SPP 2171 Spring Conference: Dynamic Wetting of Flexible, Adaptive, and Switchable Substrates

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Max Planck Institute for Polymer Research

Buch der Abstracts

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Drops dance and explode on lubricated surfaces

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In 2011, Quere, Aizenberg, and co-workers independently introduced the innovative concept of infusing a solid surface with a thin oil film to eliminate contact-line pinning [1-3]. The invention of this new material class—lubricated surfaces—has since revolutionized the design of super-repellent surfaces, with important anti-fouling and heat transfer applications.
In this talk, I will explore two intriguing phenomena observed on these surfaces. First, I will discuss how condensing drops can exhibit spontaneous collective motion, "dancing" across the surface, a unique example of active matter system fuelled entirely by condensation [4]. This phenomenon can have important applications in harvesting atmospheric water [5]. Next, I will delve into the spontaneous occurrence of Coulomb explosions in evaporating drops [6, 7]. Together, these topics highlight the rich, interdisciplinary connections between droplet physics and broader fields in soft matter physics and electrohydrodynamics.

1. T-.S. Wong, ⋯, J. Aizenberg, "Bioinspired self-repairing slippery surfaces with pressure-stable omniphobicity,"Nature (2011)
2. A. Lafuma, J. Aizenberg, "Slippery pre-suffused surfaces," Europhys. Lett. (2011)
3. D. Daniel, …, J. Aizenberg, "Oleoplaning droplets on lubricated surfaces", Nature Physics (2017)
4. M.Lin, …, D. Daniel*, "Emergent collective motion of self-propelled condensate droplets", Phys. Rev. Lett. (2024).
5. S. Ahmad, …, D. Daniel, *S. Yang, Q. Gan*, "Lubricated surface in a vertical double-sided architecture for radiative cooling and atmospheric water harvesting,"Adv. Mater. (2024).
6. M. Lin, …, D. Daniel*, "Evaporation-driven electrosprays in charged drops on lubricated surfaces" , Preprint (2024). DOI:10.13140/RG.2.2.27778.90565
7. M. Lin, F. W. Wardani, D. Daniel, "Exploding drops on lubricated surfaces", DOI:10.1103/APS.DFD.2024.GFM.V2634768

Short Talks / 9

Breaking Liquid Diodic Strucutres

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Liquid diodes are surface structures that enable the flow of liquids in one direction but prohibit flow in the reverse direction[1]. When these diodes are made from flexible materials, their structure can deform under external compressive forces, and, in return, their diodic nature can break. In a previous study by Sammartino et al.[2], it was demonstrated that reverse flow in liquid diodes can be activated, depending on the velocity of compression. The reverse flow occurs due to the formation of a convex meniscus at the opening of the diode. When the liquid front reaches a counter surface at the diode, it forms a capillary bridge that enables reverse flow.
The objective of my research is to deepen our understanding of the mechanisms governing this reverse flow by examining the factors that influence the formation of a transient convex meniscus, including geometric configurations and compression dynamics. In practice, the length of the channel leading into the diode. These findings will lay the groundwork for a broader exploration of how geometry influences reverse flow in liquid diodes. Furthermore, a comprehensive understanding of these factors is essential for optimizing the performance of liquid diodes, especially when integrated into 2D networks[3]. When such networks are subject to a global compressive force, diodes can

locally break, resulting in reverse flow. This local effect can, in turn, affect the flow in the whole network.

[1] C. Sammartino, M. Rennick, H. Kusumaatmaja, and B.-E. Pinchasik, "Three-dimensional printed liquid diodes with tunable velocity: Design guidelines and applications for liquid collection and transport,"Phys. Fluids, vol. 34, Nov. 2022, doi: 10.1063/5.0122281.

[2] C. Sammartino and B.-E. Pinchasik, "Liquid Zener diodes,"Mater. Horiz., vol. 11, no. 20, pp. 4925–4931, Oct. 2024, doi: 10.1039/D4MH00688G.

[3] C. Sammartino, Y. Shokef, and B.-E. Pinchasik, "Percolation in Networks of Liquid Diodes,"J. Phys. Chem. Lett., vol. 14, no. 34, pp. 7697–7702, Aug. 2023, doi: 10.1021/acs.jpclett.3c01885.

Short Talks / **24**

High-Order Methods for Wetting and Dewetting Phenomena on Soft and Rigid Substrates including Heat transfer

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We are going to present a numerical method which combines the fluid-structure-interaction solver for simulating the wetting of solid substrates, developed in the first funding period of the priority programme with a solver for heat transfer and evaporation. This solver is based on the highly accurate Extended Discontinuous Galerkin discretization, to achieve a highly accurate spatial discretization. Both, the fluid as well as the solid phase are modelled in a Eulerian frame, which enables a monolithic solver design, where all phases are discretized on the same mesh.
Preliminary results demonstrate the method's ability to capture interactions between levitating droplets (Leidenfrost effect) and soft substrates. Furthermore, we are going to present current progress regarding the fluid-structure interaction solver, e.g., with respect to validation and verification of the physical modelling.

Short Talks / **27**

Droplets on soft sheets form lenses and create wrinkling patterns

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Droplets resting on flexible sheets deform into lens-like shapes, offering promising applications in areas like tunable liquid lenses. We have extended and employ our fully three-dimensional Boundary Element Method (BEM) simulation framework [1] to investigate dynamic wetting on thin flexible sheets. Our study focuses on the intricate interplay between the mechanical properties of the sheet and droplet behavior, particularly emphasizing contact angle and droplet shape.

By varying the tension and mechanical properties of the sheet, our model demonstrates how we can control and tune the shape of the droplet. Additionally, by introducing a circular sheet, we observe the occurrence of a wrinkling pattern phenomena on our sheet. The versatility of our model suggests potential extensions to other soft material and droplet interactions, such as capillary origami and droplet motion by durotaxis. This work sheds light on the complex interactions between soft substrates and liquid interfaces, leading the way for advancements in material science and interfacial biology.

[1] J. Grawitter and H. Stark, Steering droplets on substrates with plane-wave wettability patterns and deformations, Soft Matter 20, 3161 (2024).

Short Talks / 3

Non-monotonic motion of sliding droplets on strained soft solids

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Soft materials are ubiquitous in technological applications that require deformability, for instance, in flexible, water-repellent coatings. However, the wetting properties of pre-strained soft materials are only beginning to be explored. Here we study the sliding dynamics of droplets on pre-strained soft silicone gels, both in tension and in compression. Intriguingly, in compression we find a non-monotonic strain dependence of the sliding speed: mild compressions decelerate the droplets, but stronger compressions lead again to faster droplet motion. Upon further compression, creases nucleate under the droplets until finally, the entire surface undergoes the creasing instability, causing a "run-and-stop"droplet motion. We quantitatively elucidate the speed modification for moderate pre-strains by incremental viscoelasticity, while the acceleration for larger strains turns out to be linked to the solid pressure, presumably through a lubrication effect of expelled oligomers.

Short Talks / 36

The role of substrate mechanics in osmotic biofilm spreading

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Bacteria invade surfaces by forming dense colonies encased in a polymer matrix. Successful settlement of founder bacteria, early microcolony development and later macroscopic spreading of these biofilms on surfaces rely on complex physical mechanisms. Recent data show that on soft hydrogels, substrate rigidity is an important determinant for biofilm initiation and spreading, through mostly unknown mechanisms. Using a thermodynamically consistent thin-film approach for suspensions on soft elastic surfaces supplemented with biomass production and an imposed osmotic pressure we investigate in silico the role of substrate softness in the osmotic spreading of biofilms. We show that spreading is considerably slowed down on soft substrates and may be completely halted depending on the biomass production rate. We find, that the critical slowing down of biofilm spreading on soft surfaces is caused by a reduced osmotic influx of solvent into the biofilm at the edges, which results from the thermodynamic coupling between substrate deformation and interfacial forces. By linking substrate osmotic pressure and mechanical softness through scaling laws, our simple model semi-quantitatively captures a range of experimentally observed biofilm spreading dynamics on hydrogels with different architectures, underscoring the importance of inherent substrate properties

in
the spreading process.

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Observing the structure of non-fouling polymer brushes in aqueous solutions

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Hydrophilic polymer brushes are widely utilized in biomedical applications to prevent non-specific interactions with biological fluids. While the chemical structure of the coating plays an important role in the non-fouling character and bio-functionality, the physical state of polymer chains determines the coating's properties. However, the actual physical state of the polymer chains constituting the coatings has been rarely accessed. The understanding of physical state, interfacial behavior and the investigation of conformation changes of the polymer brushes when exposed to various aqueous solutions and external stimuli is important for the correct design of biomaterials. The conformation of grafted polymer chains at the solid-liquid interface can strongly depend on the polymer brush grafting density but also on the type and concentration of salts in the surrounding aqueous phase.

In this contribution, we will report on our efforts to thoroughly examine the chemical and physical structure of polymer brushes synthesized via surface-initiated atom transfer radical polymerization (SI-ATRP) from initiating moieties bound on the surface. By tuning the surface concentration of initiating groups, we have synthesized polymer brushes of various grafting density. We have employed various surface sensitive techniques to thoroughly examine the chemical and physical structure of the polymer chains. Furthermore, we have probed the viscoelastic response of the brushes of various grafting densities by combining ex- and in-situ acoustic QCMD and variable angle spectroscopic ellipsometry (VASE) measurements. The concomitant QCM-D-VASE analysis provided insights of the scaling behavior of the end-tethered polymer brushes and their conformational behavior not only when contacted with water but also when exposed to anions of the Hofmeister series.

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Synthesis, polymerization and characterization of dye-labeled polymethacrylate brushes

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Synthesis, polymerization and characterization of dye-labeled polymethacrylate brushes

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In the project, the dynamics of wetting of the poly(di(ethyleneglycol) methyl ether methacrylate) (PDEGMA) brushes is studied by analyzing the fluorescence dynamics of a solvatochromic reporter dye. In particular, poly(di(ethyleneglycol) methyl ether methacrylate) brushes with an overall uniform height, containing a solvatochromic dye, which is able to probe the local polarity in its vicinity [1], covalently attached to the brushes in a one-dimensional depth gradient, should be employed to image the wetting dynamics with confocal fluorescence microscopy both with high lateral as well as enhanced axial resolution. Gradient brushes [2] were successfully synthesized by surface-initiated activator regenerated by electron transfer, atom transfer radical polymerization (SI-ARGET ATRP) with inverse gradient directions exploiting two consecutive polymerizations. Linear gradient brushes with dry thicknesses from 50 nm up to 400 nm were obtained and the polymerization of a second and a third block to obtain an overall uniform height was accomplished with a reinitiation efficiency of > 80%. The introduction of a short second block of a co-monomer between those two gradient polymerizations was achieved to obtain a unique block copolymer brush architecture. In this contribution, the synthesis, polymerization and characterization of a dye-containing co-monomer will be presented, along with the synthesis of precisely tuned probe molecules based on Nile red and aurone units as fluorescent probes for the detection of local polarity and mobility of the environment in the polymer. Copolymerization of PDEGMA and this Nile red-based dye-containing methacrylate will be presented as an attempt to affect the local surrounding of the dye. Fluorescence lifetime imaging microscopy (FLIM) imaging of such surfaces in dry and wet conditions was conducted to characterize effects of the surface wetting. In the future the incorporation of other dye methacrylates into the gradient brush architecture will be attempted, to finally investigate the wetting dynamics of these polymer brush systems.

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References

[1] A. Yadigarli, Q. Song,S. I. Druzhinin, H. Schönherr, Beilstein J. Org. Chem. 2019, 15, 2552.
[2] S. Großhans, I. Lilge, H. Schönherr, Macromol. Biosci. 2018, 18 (2), 1700317.

Short Talks / 18

Hydrodynamic effects in adhering vesicles on periodically modulated substrates

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Vesicles on substrates play a crucial role in various biological transport processes, including neurotransmitter release at the synapse, transport between cells, and drug delivery using synthetic vesicles. The adaptive adhesion of the vesicles to a biological substrate is crucial for all these processes. Although in shape similar to droplet wetting, vesicle adhesion is fundamentally different as it is governed by the membrane's bending rigidity, whereas wetting is driven by surface tension.

In this study, we investigate the dynamics of permeable vesicles on substrates with periodically modulated adhesion strength using coarse-grained molecular dynamics (MD) simulations. The volume-enclosing membrane, which distinguishes vesicles from droplets, deforms during the adhesion process, inducing fluid flow both inside and outside the vesicle. This interaction between membrane deformation and hydrodynamics is complex and significantly affects the shapes observed during adhesion. A key factor in this process is the membrane's permeability.

By combining periodically modulated adhesion strength with a selected permeability, we modulate the vesicle-substrate contact, providing an effective control mechanism for both the contact time and area. Moreover, the hydrodynamic flows generated in the course of adhesion may enhance the transport of molecules toward the membrane, making this a vital element for controlling transport in biological vesicles.

Short Talks / **7**

Adaptive wetting device based on conducting polymers

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Conducting polymers (CPs) are used in a wide range of electrochemical devices, such as organic field effect transistors, batteries, actuators, and chemical-biological sensors. Compared to other conducting materials, CPs offer advantages such as lightweight, low cost, non-toxicity, flexibility, ease of processing, low-voltage operation (around 1 volt), and low power consumption. Poly(3-hexylthiophene) [1] is the most studied material in our group due to its high conductivity and electrochromic properties, which are controlled by its doping state. [2] In this context, electrochemical doping is explored as a versatile tool to change chemical and physical properties of P3HT, with a particular focus on wettability.
We observe significant wettability changes of spin-coated P3HT films which are doped by an ex-situ electrochemical doping strategy. The sessile drop technique is applied under controlled relative humidity (r. h.) condition, and yields water contact angle between 67° to 112°. Further investigations involve dynamic wettability measurements to determine hysteresis effect. Direct correlations with in-situ spectroelectrochemistry, solid state conductivity and absorption measurements allow us to quantify the degree of doping. The role of electrochemical doping on morphological changes gives further insights into ionic mixed conducting polymer films as flexible, adaptive substrates for wetting applications.

Short Talks / **4**

Wetting of Surface Grafted Hydrophilic-b-Hydrophobic Block Copolymer Brushes

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We studied the wetting of diblock copolymer brushes by water. Goal of this work is to understand how the thickness of the bottom and top copolymer block affect the wetting behavior, respectively. For the synthesis of diblock copolymer brushes we grafted the bottom block, a hydrophilic poly(2-hydroxyethyl methacrylate) (PHEMA) brush from a silanized silicon wafer. Than we grafted the top block, a hydrophobic polystyrene (PS) or poly(2-ethylhexyl methacrylate) (PEtHexMA) from the PHEMA block. Hereby, we obtained a hydrophilic-b-hydrophobic diblock copolymer. The top copolymer block determined the advancing contact angle of the copolymer brushes in their pristine state. The receding contact angle depends on the thickness of the top and bottom copolymer block. For a top copolymer thickness < 30 nm the receding contact angle decreased. An increase of the thickness of the bottom block to 35 nm decreased the receding contact angle as well. By exposing our diblock copolymer brush with a thickness of the top block >30 nm to warm water the wetting properties switched from a hydrophobic to a hydrophilic. The surface switched back to the hydrophobic state by exposing it to toluene and subsequent temperature annealing.

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Dynamic wetting of self-assembled monolayers and polymer brushes functionalized with molecular photoswitches

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Molecular photoswitches are a unique type of molecules that can be switched reversibly between two isomers (shapes) upon irradiation with light. Since the two isomers of the molecular photoswitch have different properties, incorporation of photoswitches into materials and coatings can result in macroscopic effects such as photoswitchable surface wettability. In this project we will investigate a new type of molecular photoswitch to prepare surfaces with photoresponsive wettability. Due to optimized molecular design, the photoswitch can be self-assembled in molecular monolayers or embedded in polymer brush nanofilms with enhanced dynamic wettability.

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Surfaces Slippery to Liquids

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Frictional forces resisting droplet motion often appear to be separate to surface wettability and liquid adhesion. Here I will show how equilibrium surface wettability, representing normal adhesion, combines with hysteresis, representing surface heterogeneity, to produce static and kinetic contact line friction. I will show how an Amontons-like liquid-on-solid law provides a unified view for the design of superhydrophobic, liquid-infused and liquid-like surfaces slippery to liquids. I will show how a contact line coefficient of friction, defined as the ratio of the frictional to normal component of surface tension forces, can be related to the Kawasaki-Furmidge equation. I will present experimental data from tilt angle experiments on liquid-like surfaces with low and high mobility for water droplets showing measurements are consistent with the predicted shape factor $k=\pi/4$. Finally, I will discuss the observed non-linear velocity-force relationship and a possible model based on a molecular kinetic type theory.

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Contact dynamics and morphology under drops impacting an oil-covered substrate

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Droplets impacting at low Weber numbers on sufficiently smooth solid substrates will bounce on a thin layer of entrained air, or will eventually contact the substrate. When and how this happens is influenced by the substrate properties, e.g., by charging or by elasticity. Here, we consider smooth glass slides covered by thin oil films of different thicknesses and viscosity. We investigate this impact situation using high-speed interferometry at oblique incidence and side / top view imaging. The thickness profile of the entrained air layer displays a central bubble, followed by a broad annual region of only slightly varying thickness in the range of few hundreds of nanometers. When the Weber number is just too large for the droplet to rebound or when local disturbances exist, a localized contact between the drop and oil layer emerges. While we do not control when and where the contact forms, we are mainly interested in the spreading dynamics and morphology of the contact line. The physical problem at hand can be seen from both the wetting perspetive of the drop liquid on the thin layer as well as from the perspective of the air film, rupturing between the drop and the microscopic viscous layer. We analyse the dynamics experimentally in view of both situations.

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Gradient dynamics model for volatile binary mixtures including Marangoni flows

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We present a mesoscopic thin-film model in gradient dynamics form for binary liquid mixtures on solid substrates incorporating interface tension-induced flow, and volatility in a narrow gap. Thereby, we use and expand models established in [1–4] by accounting for the two substances in each of two bulk phases - liquid and gas - and for the enrichment of one component at the liquid-gas interface. We discuss the different contributions to the free energy, thereby employing Flory-Huggins theory of mixing for the condensed phase and assuming ideal gases for the vapor phase. The resulting five-field model is then analyzed with numerical time simulations focusing on the interplay of the drop dynamics with the developing lateral concentration gradients, and the resulting Marangoni flows. The results are compared to experimental findings [5].

[1] Uwe Thiele, Andrew J. Archer, and Len M. Pismen. Physical Review Fluids, 2016. doi: 10.1103/physrevfluids.1.083903.
[2] Xinpeng Xu, Uwe Thiele, and Tiezheng Qian. Journal of Physics: Condensed Matter, 2015. doi:10.1088/0953-8984/27/8/085005.
[3] Simon Hartmann, Jan Diekmann, Daniel Greve, and Uwe Thiele. Langmuir, 2024. doi: 10.1021/acs.langmuir.3c03313
[4] Uwe Thiele, Desislava V. Todorova, and Hender Lopez. Physical Review Letters, 2013. doi: 10.1103/physrevlett.111.117801.
[5] Youchuang Chao, Olinka Ramírez-Soto, Christian Bahr, and Stefan Karpitschka. Proceedings of the National Academy of Sciences, 2022. doi: 10.1073/pnas.2203510119.

Short Talks / 19

Dynamics of a sessile drop exposed to a surface acoustic wave

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This talk focuses on the experimental, theoretical, and computational study of the dynamics of a thin silicon oil drop driven by the forcing resulting from applied surface acoustic wave (SAW) applied to the underlying substrate. Our experiments consider a drop spreading either on a flat substrate or on a substrate with a superimposed topology and serve as a test for the theoretical model and related simulations. The model itself starts from the first principles and introduces the forcing due to SAW into the standard long-wave formulation. The novel findings include some rather unexpected features of the resulting model that shed new light on the existing models that have been around for decades. Finally, our simulations allow for discussion of the influence of SAW on the time-dependent drop evolution in a fully nonlinear regime. We conclude by discussing similarities and differences between experimental and theoretical/computational results and possible directions for future work.

Short Talks / 2

Stood-up drops as a novel, easiest and fasted way to measure receding contact angles

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It is well-established that the receding contact angle (CA) plays a vital role in various applications where repelling liquids, preventing fouling, promoting self-cleaning, and drop friction are essential requirements and that it can also provide very relevant information for coating and bonding processes. However, measurements of the receding CA are typically time-consuming, challenging, and necessitate extensive protocols [1]. In this study, we introduce a novel drop deposition method that enables the rapid measurement of the recently receded CA within a few seconds and is entirely user-independent.

The method builds upon the existing "liquid-needle method" used to measure advancing CAs [2,3], wherein a thin liquid jet is meticulously controlled to deposit a droplet on the surface without imparting excess kinetic energy from the dosing process. In contrast to the liquid-needle method for advancing CA, our novel method for receding CA involves the liquid first spreading radially during dosing, forming a pancake-shaped film, and subsequently retracting to form a spherical cap-droplet shape, as illustrated in Figure 1. Consequently, we refer to such droplets as "stood-up drops" (SUD) [4].

We elucidate the crucial dosing parameters necessary to ensure that the contact angle of SUD accurately represents the recently receded contact angle and compares favorably to classically determined dynamic receding contact angles, as depicted in Figure 2. Furthermore, we provide real industrial application examples wherein this straightforward method of receding CA measurement could address production problems hitherto unresolvable with classical (advancing) contact angle measurements.

Short Talks / 11

Swelling of a polymer brush up to 100% relative humidity

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Polymers are known to respond to various stimuli, including liquid and gas phases. When partially wetted, they are exposed to both liquid and gas phases. The surrounding gas phase can influence the amount of swelling around the contact line or even change the wetting behavior depending on the gas used. While there are many studies of the brush response in the liquid phase, there are few that examine the response to the gas phase. In a partial wetting scenario with water, the brush is always exposed to a variety of relative humidities up to 100%. While there are studies at low to high relative humidities, there are none that investigate swelling up to 100% relative humidity. We present ellipsometry measurements measuring the thickness of a PNiPAAm brush up to 100% relative humidity until we start to see condensation. We find that the behavior at 100% relative humidity is the same as in water. This was shown by varying the temperature around the LCST and comparing it to the swelling in water. We also present a mean field theory, which allows us to theoretically describe and explain the swelling behavior.

[1] Besford, Q., et al., Mechanofluorescent Polymer Brush Surfaces that Spatially Resolve Surface Solvation, ACS Nano, 2022. 16(2)
[2] Schubotz, S., et al., Influence of the Atmosphere on the Wettability of Polymer Brushes. Langmuir 2023, 39, 14, 4872–4880

Short Talks / 17

Thermally activated swelling and wetting transition of frozen polymer brushes: a new concept for surface functionalization

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Functional polymer brush coatings have significant potential for a wide range of industrial applications due to their responsiveness to environmental stimuli, which allows for precise tuning of surface properties. Polymer brushes can swell or collapse in response to external stimuli such as temperature changes or variations in the chemical composition of the surrounding medium, leading to changes in interfacial properties and enabling specific functionalities. In addition to these external stimuli, intrinsic polymer transitions—such as melting and glass transitions—offer another effective way to modulate the behavior of polymer brushes. These transitions provide an additional mechanism to control and actuate brush properties, expanding the potential applications of these adaptive coatings.

To investigate this concept, we examine the wetting behavior of liquid n-alkanes on oleophilic bottle brushes composed of poly-n-alkyl methacrylate (PnMA). The melting temperature of these polymer brushes can be precisely tuned by adjusting the length of their side chains. By combining macroscopic wetting experiments, Atomic Force Microscopy (AFM) adhesion measurements, and vibrational Sum-Frequency Generation (SFG) spectroscopy, we demonstrate that the melting transition of a semicrystalline oleophilic poly-octadecylmethacrylate (P18MA) brush drives a coupled swelling and wetting transition when exposed to various liquid alkanes. Notably, the top surface of the P18MA polymer exhibits a slightly higher melting temperature compared to the bulk, allowing for independent control of bulk-driven swelling and surface-driven wetting transitions. These transitions can be activated either through global heating or localized excitation using a focused laser beam. These findings introduce a novel concept for polymer brush-based functional surfaces, enabling controlled fluid transport through independently switchable surface barriers and bulk transport layers.

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Light response lamellar structures based on carbon nanoparticles and polymer matrix

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Wettability can be applied in many applications such as microfluidic devices, oil/water separation, water energy harvesting, etc. There are two known approaches to modify the wettability properties of different materials: changing their topography or chemical modification of the surface The topography of materials also can be modified by applying external stimuli such as temperature, magnetic field, electric field, light and others. One large group of materials with switchable topography is shape memory polymers. These materials can reversibly change their topography upon external stimuli. Their topography changing effect can be based on melting/crystallization processes of crystalline parts. For example, the lamellar structure of polyether-urethane with poly(1,10-decylene adipate) (PEU-PDA) bends in presence of capillary forces at 70℃ [1]. However, temperature is not a local stimulus, and it is difficult to control specific areas of the material. On the other hand, laser exposure can be converted into thermal energy, although energy adsorption is better for dark surfaces. An approach was presented with coating polyester-urethane with poly(1,4-butylene adipate) black ink, which showed localized heating under laser exposure [2].
Here, we present a lamellar structure based on polymer composite by incorporation 0.2 wt.% graphene nanoplates (GN) or multi-walled carbon nanotubes (MWCNT) into PEU-PDA polymeric matrix. The particles in the polymer matrix increased the melting temperature up to 10℃, and the color of the composite materials became darker and could convert light energy into heat. The lamellar structure was fabricated by melt-electrowriting. The composite was heated to 210℃ and a voltage of 3 kV was applied between the extruder and the glassslide. The lamellae were exposed to an infrared laser (808 nm). The exposed lamellae were heated up to 53℃ and 74℃ for GN and MWCNT composites respectively. The exposed area wrinkled due to melting of the soft segments and this process is reversible. Water droplets placed between two lamellae can help to determine the direction of their bending. Although in normal condition, the lamellae will not bend because the capillary forces are insufficient to overcome the elastic moduli of the lamellae and bend them. Local heating by IR radiation reduces the elastic modulus by almost 10 times, and the lamellae can be bent by a water droplet. After evaporation that position of lamellae can be reprogrammed by an additional droplet in a neighbor position, allowing topography changes due to capillary forces and local heating. Such adjustments can help us to create new types of topography in microfluidic devices or fabricate complex structure patterns.

[1] Sadilov I., Constante G., Dulle M., Schönfeld D., Pretsch T., Ionov L. Reversibly Switchable Topography Enabled by Melting and Crystallization of Melt-Electrowritten Polymer Fibers// ACS Materials Lett. 2025, 7, XXX, 401–408, DOI: 10.1021/acsmaterialslett.4c02057
[2] Constante G., Apsite I., Schönfeld D., Pretsch T., Ionov L. Reversibly Photoswitchable High-Aspect Ratio Surfaces// Small Struct. 2023, 4, 2300040, DOI: 10.1002/sstr.202300040

Keynote / **44**

How to keep solar panels clean

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Solar panels are becoming an increasingly efficient and economical source of green energy. However, they rarely operate at optimum efficiency due to the accumulation of dust, pollen and dirt, which reduces the amount of sunlight that can be absorbed. In addition, harsh outdoor conditions can cause irreversible degradation of solar panels. We want to improve the ease of cleaning while maintaining good coating durability. To address these challenges, we are developing silica-based sol-gel coatings. To improve our fundamental understanding of dirt removal, we monitor and quantify particle removal using laser scanning confocal microscopy and friction force measurements. Particle removal is sensitive to the number and size of particles. The confocal data are complemented by measurements of the frictional force as droplets roll off contaminated surfaces.

Short Talks / 16

z-GrAdd_Facile Fabrication of Wettability Gradients Via DLP 3D Printing for Liquid Manipulation Applications

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Wettability gradients are particularly advantageous for controlled liquid imbibition and transfer, and they can be achieved through compositional variations in surface energy or topographical alteration of the surface, or both. Common methods to create wettability gradients including chemical modification of surfaces or the roughness patterning through etching and/or lithography are limited in scalability, do not allow for fabrication of complex structures with high resolution and often need costly equipment. Here, we present the z-GrAdd (z-Gradient by Addition of a reagent) method, which enables continuous alteration of resin composition during the layer-by-layer 3D printing, resulting in diverse gradient properties in z-direction. We demonstrate the fabrication of gradients in surface energy and porosity to create wettability gradients using a range of acrylate-based resins. Surface energy gradients (18–29 mN/m) with subsequent static contact angle variation of 86 ° to 71 °, and porosity gradient resulting in variation of roughness between 52–401 nm (Sq) and thus, SCA changes up to 50 ° (from 88 ° to 139 °) within a single structure were created using the z-GrAdd method. Versatile wettability gradient-related applications were shown. First, conical structures featuring different range of porosity gradients were utilized to control liquid imbibition rates, demonstrating advantages compared to structures with a uniform pore size. Second, porous structures with a uniform pore size but compositional gradient were fabricated through the z-GrAdd method and employed for passive droplet manipulation; the contact line of a water droplet only moved towards the more hydrophilic areas with larger pores or more hydrophilic properties and was able to even move uphill from one side. Our results prove that the z-GrAdd method can be used to create wide range of gradients including wettability gradients within a single structure along the z axis, and is suitable for various acrylate-based resin compositions using a cost-effective setup adaptable to various vat 3D printing systems.

Keynote / 49

Fluid dynamics during spontaneous imbibition in multimodal porous media

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Using porous materials for fluid management has been practised for thousands of years, e.g. water storage and release or filtration purposes. Thereby, the chemical nature of the porous material and the pore geometries determine the capacity of a porous material to take up a specific fluid through spontaneous imbibition. This talk addresses how geometric and chemical features impact multiphase flow dynamics and macroscopic performance using multiple examples of porous systems.

For instance, surface-engineered sponges for wastewater filtration: The sponges consist of a polyurethane-based fibre network and contain a porosity of ~98%. The fibres are made hydrophobic by chemical functionalization for wastewater filtration and oil spillage clean-up [1]. However, the displacement mechanism within them is guided through the hierarchical pore structure. First, the porous fibres are filled with oil, which then facilitates macroscopic displacement or nucleation of oil drops out of an emulsion between the fibres.
In another example, water imbibing an air-filled porous rock, we observe reverse behaviour. The large pores in between the grains are filled first, whereas the air from intergranular pores is released slowly [2].
These examples illustrate the careful considerations needed for the efficient design of porous materials in various applications and guide future design choices.

1. Cherukupally, P., Sun, W., Wong, A. P. Y., Williams, D. R., Ozin, G. A., Bilton, A. M., & Park, C. B. (2019). Surface-engineered sponges for recovery of crude oil microdroplets from wastewater. Nature Sustainability, 3(2), 136–143.

2. Wensink, G., Schröer, L., Dell, H. P., Cnudde, V., & Rücker, M. (2023). Spontaneous Imbibition and Evaporation in Rocks at the Nanometer Scale. Energy & Fuels, 37(23), 18713-18721.

Short Talks / **35**

Beyond the Cassie-Baxter Model: New Insights for Predicting Imbibition in Complex Systems

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We revisit the classical problem of liquid imbibition in a single pore with spatially varying wettability. Starting from the Lucas-Washburn equation, we derive analytical solutions for the imbibition time (crossing time) in systems where wettability alternates between two materials. For ordered arrangements, we demonstrate that the imbibition speed depends non-trivially on the spatial distribution, with the "more hydrophobic-first" configuration being optimal. For disordered systems, where segment lengths follow a Gaussian distribution, we show that the classical Cassie-Baxter contact angle, originally derived for static wetting, fails to predict the dynamics of capillary-driven flow. To address this, we propose a new harmonic averaging method for the contact angle, which accurately predicts the viscous crossing time in such heterogeneous systems. Our findings reveal fundamental insights into the role of wettability heterogeneity in capillary-driven flow, offering a basis for understanding imbibition dynamics in complex heterogeneous systems.

Poster Session / **26**

Dynamics of drop-induced lubricant separation and depletion on oleophilic polymer brushes

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Polymer brushes with infused lubricants show significant potential in reducing drop adhesion, yet the depletion of lubricant hinders its durability and the underlying mechanisms remain poorly understood. Our study focuses on observing and analyzing drop-induced lubricant depletion process on Poly Lauryl Methacrylate (PLMA) brushes with dimple and wetting ridge forming. We achieved controllable lubricant saturation in brushes by hexadecane vapor infusing, e.g., from 0% to ~400% within ten minutes, to explore the saturation-dependent oil transport dynamics. We developed a thin-film interference-based colorimetric reflectometry method to measure the real-time brush thickness, which helps to record the oil depletion process from brush layer, resulting in a local brush collapsing for tens of nanometers and the region of collapsing extend to around two hundreds of micrometers. The wetting ridge growth was recorded by confocal scanning laser microscope with fluorescence dyed hexadecane. Now, we are trying to establish a quantitative oil transfer model to interpret the dynamics of oil depletion and phase separation. This approach may help us unravel the competition between capillary force-driving lubricant extraction and osmotic pressure-induced lubricant retention.

Poster Session / 28

Removing particles from hydrophobic surfaces by single water drops

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The accumulation of dust on surfaces is a well-known phenomenon in everyday life, for example on windows and solar panels. Both manual cleaning and self-cleaning of hydrophobic surfaces with water can restore the properties of soiled surfaces. However, it is not yet understood how particles are removed by a water drop and which forces play a role for successfully removing the particles. We investigated the removal of two or more particles from hydrophobic surfaces by a single water drop. For this purpose, we used a confocal microscope with a sliding drop setup. This implies that the particles was moved at constant velocity while the drop can be imaged. From the deflection of the blade, we can determine the force required to pull the particles along with the drop. Here, we focus on the removal of spherical model particles and the impact of drop volume, particle size and particle velocity on the particle removal. At low velocities the particles remain attached to the drop. With increasing velocity we observe that the particle detachment becomes more likely. In case of particle detachment, we observe a correlative effect: either all particles stay in contact to the drop or all particles detach together.

Poster Session / 6

Spontaneously Charged Water Drops Induce Corrosion

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Water drops spontaneously become electrically charged when moving on different surfaces, such as plant leaves, building walls, window glass, and plastic. This process is called contact or slide

electrification. The electric potential of water drops charged in this way can even exceed 1 kV. A vital question as yet unanswered is whether the charge in water drops generates corrosion. Here, we demonstrate that even on metal surfaces that have a protective coating, spontaneously charged water drops can cause dielectric breakdown of the coating and then corrode the metal through electrochemical reactions. We encounter many surfaces in daily life where this corrosion mechanism occurs easily and yet has been completely overlooked.

Poster Session / 30

Lateral adhesion of droplets measured with the scanning drop friction force instrument

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The understanding of wetting phenomena plays a crucial role in many daily processes. For example, dirt repelling glasses can be achieved by a hydrophobic coating. Typically, the wetting properties of such a coating are characterized by measurements of the advancing and receding contact angles by sessile drop goniometry [1]. However, this method provides only information on the selected areas corresponding to the observed moving contact line. In sessile drop goniometry this area is typically a few mm^2. Thus local variation of wetting properties of cm2 samples remaining hidden in case the contact line does not cover this area. Therefore, in order to obtain a representative information of the surface of interest a method where the contact line is scanned over cm^2 area is of interest.
Recently, Hinduja et al, reported on a scanning drop friction force instrument (sDoFFI) to analyse friction forces of drops on surfaces [2]. This method allows to image wetting properties on cm^2 large areas within a few minutes. A drop is fixated to an elastic glass capillary which acts as a spring with spring constant κ. The sample underneath the drop is moved with a constant speed u leading to sliding of the drop at a defined trajectory along surfaces. The deflection of the capillary, d, provides information about the friction force between the drop and the surface, F_meas= κ·d. Forces arising from CAH are given by the Furmidge equation [3], where the drop's sliding force F_CAH corresponds to
F_CAH=k ·γ·w·(cos(θ_rec)-cos(θ_adv))
Where k is a geometrical factor, γ is the liquid surface tension, w the width of the drop and θ_rec and θ_adv are the receding and advancing contact angles, respectively. For small u we assume F_meas= F_CAH. The parameters γ, w, θ_rec and θ_adv are known or can be measured optically. Thus the geometrical factor k can be calculated. We realize different geometries of the drop by glueing metal rings to the elastic glass capillary. Shaping the metal rings forces the drop to shape. We discuss experiments where we shape the drop into different width and discuss dependence of the geometrical factor k.

[1] Huhtamäki, Tommi, et al. "Surface-wetting characterization using contact-angle measurements." Nature Protocols (2018): 1521-1538.
[2] Hinduja, Chirag, et al. "Scanning drop friction force microscopy." Langmuir (2022): 14635-14643
[3] Collet,P, et al. "Dynamics of the Contact Line: Contac Angle Hysteresis."Phys. Rev. Lett., 79 (1997) 3704.

Poster Session / 13

Dynamic Wetting of Adaptive Polyelectrolyte Substrates: A multiscale approach

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Wetting phenomena are of great importance across various scientific disciplines, and as a fundamental research area, the wettability dynamics of adaptive substrates, such as polyelectrolyte multilayers (PEM), have gained significant attention. Notably, an interesting property of polyelectrolyte (PE) substrates is their propensity to swell in a liquid environment. However, the complexities such as the disparity between time and length scales and surface deformation beyond the three-phase contact line (TPCL), make experimental investigations quite challenging.
We prepared PE substrates by the layer-by-layer method invented by Decher [1], with a focus on their wettability at the nanoscale. We used atomic force microscopy (AFM) as the main characterisation technique at the nanoscale for investigation of properties like layer morphology, swelling kinetics, etc. Also, an optical contact angle (CA) tensiometry method is used for macroscopic measurements. The layer thickness is determined by ellipsometry and X-ray reflectometry (XRR). Previous results show that the water CA on silicon wafers coated with polystyrene sulfonate (PSS) as outermost layer decreases in water-saturated atmosphere [2]. To investigate the dependence on layer thickness, polymer chain length and overall charge of the outermost layer, different PEMs consisting of PEI, PSS and PAH were fabricated and characterised. Here, the substrates were investigated with an AFM and showed to exhibit very smooth surfaces while linearly increasing in thickness. Furthermore, the decrease in water CA is more pronounced with an increasing layer thickness and differs if PSS or PAH are outermost layer. [3]

[1] G. Decher, Science 1997, 1232 –1237.
[2] K. Hänni-Ciunel, G. H. Findenegg, R. v. Klitzing, Soft Materials 2007, 61 –73.
[3] The authors acknowledge funding from the DFG, Priority program 2171, KL1165/34, Grant Number 505842923.

Poster Session / 51

Kinetics of Cloak Development of Droplets on Lubricated Polymer Brushes

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The interaction of liquid droplets with lubricated substrates is rich with interesting physics combining thermodynamics, polymer science, and fluid dynamics, and has the potential for various industrial applications. In previous work, we showed the existence of a cloaking transition where the lubricant covers the surface of the droplet at equilibrium. Here, we describe the kinetics of the developing cloak. We show that in simulation the time scales are diffusive, and model them through a simple diffusion model. We in addition illustrate the peculiar effect of the simulation parameters.

Poster Session / 33

Synthesis and investigation of Nile Red- and aurone-labeled methacrylate derivatives as novel solvatochromic probes for polymer analysis

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Synthesis and investigation of Nile Red- and aurone-labeled methacrylate derivatives as novel solvatochromic probes for polymer analysis

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Fluorosolvatochromic dyes are known for their ability to change their emission properties in response to the polarity of respective solvent, thus providing valuable insight into local polarity and dynamics of the surrounding solvent shell. In this context, Nile Red is widely used as solvatochromic dye in cell biology, for example, to detect and characterize membranes.[1] Likewise, it may be applied for the fluorimetric analysis of polymers brushes. For this purpose, however, it has to be covalently incorporated into the polymers, which may be accomplished by the attachment to the corresponding monomer units.

In this study, we present the functionalization of methacrylate monomers with Nile Red and selected aurone derivatives. Specifically, we investigated the properties of the resulting dye conjugates for the application as solvatochromic probes for the detection of local polarity and mobility of the environment, both as monomer and when incorporated into a polymer. In particular, the aurones proved to be a valuable fluorophore because of their properties as dual-state emission (DSE) fluorophores.[2]

Literature:
[1] G. Ballarin, M. Biasiotto, A. Reisbitzer, M. Hegels, M. Bolte, S. Krauß, D. V. Berdnikova, RSC Med. Chem. 2024, 15, 3092.
[2] D. V. Berdnikova, S. Steup, M. Bolte, M. Suta, Chem. Eur. J. 2023, 29, e202300356.

Poster Session / 32

Block copolymer gradient brushes: A detailed look at the synthesis and characterization

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Block copolymer gradient brushes: A detailed look at the synthesis and characterization

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In the SPP project, we develop polymer brush architectures to be able to study the dynamics of wetting by analysing the fluorescence dynamics of a solvatochromic reporter dye. Specifically we focus on poly(di(ethylene glycol) methyl ether methacrylate) (PDEGMA) brushes with an overall uniform height, containing a solvatochromic dye, which is able to probe the local polarity in its vicinity [1]. This dye should be covalently attached to the brushes in a one-dimensional depth gradient, which allows one to image the wetting dynamics with confocal fluorescence microscopy both with high lateral as well as significantly enhanced axial resolution. In this contribution we focus on the details of the synthesis and characterization PDEGMA brushes. Gradient brushes [2] were successfully synthesized via surface-initiated activator regenerated by electron transfer, atom transfer radical polymerization (SI-ARGET ATRP) with inverse gradient directions exploiting two consecutive polymerizations in which the substrate is immersed for different times in the polymerization solution. This was realized by pumping the corresponding solution into a reactor, in which the substrates were placed vertically. In this contribution, details on the polymerization of linear gradient brushes with dry thicknesses from 50 nm up to 400 nm, the addition of a thin second block by conventional atom transfer radical polymerization (ATRP) of a different monomer on top of the gradient brushes and the final gradient brush polymerization with inverse direction as third block to obtain an overall uniform height with a reinitiation efficiency > 80% will be presented. The middle block may contain the reporter dye moieties. The samples were characterized after each step of this block copolymer brush synthesis by ellipsometry, X-ray photoelectron spectroscopy (XPS), infrared (IR) spectroscopy, static and dynamic contact angle measurements and atomic force microscopy (AFM). In the future the incorporation of dye methacrylates into the gradient brush architecture will be attempted, to finally investigate the wetting dynamics of these polymer brush systems.

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References

[1] A. Yadigarli, Q. Song,S. I. Druzhinin, H. Schönherr, Beilstein J. Org. Chem. 2019, 15, 2552.
[2] S. Großhans, I. Lilge, H. Schönherr, Macromol. Biosci. 2018, 18 (2), 1700317.

Poster Session / 40

Stimulus Responsive Polymer Brushes for Control of Static and Dynamic Wetting with Lipid Vesicles

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We designed and fabricate stimulus responsive polymer brushes which can switch the chain conformation reversibly in response to addition/removal of small amount of Cd2+ions. Design of the polymer structure was inspired by plant protein (phytochelatin) that selectively detect and capture Cd2+ ions. As our polymer realized an excellent affinity to Cd2+ (KD ~ 10-9 M), the brush conformation and mechanical properties can be switched without changing the osmolarity of electrolytes.[1,2] The surface coated by this bio-inspired polymer brush was used to switch the wetting with lipid vesicles, whose shape are determined not only by tension but also by elasticity. First we observed the shape of vesicles at various [Cd2+] and found that cell-sized giant vesicles (diameter ~ 10 µm) adapt their shape in response to [Cd2+], yielding the critical concentration causing wetting/non-wetting transition. Within SPP2171, we collaborated with Müller Group (Göttingen) and demonstrated that our experimental data were quantitatively reproduced by simulations.3 Moreover, we successfully observed the dynamic wetting transition in real time by integrating the brush system into microfluidics.[3] Owing the outstanding affinity and selectivity to Cd2+, this material has recently been used for the treatment of polluted groundwater, which is considered as a "synthetic phytoremediation" .[4]

1. Yamamoto, A., Hayashi, K., Sumiya, A., Weissenfeld, F., Hinatsu, S., Abuillan, W., Nakahata, M., and Tanaka, M. (2022). Modulation of viscoelasticity and interfacial potential of polyelectrolyte brush by Ion-specific interactions. Frontiers in Soft Matter 2, 959542. 10.3389/frsfm.2022.959542.
2. Yamamoto, A., Ikarashi, T., Fukuma, T., Suzuki, R., Nakahata, M., Miyata, K., and Tanaka, M. (2022). Ion-specific nanoscale compaction of cysteine-modified poly(acrylic acid) brushes revealed by 3D scanning force microscopy with frequency modulation detection. Nanoscale Advances 4, 5027-5036. 10.1039/D2NA00350C.

3. Weissenfeld, F., Wesenberg, L., Nakahata, M., Müller, M., and Tanaka, M. (2023). Modulation of wetting of stimulus responsive polymer brushes by lipid vesicles: experiments and simulations. Soft Matter 19, 2491-2504. 10.1039/D2SM01673G.

4. Nakahata, M., Sumiya, A., Ikemoto, Y., Nakamura, T., Dudin, A., Schwieger, J., Yamamoto, A., Sakai, S., Kaufmann, S., and Tanaka, M. (2024). Hyperconfined bio-inspired Polymers in Integrative Flow-Through Systems for Highly Selective Removal of Heavy Metal Ions. Nature Communications 15, 5824.

Poster Session / 25

Robust, Easy-To-Clean Silica Sol-Gel Solar Panel Coatings

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The advancement of renewable energies is crucial in an age in which we are confronted with growing climate and environmental challenges. Solar energy is considered a highly promising, efficient and environmentally friendly source of energy. However, solar panels lose a significant amount of efficiency due to soiling [1]. Thus, a lot of water (more than 35 billion liters per year) is required to keep the panels clean [2]. Hydrophobic coatings that reduce water consumption by promoting self-cleaning via natural rainfall are of high interest. Further desired properties for solar panel coatings are high transparency and mechanical robustness. Our approach is to prepare a hydrophobic, transparent and mechanically stable prototype material by a sol-gel process based on tetraethyl orthosilicate (TEOS) and an alkyl trimethoxysilane (alkylTMS). Here, we vary the alkyl chain lengths (methyl, propyl and hexyl) and precursors'solid weight ratios. The resulting coatings have a transparency of around 90%, comparable to those of plain glass. With increasing alkyl chain length and concentration, we obtain increasing hydrophobicity with contact angles higher than 90° and hysteresis of around 10°. For the evaluation of self-cleaning features, scanning drop friction force microscopy (sDoFFI) was utilized. Here, lower drop friction force correlates to better self-cleaning properties. Drop friction decreased with increasing alkyl chain length and concentration. For fixed methylTMS/TEOS and hexylTMS/TEOS ratios, a respective average friction force of 41±2 µN and 23±2 µN was observed at a drop volume of 5 µL. Moreover, this technique enables the characterization of coating homogeneity. A thoroughly uniform frictional force was observed on the respective surfaces (Figure 1). Our methods thus enable the production of transparent, uniform and hydrophobic surfaces whose suitability as solar cell coatings can be investigated by sDoFFI.

[1] Chandler, D. L. (2022, March 15), This is how solar panels can be kept clean - without using water. Weforum. Retrieved June 20, 2024, from https://www.weforum.org/agenda/2022/03/solar-panels-waterless-clean/
[2] (a) Borah et al., Sustainability 2023, 15, 16669. (b) Najmi et al., Energies 2023, 16, 7960.

Poster Session / 20

Estimating sliding drop width via side-view features using artificial neural networks

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High-speed side-view videos of sliding drops enable researchers to investigate drop dynamics and surface properties. However, understanding the physics of sliding requires knowledge of the drop width, which necessitates a front-view perspective. The drop's width is a crucial parameter due to its association with the friction force. Incorporating extra cameras or mirrors to monitor changes in the width of drops from a front-view perspective is cumbersome and limits the viewing area. This limitation impedes a comprehensive analysis of sliding drops, especially when they interact with surface defects.

To address these challenges, our study explored the use of regression and multivariate sequence analysis (MSA) models to estimate the drop width at a solid surface solely from side-view videos. This approach eliminates the need for additional equipment, ensuring an unlimited viewing area for sliding drops. Among the tested methods, the Long Short Term Memory (LSTM) model with a 20-frame sliding window achieved the best performance, with a root mean square error (RMSE) of approximately 68 µm. Considering the range of drop widths in our dataset (1.6 to 4.4 mm), this corresponds to an error margin of about 2.5%. Notably, the LSTM model provided drop width predictions across the entire sliding length of 5 cm, a capability previously unattainable.

Building on this foundation, our subsequent research advanced the methodology by departing from the reliance on time-series data of specific parameters like contact angles. Instead, our approach processes raw video footage to dynamically identify features most indicative of drop width. This method significantly enhances measurement precision across various environmental conditions and demonstrates robustness against noise, blur, and brightness variations. Our refined neural network architecture achieved an RMSE of approximately 55 µm, improving upon prior results and highlighting the potential of direct video analysis to extract more effective features. This advancement simplifies experimental workflows and improves measurement accuracy in drop dynamics research, enabling more detailed insights into interactions between sliding drops and surface defects.

Poster Session / 21

Estimating drop width for sliding drops using Machine Learning

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Wetting is generally regarded as an inherent property of material surfaces. Wetting imperfections contribute to contact angle hysteresis, influencing the overall wetting dynamics. Existing techniques like contact angle goniometry are not sufficient for accurately quantifying variations in wetting behavior due to temporal and local resolution limitations. A direct quantitative measurement of frictional forces during drop sliding on surfaces was recently proposed by Hinduja et al. [1]. However a direct comparison of measured forces with calculated forces by the Furmidge equation is hampered as the drop width is unknown. According to the Furmidge equation, drop width is directly proportional to the frictional force, making it a pivotal factor in generating surface-wetting maps. An additional camera for drop width imaging can be installed. The latter adds significant optical and data recording complexity to the setup.
Here we report on applying machine learning models to estimate the drop width on solid surfaces using only side-view videos obtained from scanning drop friction force microscopy (sDoFFI). The

primary objective is to predict the drop width with high precision, this will enable a deeper understanding of the forces involved in drop dynamics and drop electrification at defects and wetting imperfections. We are determining the contact angles (CA) by analyzing the video data obtained by raster scanning of drop on Kruss DSA100 goniometer using a Python script. CAs are calculated by marking a line at the solid-liquid interface called baseline within the code and applying the tangent fit. The friction force acting on the moving contact line is plotted against the position of the drop by quantifying the deflection of the capillary from its resting position using developed Python code. In addition, the need for an additional high speed camera for the DoFFI setup is eliminated which, significantly reduces the systems complexity and costs while maintaining functionality to enhance the industrial applicability of the DoFFI setup.

References:
[1] Hinduja, Chirag, Alexandre Laroche, Sajjad Shumaly, Yujiao Wang, Doris Vollmer, Hans-Jürgen Butt, and Rudiger Berger. "Scanning drop friction force microscopy." Langmuir 38, no. 48 (2022): 14635-14643.

Poster Session / 47

Correlating the slippery behavior of nanoscale poly(dimethylsiloxane) layers to their liquid like molecular mobility

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Nanoscale poly(dimethylsiloxane) (PDMS) layers prepared by grafting the polymer chains on a smooth solid surfaces are typical example for the so called slippery covalently-attached liquid surfaces (SCALS). Such surfaces exhibit very low contact angle hysteresis (CAH) and low friction for sliding water drops [1-2]. These properties are commonly attributed to the liquid-like mobility of the tethered, low glass transition temperature, polymer chains. However, to date there is still no clear, molecular level understanding of the involved physical phenomena. Here, we used fluorescence correlation spectroscopy (FCS) to measure the diffusion coefficients of small fluorescent tracers dispersed in the PDMS layers as probes for the local nanoviscosity. Our results show a clear correlation between the molecular mobility in the polymer layers and their slippery behavior.

1. Gresham, I. J.; Lilley, S. G.; Nelson, A. R. J.; Koynov, K.; Neto, P. C.: Nanostructure Explains the Behavior of Slippery Covalently Attached Liquid Surfaces. Angewandte Chemie International Edition 62 (41), e202308008 (2023)
2. Zhou, X.; Wang, Y.; Li, X.; Sudersan, P.; Amann-Winkel, K.; Koynov, K.; Nagata, Y.; Berger, R.; Butt, H.-J.: Thickness of Nanoscale Poly(Dimethylsiloxane) Layers Determines the Motion of Sliding Water Drops. Advanced Materials 36 (29), 2311470 (2024).

Keynote / 46

Wettability in porous materials to design of fluid imbibition and molecular transport

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Nanopores are a key component in various technologies from oil production, separation and sensing, to drug delivery or catalysis and energy conversion. In contrast to technological pores, biological pores and channels demonstrate highly precise transport being directed, highly selective, and gated. A key factor to this performance is their nanoscale structure and local control on charge regulation and polarity. Inspired by this performance and nanoscale precision we are interested in designing precisely functionalized nanoscale porous materials to understand and advance transport performance of technological pores.[1]
This talk will highlight the role of nanopore wettability regarding fluid imbibition,[2] and molecular transport.[3] Strategies to adjust nanopore wettability of mesoporous silica films and with this ionic transport will be presented, for example, using gas phase deposition of fluorinated silanes, spiropyran as a photoresponsive molecule[4]. The gained knowledge on wettability in nanopores was used to apply adjusted wettability transitions together with orthogonal surface chemistry to locally place three different functions or polymers into a nanopore[5] or to use wettability transition design to gate water imbibition and droplet coalescence by light.[4] Looking at more complex hierarchical materials dense and mesoporous silica coatings can be introduced into paper to design paper wettability and with this prevent or accelerate fluid transport in this very hierarchical material even with three dimensional control. Mechanistic insights into this design of paper properties as obtained by high resolution microscopy will be given.[6, 7]

1. R. Pardehkhorram, A. Andrieu-Brunsen, Chem. Commun., 2022, DOI: 10.1039/D2CC01164F
2. A. Khalil, F. Schäfer, N. Postulka, M. Stanzel, M. Biesalski, A. Andrieu-Brunsen, Wettability-defined droplet imbibition in ceramic mesopores, Nanoscale, 2020, 12, 24228.
3. A. Khalil, M. Zimmermann, A. K. Bell, U. Kunz, S. Hardt, H.-J. Kleebe, R. W. Stark, P. Stephan, A. Andrieu- Brunsen, "Insights into the interplay of wetting and transport in mesoporous silica films", J. Colloid Interf. Sci., 560, 369, (2019).
4. A. Khalil, P. Rostami, G.K. Auernhammer, A. Andrieu-Brunsen, Mesoporous Coatings with Simultaneous Light-Triggered Transition of Water Imbibition and Droplet Coalescence, Adv. Mater. Interfaces, 2021, 8, 2100252.
5. M. Ochs, R. Mohammadi, N. Vogel, A. Andrieu-Brunsen, „Wetting-controlled localized placement of surface functionalities within nanopores", Small, 2020, 16, 1906463
6. M. Nau & N. Herzog, J. Schmidt, T. Meckel, A. Andrieu-Brunsen & M. Biesalski, Janus-Type Hybrid Paper Membranes, Adv. Mater. Interf., 2019, 6, 1900892.
7. J. J. Mikolei, M. Biesalski, M. Ceolin, A. Andrieu-Brunsen, Local water management in cotton linter papers with silica-based coatings, Cellulose, 2024, 31, 5855.

Short Talks / **5**

Biomolecular condensates wetting membranes - dynamical insights from numerical simulations

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Biological cells use membranes and condensates (liquid-like droplets) to compartmentalize their interior. As every structure within a cell is either enclosed by a membrane or by a liquid interface it is fundamental to understand what happens if these two come into contact. Recent studies suggest that membrane-droplet interactions are involved in various key biological processes. As experimental image resolution is limited at the corresponding length and time scales, numerical methods are essential to shed light on the dynamics of the process.

Using a combination of sharp and diffuse interface models, we derive a mathematical model to describe the interplay of a thin elastic membrane with a two-phase fluid.
We demonstrate that the wetting interaction by capillary forces leads to a range of fascinating phenomena like droplet wrapping, endocytosis and an inverted cheerios effect.

Short Talks / 39

Stimulus Responsive Polymer Brushes for Control of Static and Dynamic Wetting with Lipid Vesicles

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We designed and fabricate stimulus responsive polymer brushes which can switch the chain conformation reversibly in response to addition/removal of small amount of Cd2+ions. Design of the polymer structure was inspired by plant protein (phytochelatin) that selectively detect and capture Cd2+ ions. As our polymer realized an excellent affinity to Cd2+ (KD ~ 10-9 M), the brush conformation and mechanical properties can be switched without changing the osmolarity of electrolytes.[1,2]
The surface coated by this bio-inspired polymer brush was used to switch the wetting with lipid vesicles, whose shape are determined not only by tension but also by elasticity. First we observed the shape of vesicles at various [Cd2+] and found that cell-sized giant vesicles (diameter ~ 10 µm) adapt their shape in response to [Cd2+], yielding the critical concentration causing wetting/non-wetting transition. Within SPP2171, we collaborated with Müller Group (Göttingen) and demonstrated that our experimental data were quantitatively reproduced by simulations.3 Moreover, we successfully observed the dynamic wetting transition in real time by integrating the brush system into microfluidics.[3] Owing the outstanding affinity and selectivity to Cd2+, this material has recently been used for the treatment of polluted groundwater, which is considered as a "synthetic phytoremediation" .[4]

1. Yamamoto, A., Hayashi, K., Sumiya, A., Weissenfeld, F., Hinatsu, S., Abuillan, W., Nakahata, M., and Tanaka, M. (2022). Modulation of viscoelasticity and interfacial potential of polyelectrolyte brush by Ion-specific interactions. Frontiers in Soft Matter 2, 959542. 10.3389/frsfm.2022.959542.
2. Yamamoto, A., Ikarashi, T., Fukuma, T., Suzuki, R., Nakahata, M., Miyata, K., and Tanaka, M. (2022). Ion-specific nanoscale compaction of cysteine-modified poly(acrylic acid) brushes revealed by 3D scanning force microscopy with frequency modulation detection. Nanoscale Advances 4, 5027-5036. 10.1039/D2NA00350C.
3. Weissenfeld, F., Wesenberg, L., Nakahata, M., Müller, M., and Tanaka, M. (2023). Modulation of wetting of stimulus responsive polymer brushes by lipid vesicles: experiments and simulations. Soft Matter 19, 2491-2504. 10.1039/D2SM01673G.
4. Nakahata, M., Sumiya, A., Ikemoto, Y., Nakamura, T., Dudin, A., Schwieger, J., Yamamoto, A., Sakai, S., Kaufmann, S., and Tanaka, M. (2024). Hyperconfined bio-inspired Polymers in Integrative Flow-Through Systems for Highly Selective Removal of Heavy Metal Ions. Nature Communications 15, 5824.

Short Talks / 15

Shape of polystyrene droplets on soft PDMS: Exploring the gap between theory and experiment at the three-phase contact line

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The shapes of liquid polystyrene (PS) droplets on viscoelastic polydimethylsiloxane (PDMS) substrates are investigated experimentally using atomic force microscopy for a range of droplet sizes and substrate elasticities. These shapes, which comprise the PS-air, PS-PDMS, and PDMS-air interfaces as well as the three-phase contact line, are compared to theoretical predictions using axisymmetric sharp-interface models derived through energy minimization. We find that the polystyrene droplets are cloaked by a thin layer of uncrosslinked molecules migrating from the PDMS substrate. By incorporating the effects of cloaking into the surface energies in our theoretical model, we show that the global features of the experimental droplet shapes are in excellent quantitative agreement for all droplet sizes and substrate elasticities. However, our comparisons also reveal systematic discrepancies between the experimental results and the theoretical
predictions in the vicinity of the three-phase contact line. Moreover, the relative importance of these discrepancies systematically increases for softer substrates and smaller droplets. We demonstrate that global variations in system parameters, such as surface tension and elastic shear moduli, cannot explain these differences but instead point to a locally larger elastocapillary length, whose possible origin is discussed thoroughly.

Short Talks / **22**

Charge separation at contact lines slows down the breakup of liquid bridges on surfaces

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Electrostatic charge separation at receding contact lines, called slide electrification, has been extensively studies in recent years. Resulting electrostatic interactions fundamentally contribute to contact angle hysteresis and can significantly slow down the movement of sliding drops. Yet, the relevance of electrostatic effects in dynamic wetting beyond single drops has largely remained obscure. Here, we experimentally study the breakup of liquid bridges on non-conductive surfaces and find a substantial influence of electrostatic charge separation. First, electrostatic interactions lead to spontaneous random movement of satellite drops after the liquid bridge breakup. Second, electrostatic forces slow down the dynamics of the breakup process. We find that the influence of electrostatic increases with the liquid viscosity and that our experimental observations align with slide electrification theory. Our results highlight the wider importance of slide electrification in dewetting scenarios beyond drops, even when the liquid is connected to a large reservoir.

Short Talks / **42**

Electrostatic Surface Charging by Water Dewetting

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Water dewetting generates static electricity. We studied the charging of polymer slides and metal electrode supported polymer films withdrawn vertically from a pool of aqueous solutions. For pure water, charging was negative and surface charge densities increased with the speed of dewetting, which we explain by the entrainment of nanometer-sized water droplets charged by unbalanced adsorbed electric double-layer ions. At low salinity c ⊠ 10 µM, charging was proportional to electrokinetic interfacial charge densities: Charge polarity was inversed to positive for a cationic surfactant, a salt with a highly positively charged cation, and for a strong acid at approximately pH 4. We furthermore show that the surface charge distribution, imaged by charged toner powders and measured microscopically by Kelvin probe force microscopy, is a record of the dewetting process that provides spatial and kinetic information about the three-phase contact line motion.

Keynote / 50

Theory of non-dilute binding and surface phase separation

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Surface binding and surface phase separation of cytosolic scaffold proteins on lipid membranes are involved in many cellular processes, such as cell signaling, cell adhesion, and cortex regulation. However, the interplay between surface binding and surface phase separation is poorly understood. In this work, we study this interplay by deriving a general thermodynamic model and applying it to in vitro reconstitution experiments of membrane-binding proteins involved in tight junction initiation. Our theory extends the classical surface binding isotherm to account for non-dilute and heterogeneous conditions where components can phase separate. We use our theory to demonstrate how surface phase separation is governed by the interaction strength among membrane-bound scaffold proteins and their binding affinity to the membrane surface. Comparing the theory to reconstitution experiments, we show that tuning the oligomerization state of the adhesion receptors in the membrane controls surface phase transition and patterning of the scaffold protein ZO1. These findings suggest a fundamental role of the interplay between non-dilute surface binding and surface phase separation in forming the tight junction. More broadly, our work highlights non-dilute surface binding and surface phase separation as a common organizational principle for membrane-associated structures in living cells.

Short Talks / 1

Does the topology of polymer brushes determine their sorption characteristics in vapors?

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Previous studies have shown that a pure architecture change of polymer brushes from linear to unconcatenated cyclic chains without a change of effective grafting density, can only lead to trivial changes of swelling properties of brushes in solutions. But it remains unknown whether this conclusion is valid for the swelling characteristics of brushes in vapor phase, because vapors often introduce additional surface-tension effects comparing with solutions. Thus, we have done well-defined molecular dynamics simulation study on the vapor sorption characteristics of brushes with different topological structures (linear and cyclic brushes). Our results showed that a topological variation of brushes can drastically influence the vapor sorption characteristics of brushes, in agreement with recent experimental investigations. The simulation results clearly showed that cyclic brushes swell

much less comparing with their topological counterparts (linear brushes) and adsorbs much more solvent in the interface between brush and vapor phases. Our results also indicated that the different vapor sorption characteristics between linear and un-concatenated cyclic topological brushes, is not due to the change of polymer architecture but due to the change of effective grafting density.

Short Talks / **41**

Evaporation near the contact lines of droplets and rivulets on topographically complex surfaces

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Wetting of morphologically complex substrates is omnipresent, since a rare surface is perfectly physically homogeneous. Surface defects, roughness, porosity and/or peculiarities of the upper-layer structure of a surface dictated by the industrial needs often result in the different wetting and evaporation dynamics, when compared to that on a smooth surface. In order to better predict and control the droplet/rivulet behavior, the understanding of physics behind it is crucial.
In the present work, we consider volatile droplets and rivulets deposited on a complex surface. We assume that the contact line is pinned to a wedge-shaped substrate non-uniformity and that the evaporation is governed by the transport of vapor in the ambient gas. We consider the vicinity of the contact line and propose an analytical model to describe the flows in both liquid and gas phases in that region. We determine the critical contact angles, at which the dominant contribution to the flow changes, and propose a simple approximation allowing to calculate them for the known wedge opening angles. We analyze the flow topology and particularly, the emergence of separatrices in both phases for different opening angles of a wedge and different ratios of liquid and gas viscosity.

Short Talks / **48**

Slide electrification

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Water drops moving on surfaces are not only an everyday phenomenon seen on windows but also form an essential part of many industrial processes. Like in triboelectricity, moving drops can separate electric charges. This phenomenon is called slide or contact electrification. Typically, water drops sliding down hydrophobic surfaces spontaneously acquire a positive charge while they deposit negative charges on the solid surface. Three questions will be addressed: How can one measure charge separation and describe it quantitatively? How does charging influence the motion of sliding water drops? What are other consequences of slide electrification?

Short Talks / **10**

Time evolution of surface charges deposited by evaporating water droplets

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The evaporation of a water droplet on a solid surface is ubiquitous in both natural and industrial settings. However, the mechanism by which evaporating droplets deposit charges on the interface, driven by the movement of the three-phase contact line, remains poorly understood. In this study, we investigate the nanoscale charge deposition of evaporating droplets and subsequent charge decay dynamics using Kelvin Probe Atomic Force Microscopy. Our findings reveal that the charge deposition patterns by evaporating droplets differ significantly depending on the surface chemistry of the substrate. Understanding how long and how effectively the charges generated at the solid/liquid interface persist is crucial, as many physicochemical phenomena are influenced by these charges.

Short Talks / 23

Spontaneous charge separation by drop motion across of a hydrophobic tube

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Charge separation at the moving interface of liquid-solid has been observed and studied through the years [1]. Water droplets impinging on a solid substrate [2,3], coalescence induced droplet jumping [4] and slide electrification [1,5] are among the phenomena which lead to voltage generation. It is shown that sliding water drops on hydrophobic insulating surfaces leads to charge separation at the three-phase contact line [1]. Dewetting velocity plays an important role in the amount of charge deposited at the receding contact angle [6]. Slide electrification is mainly studied through the drops motion on a tilted surface [7]. In this study, we make use of better control over parameters like drop velocity and drop contact time with the surface to investigate the influence of wetting kinetics on charge separation. Systematic measurements are carried out to quantify the amount of voltage generated by the drops motion and understand the governing mechanisms. Molecular dynamics simulations provide insight into how the non-equilibrium processes of charge separation are influenced by the surface chemistry, pH of water, and droplet velocity. Our findings on charge separation by dynamic wetting broaden the current insight into the liquid/solid interface and charge separation but also can be useful for possible future integration of slide electrification into energy harvesting systems.

References
[1] Leibauer B, Pop-Georgievski O, Sosa MD, Dong Y, Tremel W, Butt H-J et al. How Surface and Substrate Chemistry Affect Slide Electrification. J. Am. Chem. Soc. 2024;146(14):10073–83.
[2] Xu W, Zheng H, Liu Y, Zhou X, Zhang C, Song Y et al. A droplet-based electricity generator with high instantaneous power density. Nature 2020;578(7795):392–6.
[3] Wang L, Song Y, Xu W, Li W, Jin Y, Gao S et al. Harvesting energy from high-frequency impinging water droplets by a droplet-based electricity generator. EcoMat 2021;3(4).
[4] Miljkovic N, Preston DJ, Enright R, Wang EN. Electrostatic charging of jumping droplets. Nature

communications 2013;4:2517.
[5] Stetten AZ, Golovko DS, Weber SAL, Butt H-J. Slide electrification: charging of surfaces by moving water drops. Soft Matter 2019;15(43):8667–79.

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Effect of Surface Stochasticity on Droplet Motion

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Droplet motion on surfaces plays an important role in biological systems and technological applications [1–3]. Most natural and artificial superhydrophobic surfaces have irregular or stochastic roughness [4–6], making them challenging to model. However, all existing studies on wetting have been done for well-defined surfaces, such as micropillar arrays with a regular structure [7–11]. Here, I will show some of our recent fundings on how the behavior of droplets on stochastic surfaces fundamentally differs from that on regular surfaces. First, I will demonstrate how stochasticity influences droplet behavior in confined systems, enabling more viscous liquids to flow faster than those with lower viscosity [12]. Next, I will discuss the impact of stochastic roughness on droplet friction on flat surfaces. We found that the friction experienced by droplets at very low speeds (quasi-static regime, around micrometers per second) is ten times greater than at higher speeds (dynamic regime, from centimeters to meters per second) [13]. This finding contrasts sharply with current research [14,15]. Through imaging and modeling, we will examine how the adaptation of the droplet meniscus to surface roughness depends on droplet speed. Finally, I will introduce the concepts of static and dynamic solid fractions to explain these differences while highlighting the stochasticity levels required to repel droplets of varying sizes effectively. This knowledge paves the way for developing new designs for superhydrophobic surfaces.

References

1. Quéré, D. Wetting and Roughness. Annu. Rev. Mater. Res. 38, 71–99 (2008).
2. Schutzius, T. M. et al. Spontaneous droplet trampolining on rigid superhydrophobic surfaces. Nature 527, 82–85 (2015).
3. Bird, J. C., Dhiman, R., Kwon, H.-M. & Varanasi, K. K. Reducing the contact time of a bouncing drop. Nature 503, 385–388 (2013).
4. Ensikat, H. J., Ditsche-Kuru, P., Neinhuis, C. & Barthlott, W. Superhydrophobicity in perfection: the outstanding properties of the lotus leaf. Beilstein J. Nanotechnol. 2, 152–161 (2011).
5. Barthlott, W. et al. The Salvinia Paradox: Superhydrophobic Surfaces with Hydrophilic Pins for Air Retention Under Water. Adv. Mater. 22, 2325–2328 (2010).
6. Wang, L. A critical review on robust self-cleaning properties of lotus leaf. Soft Matter 19, 1058–1075 (2023).
7. Reyssat, M. & Quéré, D. Contact Angle Hysteresis Generated by Strong Dilute Defects. J. Phys. Chem. B 113, 3906–3909 (2009).
8. Pilat, D. W. et al. Dynamic Measurement of the Force Required to Move a Liquid Drop on a Solid Surface. Langmuir 28, 16812–16820 (2012).
9. Extrand, C. W. Model for Contact Angles and Hysteresis on Rough and Ultraphobic Surfaces. Langmuir 18, 7991–7999 (2002).
10. Dorrer, C. & Rühe, J. Contact Line Shape on Ultrahydrophobic Post Surfaces. Langmuir 23, 3179–3183 (2007).
11. Butt, H.-J. et al. Energy Dissipation of Moving Drops on Superhydrophobic and Superoleophobic Surfaces. Langmuir 33, 107–116 (2017).
12. Vuckovac, M., Backholm, M., Timonen, J. V. I. & Ras, R. H. A. Viscosity-enhanced droplet motion in sealed superhydrophobic capillaries. Sci. Adv. 6, eaba5197 (2020).
13. Vuckovac, M. et al., in preparation.
14. Backholm, M. et al. Toward vanishing droplet friction on repellent surfaces. Proceedings of the National Academy of Sciences 121, e2315214121 (2024).
15. Arunachalam, S., Lin, M. & Daniel, D. Probing the physical origins of droplet friction using a critically damped cantilever. Soft Matter 20, 7583–7591 (2024).