Directed Self-Assembly in Avian Photonic Crystals

Carina BITTNER[1], Soraia BARBOSA[2,3], Miguel CARNEIRO[2,3], Nicolas VOGEL*[1]

[1] *Institute of Particle Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany*
[2] *CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Universidade do Porto, Vairão, Portugal*
[3] *BIOPOLIS Program in Genomics, Biodiversity and Land Planning, CIBIO, Vairão, Portugal*

Keywords: Structural coloration, Photonic crystals, Self-assembly, Bio-inspired materials, Melanin analogues

The striking iridescent coloration observed in bird feathers originates from photonic crystals: nanostructured materials that interact with light to produce vivid structural colors. A prominent example is found in the iconic eyespot of the tail feathers of the peacock, where a two-dimensional photonic crystal composed of rod-shaped melanosomes embedded in a keratin matrix with air channels gives rise to intense iridescence.

Selective breeding has generated a wide range of peafowl color morphs, spanning from highly iridescent blue feathers to weakly iridescent or even non-iridescent completely black phenotypes. Here, we investigate how these color variations correlate with structural modifications of the underlying photonic crystal. Our analyses reveal that melanosome morphology strongly influences both the formation and degree of order of the photonic crystal, ultimately determining the optical appearance and color saturation of the feathers.

To disentangle the key parameters governing structural coloration, we mimic peacock photonic crystals using bio-inspired synthetic materials and focus on two central characteristics. First, we investigate the role of optical absorbers, which are naturally present in melanosomes as melanin. Using our synthetic model system, we show that absorber concentration critically controls color saturation and identify an optimal absorber regime that enhances chroma while preserving brightness. Second, we isolate the role of particle shape in the self-assembly process.

To this end, we developed a biomimetic model system based on synthetic melanosome analogues. Polystyrene–polydopamine core–shell particles were thermo-mechanically stretched to produce anisotropic building blocks. We find that the polydopamine shell thickness strongly influences shape evolution during stretching and establish a model that rationalizes particle morphology based on the mechanical interplay between core and shell. By varying shell thickness, we obtain tunable particle morphologies that enable systematic investigation of shape-dependent self-assembly.

This bio-inspired approach provides a controllable platform to elucidate how tailored particulate building blocks govern the structure and optical properties of colloidal photonic crystals and offers new design principles for optimized self-assembly in structurally colored materials.

Design and Fabrication of Hierarchical 3D Printed Catalytic Structures

Ray JU,[1] Derek ARANGUREN VAN EGMOND, [2] Kurtis LAQUA, [2] Benjamin HATTON *[1]
[1]University of Toronto, Toronto, Canada; [2]National Research Council of Canada, Mississauga, Canada;

Keywords: Hydrogel Infusion, Hierarchical Porosity, Metamaterials

In industrial catalysis, maximizing efficiency remains a critical challenge due to the inherent tradeoff between active surface area and mass transport volume. Conventional manufacturing techniques struggle to optimize both parameters simultaneously, often leading to reduced performance from restricted flow and lowered reaction rates. To overcome this limitation, structural hierarchy serves as our key design approach. This draws inspiration from biological materials such as the multi-scale porous networks found in bone or plant leaves, which naturally balance surface areas with efficient transport pathways [1, 2]. As such, we present a scalable and low-cost process for integrating micro–nanoscale porosity onto macro-scale surfaces, creating customizable hierarchical "metamaterials". This work explores combining two primary fabrication methods: Inverse Opal Colloidal Deposition (IOCD) and Hydrogel Infusion Additive Manufacturing (HIAM). While IOCD offers high surface area through self-assembled templates [3], HIAM enables the creation of complex, free-standing metallic architectures that are extremely difficult to process using conventional manufacturing [4]. In the HIAM approach, Digital Light Processing (DLP) fabricated micro-architected hydrogel structures with high geometric fidelity. These sacrificial scaffolds are infused with Nickel Nitrate Hexahydrate, followed by calcination and reduction processes to convert the hydrogel into a solid metallic structure [5]. To maximize infusion efficiency and diffusion kinetics, gyroid-cube lattices with thin walls were selected.

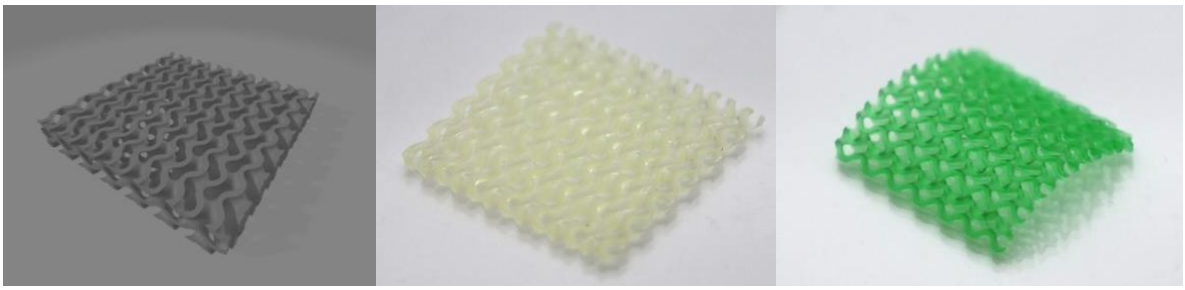

Fig. 1: Left: Gyroid Lattice. Middle: Printed Hydrogel Lattice. Right: Ni-Infused Lattice

Preliminary results demonstrate the successful synthesis of solid Ni lattices via the HIAM route.
As shown in Figure 1, the hydrogel scaffolds served as effective templates for metal ion infusion.
Post-processing analysis via Scanning Electron Microscopy (SEM) and Thermogravimetric Analysis (TGA) confirms that the final metallic structures retain the complex gyroid geometry of the original print, with sufficient Ni infusion into the polymer matrix. The successful conversion of hydrogel to solid Ni validates this method for producing high-surface-area catalysts with tunable macro-geometries.

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3D Printing Polyurethane Elastomer Pillars for Bio-Inspired Microgrippers

Kiran MUNGROO*,[1] Lu YIN[1], Boxin ZHAO[1]

[1]*Department of Chemical Engineering, Waterloo Institute for Nanotechnology, Institute for Polymer Research, Centre for Bioengineering and Biotechnology, University of Waterloo, Waterloo, Canada;*

Keywords: 3D Printing, Polyurethane Elastomers, Soft Robotics, Microgrippers

The development of functional soft robotics and biomedical devices requires materials that can maintain adhesion/gripping capability while allowing for the fabrication of complex microstructures. Currently, a significant gap exists between these two requirements. While some 3D-printed designs take inspiration from nature for adhesion, reliance on Van der Waals forces often leads to weak adhesion. Conversely, specialized tissue adhesives engineered for powerful adhesion are typically bulk materials unsuitable for the controlled, high-fidelity additive manufacturing required for intricate microgrippers. In this work, we tackle this issue with a new type of UV-responsive polyurethane elastomer, built for solvent-assisted vat photopolymerization. Its segmented block copolymer structure imparts the toughness and elasticity (hard segments and soft PPG) required for conformal substrate contact, while its functionalization with polar carboxylic acid groups enable adhesion via intermolecular interactions. End capping with acrylates containing vinyl groups then enables rapid UV crosslinking. We investigate the 3D-printing of micropillars through balancing this material's rheology and curing kinetics. To evaluate functional performance, we conduct pull-off and lap-shear adhesion tests on 3D-printed pillar arrays and perform comparative benchmarking between functionalized micro-pillars, unpatterned PU films, and conventional non-polar 3D-printed pillars, investigating the synergistic effect of tailored surface chemistry and micro-architecture. A soft robotic microgripper prototype using this material is fabricated to demonstrate the capability of gripping, manipulation, and release of objects. These results may have technical implications for opening a new design paradigm for customized microgrippers.

Stepwise Dewetting in Micro-Architectures for Voxelated Additive Manufacturing

Xin TANG[1,2*], Hongtu TAN[1,2]

[1]*Centre for Complex Flows and Soft Matter Research, Southern University of Science and Technology, Shenzhen, Guangdong, China.*
[2]*Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology, Shenzhen, Guangdong, China.*

Keywords: dewetting, 3D printing, microarchitecture

Cascade phenomena, characterized by stepwise progressions rather than long-range leaps, are central to diverse fields such as turbulent energy transfer, biochemical reaction networks, and biological extinction dynamics. While capillarity-driven wetting in three-dimensional (3D) micro-architectures with periodic unit cells has been extensively studied for liquid transport and trapping via three-phase contact line control, the reverse process, dewetting in such 3D frameworks, remains largely unexplored. In this presentation, we study liquid depletion in micro-architectures whose struts are arranged in configurations analogous to cubic Bravais lattices, revealing a capillarity-driven stepwise cascade behavior. Within individual unit cells, lattice frameworks pin inwardly receding contact lines, and the interplay between adhesion and cohesion yields a geometry- and wettability-dependent implosive Laplace pressure. When cells are interconnected, depletion triggers sequential implosions ordered by lattice type, producing an intercellular capillary cascade that progresses from higher to lower implosive pressures. We further demonstrate how this capillary cascade can be harnessed to pattern and deposit fluids in 3D space. This approach offers a simple, high-resolution route to voxelated multi-material fabrication, with promising applications in power source engineering, controlled catalyst distribution, and the design of protective mechanical meta-materials.

Nature's Roughness: Smart Wetting with Diatomaceous Earth

Alfonso B. Mosquera*, Rafael Zarzuela, María J. Mosquera

TEP-243 Nanomaterials Group, Department of Physical-Chemistry, Faculty of Sciences, University of Cadiz, 11510 Puerto Real (Spain)
IMEYMAT, Institute of Electron Microscopy and Materials, University of Cadiz, 11510 Puerto Real (Spain)

Keywords: superhydrophobia; hierarchical roughness; diatomaceous earth; self-cleaning

Nowadays, superhydrophobic surfaces find many applications for the protection of materials from water-induced degradation. Additionally, they give rise to a self-cleaning performance due to their repellent properties. Superhydrophobicity is achieved by a synergistic action of a component with low surface energy and the creation of a hierarchical micro/nanostructure preventing water droplets entrapped into the substrate. Ormosil coatings, produced via sol-gel, are a versatile and common strategy for preventing water ingress into porous materials. Repellence is obtained by incorporating nanoparticles to ormosil, creating a coating with nanometric roughness. This is a successfully strategy in porous materials with micro-roughness. However, it fails in materials with large pores, where nanoparticles penetrate instead of accumulating on the surface, or on very smooth surfaces, where a hierarchical roughness requires to be implemented to produce repellence.

This work reports a bottom-up method for producing superhydrophobic coatings with a hierarchical micro/nano-roughness by the incorporation of modified diatomaceous earth (DE) to an ormosil coating. Nanometric laminar calcium silicate hydrate (CSH) structures are grown on the surface of DE by a hydrothermal process, producing hierarchical particles (DE@CSH). This simple synthesis process allows the easy creation of hierarchical structures for in situ applications over large areas. Thus, these coatings containing DE@CSH were evaluated on different building materials, employed in construction, of varying pore structure and surface finishing. The hierarchical DE@CSH consistently improved the superhydrophobic properties on all substrates, compared to fumed silica NPs or unmodified DE. Furthermore, a higher durability was observed and attributed to the capacity of the CSH structures to chemically interact with both carbonate and silica phases from the substrates.

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Durable Superhydrophobic/Superamphiphobicity Coatings for Prevention of Rain Attenuation of 5G/Weather Radomes and Anti-icing of High-voltage Transmission Tower

Jinfei WEI,[1] Junping ZHANG *,[1]

[1] *Research Center of Resource Chemistry and Energy Materials, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou, P.R. China*

Keywords: Superhydrophobic; Superamphiphobicity; Durable; Industrial application

Abstract: This study explores the development and application of durable superhydrophobic/superamphiphobic coatings. We employed a universal preparation method involving the spraying of a suspension containing silica nanoparticles decorated with perfluorodecyl polysiloxane and adhesive microparticles. This technique effectively creates a reentrant tri-tier hierarchical micro-/nano-/nanostructure, ensuring superior superhydrophobicity/superamphiphobicity, mechanical robustness and pressure resistance. Furthermore, these coatings show excellent anti-icing performance/prevention of rain attenuation of 5G/weather radomes, making them ideal for practical applications such as protecting high-voltage transmission towers in harsh winter conditions/decreases signal loss in the rain. The simple, cost-effective, and scalable production method underscores the potential for widespread industrial adoption, providing a durable solution for enhancing the longevity and efficacy of superhydrophobic surfaces across various sectors. This research contributes valuable knowledge to the field, paving the way for further innovations in the design and application of high-performance superhydrophobic coatings.

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Liquid Impalement Resistance and Mechanically Robust Superhydrophobic Coatings with Anti-icing Performance

Bucheng Li,[1] Junping ZHANG *,[1]

[1] *Research Center of Resource Chemistry and Energy Materials, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou, P.R. China*
Email address: libucheng@licp.cas.cn; jpzhang@licp.cas.cn

Keywords: Superhydrophobic; Impalement resistance; Mechanically robustness; Anti-icing

Abstract: Superhydrophobic coatings attract interest for their wettability and application potential, but balancing impalement resistance and mechanical robustness remains challenging. Herein, we report a superhydrophobic coating with both properties, achieved via rational design of hierarchical micro-/nanostructures. The coating exhibits excellent superhydrophobicity, outstanding impalement resistance (withstanding water jets of 7.8 m s^{-1} and 30 d immersion), and high mechanical robustness (surviving 2000 Taber abrasion and 400 tape-peeling cycles), along with good chemical and UV stability. This performance stems from its hierarchical structure, microstructure protection, and low surface energy. Consequently, it shows excellent anti-icing performance: delayed icing, ultra-low ice adhesion (<70 kPa at -10 °C), and high durability over repeated icing/deicing cycles. This work offers a feasible strategy to enhance coating robustness for diverse applications.

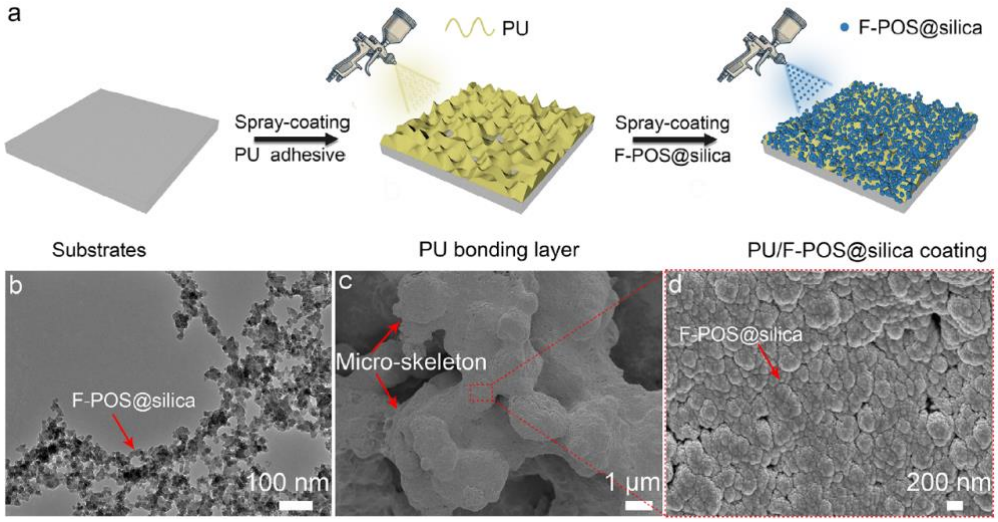

Fig. 1: Schematic preparation of the superhydrophobic anti-icing coatings

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A Sintering Model of Snow Adhesion

Matthew WU,[1,2] Anish TUTEJA*,[1,2,3,4]

[1]*Macromolecular Science and Engineering, University of Michigan, Ann Arbor, USA;*
[2]*Biointerfaces Institute, University of Michigan, Ann Arbor, USA;*
[3]*Department of Materials Science and Engineering, University of Michigan, Ann Arbor, USA;*
[4]*Department of Chemical Engineering, University of Michigan, Ann Arbor, USA;*

Keywords: Snow-shedding, ice-shedding, adhesion, sintering, lubricant-infused surfaces

Promising passive strategies for mitigating ice accumulation to surfaces are actively being developed and researched, however the mechanisms of adhesion and shedding for other forms of atmospheric fouling remain relatively unexplored. In particular, the mechanisms of snow adhesion to surfaces are not well understood given the complexities of the porous ice-surface interface. Notably, measured snow adhesion strengths are observed to be time-dependent, significantly increasing over time. Comparable increases in ice adhesion strength are not typically observed. In this study, we propose that these apparent increases in snow adhesion strength can be attributed to microstructural changes at the snow-surface interface. Due to its high specific surface area, snow readily undergoes particle sintering processes at high homologous temperatures. By adapting expressions for neck growth during ice-ice particle sintering, snow adhesion is modeled as a power-law function of time and surface energy. To validate this model, microscopy and adhesion tests on lab-made snow with well-defined properties are conducted. The power-law exponents predicted by our model (n = 5) strongly fit most of the experimental data. Shortcomings of the model are discussed, considering the high-residual deviations on high-energy surfaces and at long adhesion times. The potential of sintering-inhibiting lubricant-infused surfaces as snow-shedding surfaces is also discussed.

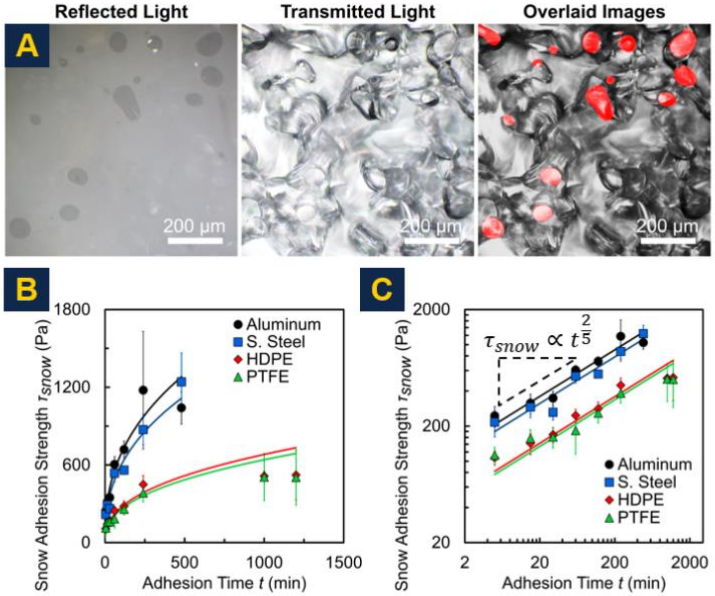

Fig. 1: (A) Snow-glass interfaces appear as "footprints" using reflected light microscopy. **(B)** τ_snow plotted against time for four surfaces. **(C)** τ_snow vs time on a log-log plot to illustrate the power-law relationship.

Biocompatibility Study of ECM-Mimicking Eggshell Membrane-Containing GelMA Cryogel for Microstructure Control

Yong-Seok Jang,[1,2] Jeonghui Ji,[1,2] Ilsong Park,[2,3] Min-suk Oh,[3] Min-Ho Lee*,[1,2]

[1]*Department of Dental Biomaterials, Institute of Biodegradable Materials, School of Dentistry, Jeonbuk National University, Jeonju, Republic of Korea*

[2]*Institute of Biodegradable Materials, Jeonbuk National University, Jeonju, Republic of Korea*

[3]*Division of Advanced Materials Engineering, Research Center for Advanced Materials Development and Institute of Biodegradable Materials, Jeonbuk National University, Jeonju, Republic of Korea*

Keywords: Eggshell membrane, GelMA, Cryogel scaffold, Biocompatibility

This study demonstrates that the incorporation of nature-derived ESM into GelMA cryogels effectively modulates the internal surface topography and biochemical cues, successfully mimicking the natural ECM microenvironment. Gelatin methacryloyl (GelMA)-based cryogels offer interconnected macropores ideal for bone scaffolds, yet their limited bioactivity remains a challenge. To resolve this, we engineered nature-inspired composite scaffolds by incorporating eggshell membrane (ESM)-a collagen-rich protein network-into GelMA cryogels to mimic the native extracellular matrix (ECM).

Cryogels (15 mg/mL) with varying ESM contents (0–15 wt%) were synthesized via redox-initiated polymerization. SEM confirmed well-defined interconnected pores, though pore size decreased with higher ESM loading due to ice crystal inhibition. While moderate ESM addition significantly enhanced compressive strength, excessive loading (15 wt%) led to particle aggregation and stress concentration. All scaffolds demonstrated excellent cytocompatibility, with high cell viability and uniform distribution confirming that ESM provides a biomimetic microenvironment for cell adhesion. The 10 wt% ESM group exhibited the most balanced structural and biological performance.

Beyond its role as a standalone scaffold, this nature-inspired GelMA/ESM composite system holds significant potential as a multifunctional coating layer for metallic biomaterials (e.g., Titanium implants). By applying this biomimetic cryogel to the surfaces of bio-inert metallic implants, it is expected to bridge the gap between rigid inorganic surfaces and soft biological tissues, enhancing osseointegration and reducing fibrous encapsulation.

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Durable, broad-spectrum anti-biofouling polyurethane-based coatings

Zoe MEYER,[1,2] Taylor REPETTO, [1,2] Shane STAFSLIEN, [3]
Geeta MEHTA, [1,4,5] Abdon PENA-FRANCESH,[1,2,4,6,7] Dean WEBSTER, [3] Anish TUTEJA*[1,2,4,6]

[1] *Department of Materials Science & Engineering, University of Michigan, Ann Arbor, MI, USA;*
[2] *Biointerfaces Institute, University of Michigan, Ann Arbor, MI, USA;*
[3] *Department of Coatings and Polymeric Materials, North Dakota State University, Fargo, ND, USA;*
[4] *Macromolecular Science & Engineering, University of Michigan, Ann Arbor, MI, USA;*
[5] *Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI, USA;*
[6] *Department of Chemical Engineering, University of Michigan, Ann Arbor, MI, USA;*
[7] *Robotics Institute, University of Michigan, Ann Arbor, MI, USA*

Keywords: biofouling, polymers, marine, non-toxic

Biological fouling, or biofouling, refers to the accumulation of unwanted organisms or biological components on a surface. In marine applications, biofouling on ship hulls diminishes functional efficacy by increasing drag, noise signature, maintenance requirements, and fuel consumption, while reducing top speeds, material integrity, and vessel service life. Despite a concerted effort to transition away from the use of heavy metal copper-based anti-biofouling marine coatings, they are still widely used in the marine and naval sectors due to insufficiently effective non-toxic alternatives. This work investigates non-toxic anti-biofouling surface modification to address these challenges. By incorporating antimicrobial compounds derived from naturally occurring essential oils into a polyurethane-based coating, we achieve long-acting biocidal surface properties while maintaining the durability of polyurethane. We developed several coatings utilizing a range of antimicrobial compounds, demonstrating up to a 100% reduction in 48-hour biofilm growth of *Navicula incerta*, a common marine microalga (benthic diatom) implicated in marine fouling, compared to top-performing commercially available reference coatings. Furthermore, the coatings exhibited up to nearly a 100% reduction in 24-hour biofilm growth of common marine bacteria *Cellulophaga lytica*, and of 48-hour biofilm growth of green microalgae *Chlorella vulgaris* compared to references. Additionally, our antimicrobial polyurethane coating was applied to a fully functioning ship and demonstrated superior anti-biofouling performance over a 5-month operational period compared to state-of-the-art copper-based marine paint (**Fig. 1**). These coatings show significant advancement toward the development of durable, non-toxic, cross-application solutions that provide robust, broad-spectrum active anti-biofouling protection.

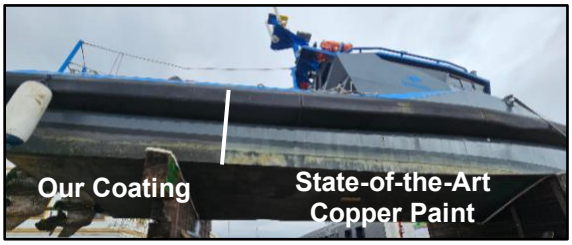

Fig. 1: Real-world demonstration of the superior antibiofouling performance of our coating compared to state-of-the-art copper-based coatings.

Mode-dependent adhesion characterization of ice-shedding surfaces

Tyler OLSON,[1] Jiayue HUANG,[2,3] Ronglin QIAO, [2] Anish TUTEJA*[1,2,3]

[1]*Applied Physics, University of Michigan, Ann Arbor, United States;*
[2]*Materials Science and Engineering, University of Michigan, Ann Arbor, United States;*
[3]*Macromolecular Science and Engineering, University of Michigan, Ann Arbor, United States;*

Keywords: ice adhesion, mode-dependent fracture, interface

Surfaces that combat the accretion of ice and snow are crucial to preventing losses in many fields, such as the transportation, infrastructure, and energy industries. However, there exists no universally accepted method of measuring the ice-shedding capability of these surfaces. Variability in test methodology can lead to differences in reported adhesion data, even for the same material, complicating direct comparison across studies [1]. The fracture of ice from an underlying substrate is complex and dependent on several factors, including the mode of ice detachment and interfacial length-scale. The direction of the applied ice-removal load can lead to varying stress concentrations at the interface and, thus, differences in the fracture behavior of ice from an underlying substrate. Further, interfacial length-scale determines whether interfacial strength or toughness should be used to describe ice detachment [1, 2]. While many researchers utilize ice adhesion testing systems, adhesion properties are often only measured using one mode of detachment and interfacial length, and this limited data is insufficient to claim that a material will perform well for all de-icing applications. This work focuses on the development and utilization of a comprehensive ice adhesion testing methodology used to further characterize ice-shedding materials under many removal conditions. Through use of several adhesion tests spanning various geometries, detachment modes, and length-scales, the specific performance limits of baseline and low-adhesion materials are assessed. The results confirm that ice adhesion behavior varies across materials as a function of testing mode, geometry, length-scale, and other factors, highlighting the limitations of single-test evaluations. These insights ultimately allow the design of ice-shedding materials to be optimized for specific applications by accounting for the mechanical loads and environments they are likely to experience under real-world operating conditions.

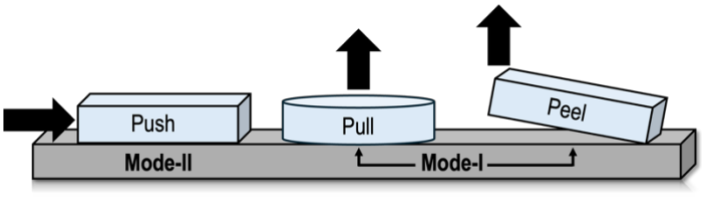

Figure 1: Three of the fundamental ice adhesion tests utilized in this study. The pull and peel tests are predominantly mode-I (tensile), while the push test is predominantly mode-II (shear).

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Auxetic Structures Fabricated via Femtosecond Laser Micromachining

Teresa BUSCH,[1] Shruti MANDHANI,[2] Glen MCHALE,[3] Anne-Marie KIETZIG*[1]
[1]*McGill University, Montreal, Canada;*
[2]*Sheffield Hallam University, Sheffield, United Kingdom*
[3]*University of Edinburgh, Edinburgh, United Kingdom*

Keywords: Auxetic metamaterials, Femtosecond Laser, Strain-dependent wetting, Springtail

The cuticle of the collembola (springtail) species exhibits an array of overhanging triangular granules in a hexagonal configuration to support robust cutaneous respiration [1]. These granules have been replicated in the literature as micro-pillars with overhanging edges arranged in rectangular arrays, yielding pressure-stable omniphobic surfaces [2]. More recent work has proposed a new link between the overall cuticular pattern and a hexagonal connected three-pointed star auxetic array. It has also separately demonstrated that the wetting behavior of a planar re-entrant hexagonal auxetic array depends on the auxetic rotation angle (α in **Error! Reference source not found.**) and the solid fraction in contact with the droplet [3]. Auxetic materials are materials capable of lateral growth under axial strain, contrary to conventional materials which shrink laterally when pulled apart.

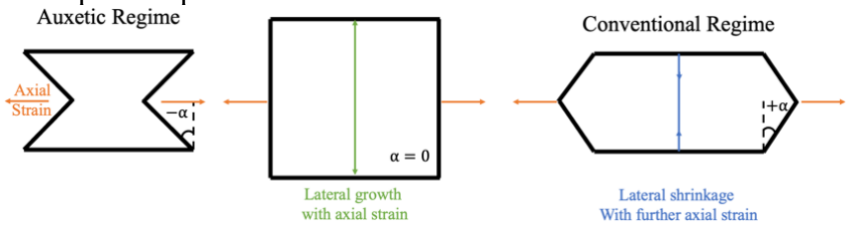

Fig. 1. Transition of a re-entrant auxetic shape to a non-auxetic hexagonal shape under strain.

The strain-dependence of the anti-wetting behavior of a biomimetic surface linking the overhanging features of the triangular primary granules and the auxetic-like hexagonal interconnectedness of these granules remains to be explored. Fabrication methods for overhanging features and auxetic arrays are generally complex and limited to specific materials. Here we present femtosecond laser micromachining (FLM) as a method to produce 2D auxetic arrays on polymer and metal samples, whose dimensions fall within the smallest length scales achieved in literature. The FLM system utilizes a fs pulsed laser with a 1030 nm wavelength. We compare an accurate stage-scanning setup (5-axis stage) to a laser-scanning (galvo-scanning) setup capable of high processing speeds and have shown that there is no loss of accuracy when using the laser-scanning setup for pore sizes in the 10^{-2} mm^2 range. Overall, we have demonstrated the capabilities of FLM in producing highly precise microscale auxetic structures through a variety of pore cutting methods and have demonstrated their anti-wetting behavior under continuous strain for auxetic pores with solid fractions ranging from 0.35 - 0.75, and pore sizes ranging from 10^{-3} - 10^{-1} mm^2.

Acknowledgments: This project is supported by the Royal Society (IES\R1\251121).

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ECM-Mimetic Hybrid Coating Based on Bioactive Ceramics and Natural Polymers for Osteoinductive Molecule Delivery

Seo-Young Kim [1], Min-Ho Lee [1], Jeong-Hui Ji [1], Yong-Seok Jang *,[1]
[1]*Department of Dental Biomaterials, Institute of Biodegradable Materials, School of Dentistry, Jeonbuk National University, Jeonju, Republic of Korea*

Keywords: Hybrid coating, Bioactive ceramic, GelMA, BMP-2, Biocompatibility.

Magnesium implants offer biodegradability and bone-like mechanical properties but suffer from rapid corrosion–induced instability; this study addresses this by using an osteoconductive molecule-loaded CaP–GelMA hybrid coating that mimics the hierarchical bone ECM.
CaP layer was formed on the Mg surface via hydrothermal treatment at 90 °C for 1 h using a mixture of chitosan solution (0.1 w/v% in 1% acetic acid) and CaP -based solution (0.25mol/L Ca-EDTA and 0.25mol/L KH_2PO_4) at the mixing ratio of 20:80. Osteoconductive molecule-loaded GelMA layer was coated with the concentration of 5 w/v% GelMA, 1.5 w/v% TEA, 1 w/v% VC, 0.03 mM Eosin Y disodium salt, and 50 ng/μL of BMP-2. The hybrid coating was evaluated through surface characterization, corrosion testing, and MC3T3-E1 cell activity for bone regeneration.
The CaP layer consisted of octacalcium phosphate (OCP) and hydroxyapatite (HA) with a thin $Mg(OH)_2$ layer and exhibited a network structure similar to bone architecture. The osteoconductive molecule-loaded GelMA coating densely infiltrated the CaP network, forming an ECM-mimetic hybrid coating layer. This CaP layer provided high polarization resistance (R_p), while the hybrid coating contributed to increased charge-transfer resistance (R_{ct}), increased corrosion potential (E_{corr}), and decreased current density (I_{corr}). The rough CaP particles containing OCP and HA induced better cell adhesion compared to the pure Mg surface. The final hybrid surface gradually enhanced cell proliferation and osteogenic activity along with cytoplasmic spreading.
The ECM-mimetic hybrid coating formed on the magnesium surface consists of a mineral CaP layer that promotes osteoconduction combined with a gelatin-derived GelMA matrix that enables cell interaction and controlled delivery of osteoinductive molecule. Therefore, it induces uniform biodegradation of the Mg implant, enhances cell adhesion, and promotes stable bone regeneration.

"This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2021R1C1C2006915) and the Korea Foundation for Women in Science, Engineering and Technology (WISET) with funding from the Science and Technology Promotion Fund and Lottery Fund (WISET 2026-228)."

Mussel-Inspired Catecholamine Surfaces for ROS-Mediated Antimicrobial Activity Against Planktonic Bacteria and Biofilms

Belén PEPIÓ-TÁRREGA,[1] José D. BOLAÑOS-CARDET, [1] Daniel RUIZ-MOLINA, [1] Salvio SUÁREZ-GARCÍA*,[1]

[1] *Catalan Institute of Nanoscience and Nanotechnology – ICN2 (CSIC-BIST), Campus UAB, Bellaterra, 08193 Barcelona, Spain*

Keywords: mussel-inspired materials; catecholamine; reactive oxygen species; photothermal; antimicrobial

Marine mussels adhere tenaciously to virtually any surface under wet and saline conditions, a capability mediated by mussel foot proteins (mfps), rich in the amino acid 3,4-dihydroxy-L-phenylalanine (L-DOPA). The catechol side chain of L-DOPA is responsible for this behavior, forming a versatile array of covalent and non-covalent interactions with inorganic and organic substrates alike. Beyond its adhesive role, the catechol unit is inherently redox-active: it undergoes spontaneous oxidation under mild aerobic conditions, generating reactive oxygen species (ROS) including hydrogen peroxide, hydroxyl radicals, and superoxide anions. This dual character, combining strong surface affinity with sustained oxidative chemistry, makes catechol an exceptional building block for the design of functional antimicrobial materials. [1]

Inspired by this chemistry, a family of catecholamine materials has been developed through the aqueous co-polymerization of catechol derivatives with amine-based ligands at room temperature in a single synthetic step. [2] This one-pot and scalable approach enables the conformal deposition of thin coatings on a wide range of substrates, including clinically relevant materials used in biomedical and environmental applications. By changing the catechol precursor, physicochemical properties such as surface charge, photothermal properties and even ROS production can be tuned, making these types of coatings effective against a wide range of pathogens. In this work, the antimicrobial properties of these materials have been evaluated across two infection scenarios of increasing clinical complexity. On the one hand, coated biomedical grade titanium and porous 3D scaffolds exhibit potent and broad-spectrum bactericidal activity through direct contact killing, validated against Gram-positive (*Escherichia coli*) and Gram-negative pathogens, including drug-resistant strains (*Staphylococcus aureus* and Methicillin-Resistant *Staphylococcus aureus*). Finally, in a more realistic scenario, biofilm inhibition and eradication have been evaluated against clinically relevant biofilm producer's strains (*Staphylococcus aureus* and *Staphylococcus epidermidis*).

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Correlative Chemical and Nanomechanical Characterization of Resin-Dentin Hybrid Interfaces Using Confocal Raman Microscopy and Viscoelastic AFM

Hiroki ITASAKA,[1] Kumiko YOSHIHARA*,[2,3] Noriyuki NAGAOKA,[3] Sungho LEE,[1] Bart Van MEERBEEK[4]

[1]National Institute of Advanced Industrial Science and Technology (AIST), Multi-Material Research Institute, Aichi, Japan;
[2]National Institute of Advanced Industrial Science and Technology (AIST), Health and Medical Research Institute, Kagawa, Japan
[3]Okayama University, Dental School, Advanced Research Center for Oral and Craniofacial Sciences, Okayama, Japan;
[4]KU Leuven, Department of Oral Health Sciences, BIOMAT & UZ Leuven, Dentistry, Leuven, Japan

Keywords: Dentin, Adhesive, Raman spectroscopy, Viscoelastic atomic force microscopy (AFM)

Durable bonding to dentin, a complex biocomposite of collagen and hydroxyapatite, is essential for the long-term success of dental restorations. Unlike synthetic materials, this bonding must be achieved in a hydrated, biocompatible confinement under strict clinical processing limitations, and must subsequently withstand severe cyclic masticatory forces and thermal shocks. To tackle these challenges, phosphate-based functional monomers have been utilized to establish chemically and mechanically reliable interfaces via two major adhesive strategies: etch-and-rinse and self-etching [1]. The etch-and-rinse strategy infiltrates resin into a deeply demineralized collagen network, whereas the self-etch strategy simultaneously demineralizes and infiltrates the dentin matrix. Therefore, it is necessary to evaluate the nano-scale functionally graded interface between the synthetic polymer and the natural biocomposite. However, how different surface treatment strategies influence the chemical and nanomechanical integrity of this interfacial layer remains incompletely understood [2].

In this study, hybrid layers formed by a universal adhesive using both strategies were characterized by confocal Raman chemical mapping and viscoelastic atomic force microscopy (AFM). Cross-sectional Raman mapping revealed marked differences in the interfacial chemical structure between the two strategies. The etch-and-rinse adhesive formed a hybrid layer approximately 3-5 μm thick, whereas the self-etch adhesive generated a much thinner layer of less than 1 μm. These structural differences were independently verified by viscoelastic AFM imaging, which successfully mapped the local nanomechanical variations corresponding to the chemical domains observed in the Raman maps. The structure-property relationships between the nano-scale interfacial design and macro-scale dentin bond strength will be presented and discussed.

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Future Research Directions for Multifunctional Nature Inspired Surfaces: Opportunities and Challenges

Hyuneui Lim*,[1] Yuna Kang ,[2]

[1]*Nature-Insipred Research Center, Daejeon, South Korea;*
[2] *Department of Medical device, Daegu, South Korea*

Keywords: nature-inspired surface, multifunction, eco-friendly method, sustainability, future, carbon neutrality

To date, bio-inspired surfaces with various distinct functionalities have been extensively investigated, and several advanced platforms are already utilized in practical, real-world applications. However, unlike natural counterparts, artificial bio-inspired surfaces still face critical limitations regarding long-term mechanical durability and self-healing capacities under dynamic environments. Although diverse strategies have been explored to overcome these bottlenecks, definitive solutions remain elusive. To address these challenges, this paper discusses key future developmental directions for next-generation bio-inspired surfaces. Specifically, we highlight the integration of artificial intelligence (AI)-driven multi-objective optimization for material selection, the scalable manufacturing of multiscale hierarchical structures, and the development of eco-friendly, sustainable biomimetic chemistries tailored for carbon neutrality. Through this comprehensive discussion, this paper aims to provide prospective pathways and insights for the evolution of robust, adaptable, and smart multifunctional biomimetic systems.

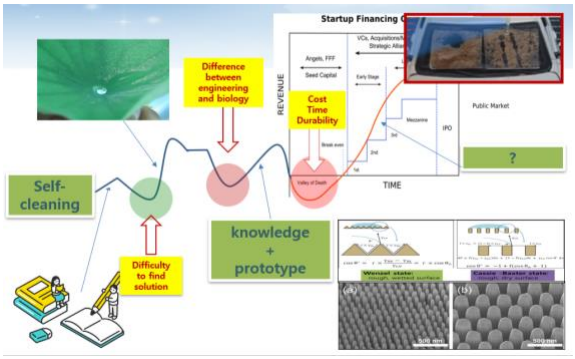

Fig. 1: Opportunities and challenges of self-cleaning glass

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Procedurally Evaluating the Snow Shedding Behavior of Coated Surfaces

Matthew WU,[1,2] Dev GURERA,[2,3] Anish TUTEJA*,[1,2,3,4]

[1]*Macromolecular Science and Engineering, University of Michigan, Ann Arbor, USA;*
[2]*Biointerfaces Institute, University of Michigan, Ann Arbor, USA;*
[3]*Department of Materials Science and Engineering, University of Michigan, Ann Arbor, USA;*
[4]*Department of Chemical Engineering, University of Michigan, Ann Arbor, USA;*

Keywords: Snow-shedding, ice-shedding, adhesion

Promising passive strategies for mitigating ice accumulation to surfaces are actively being developed and researched, however the mechanisms of adhesion and shedding for other forms of atmospheric fouling remain relatively unexplored. In particular, the mechanisms of snow adhesion are not well understood due to the difficulty of reproducibly creating and testing snow. Outdoor studies are subject to variabilities in weather, while many indoor studies do not thoroughly characterize snow properties and the spontaneous annealing it undergoes. In this study, facilities and procedures for creating snow, measuring its properties, and testing adhesion to surfaces are developed. Synthetic snow with nature-like properties is made on-demand using a controlled spray of air and water into a walk-in freezer. By monitoring snow density, liquid water content (LWC), and particle size, changes arising from particle coarsening and sintering are characterized. With our well-defined snow, reproducible indoor snow adhesion tests are conducted to determine the abilities of coated surfaces to minimize snow adhesion strength. Simultaneously, the same coated surfaces were deployed in outdoor studies over the winter season in Ann Arbor, MI. Surfaces with low snow adhesion strength indoors also demonstrated strong snow shedding capabilities outdoors, suggesting that the facilities and procedures developed here are capable of reliably assessing the snow shedding performance of coated surfaces.

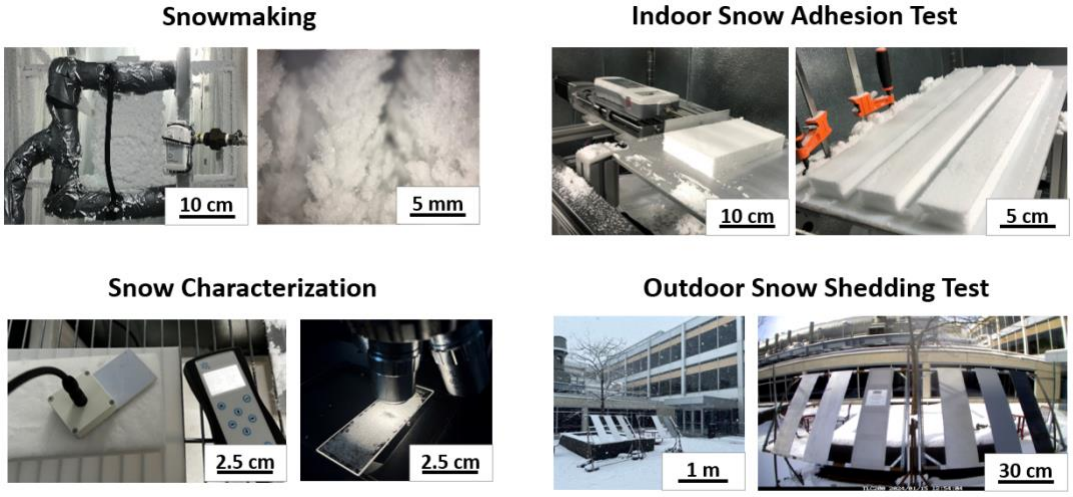

Fig. 1: Equipment for making reproducible snow and testing snow adhesion.

Enhancing PEM Fuel Cell Performance via APCVD-Engineered Superhydrophobic Aluminum Bipolar Plates

N Rahul,[1] Il-Song Park,[1] Min-Ho Lee,[2] Yong-Seok Jang,[2] Jeonghui Ji,[2] Min-Suk Oh*,[1]

[1]*Division of Advanced Materials Engineering, Jeonbuk National University, Jeonju, Republic of Korea;*
[2]*Department of Dental Biomaterials, Institute of Biodegradable Material, School of Dentistry, Jeonbuk National University, Jeonju, Republic of Korea*

Keywords: Superhydrophobic coating, Aluminum bipolar plates, PEM fuel cells

Aluminum alloy bipolar plates for proton exchange membrane fuel cells (PEMFCs) are prone to severe corrosion under acidic and humid conditions, degrading performance and durability.[1,2] Here, a scalable superhydrophobic coating (~8 μm) is developed via wet-chemical etching followed by atmospheric pressure chemical vapor deposition (APCVD) of fluoroalkylsilane. The etching process creates hierarchical micro/nano structures, which are subsequently functionalized to achieve low surface energy. The coating exhibits a corrosion current density of 3.2×10^{-8} A/cm², over three orders of magnitude lower than bare aluminum, and a positive corrosion potential shift of 0.18 V (vs. Ag/AgCl) in a simulated PEMFC cathode environment at 80°C. The surface shows a water contact angle of 157.3° and a sliding angle below 1°, enabling efficient water removal and reduced flooding. In-situ electrochemical impedance spectroscopy over 72 h confirms stable corrosion resistance and adhesion under potentiostatic polarization (0.6 V vs. NHE). Surface and electrochemical analyses demonstrate durable performance without delamination. The combined effect of surface structuring and low surface energy stabilizes the Cassie–Baxter state, effectively limiting corrosive species penetration. This approach provides a cost-effective and scalable alternative to conventional noble-metal or PVD coatings for PEMFC bipolar plates.

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