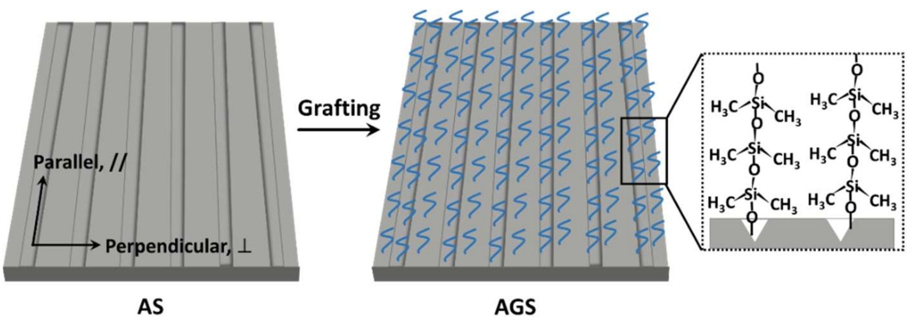
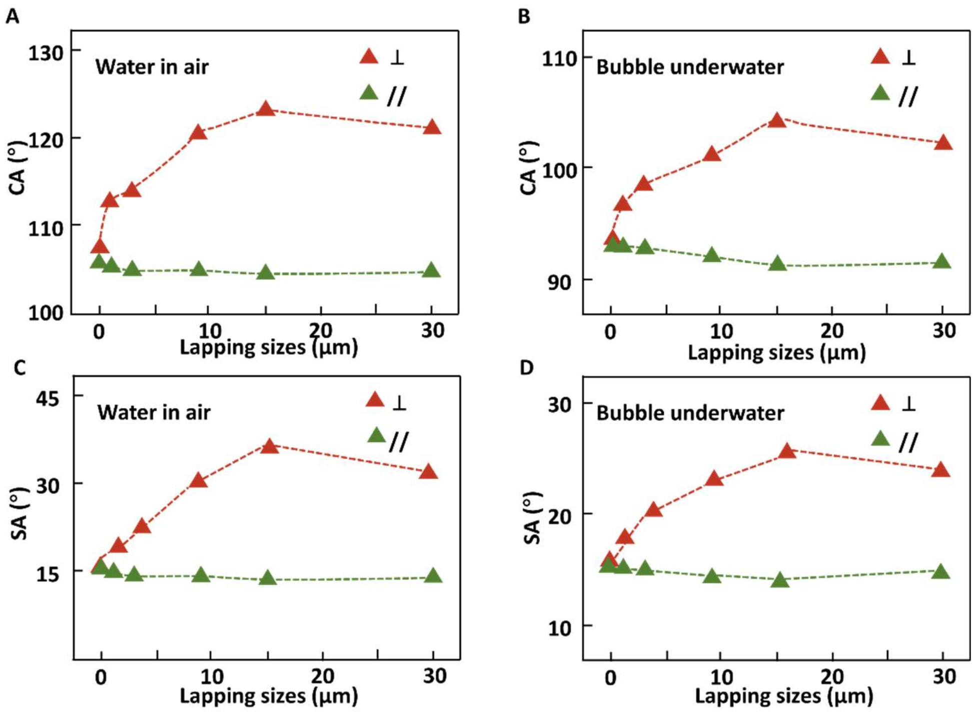
**How contact angle and adhesive force measurements can help to understand directional transportation of drops and bubbles**


Directional transportation of liquids and bubbles plays an important role in the fields of fluidic handling, microfluidic devices, underwater flammable gas collection and so on. Inspired by *Nepenthes pitcher* plants, slippery liquid-infused porous surfaces (SLIPSs) for directional transportation of liquids and bubbles were recently developed. One drawback of traditional SLIPSs is that they will lose their excellent liquid repellency once the liquid lubricants are removed or contaminated. Therefore, to better meet the demand of practical applications, a new generation of anisotropic surfaces (ASs) with a high stability is needed for directional transportation of liquids and bubbles. Polydimethylsiloxane (PDMS) brush-grafted surfaces are ideal candidates for this application since they display a low contact angle hysteresis (CAH) for various liquids (both water and oils) and possess a high stability. Recently, Wang and coworkers have fabricated anisotropic covalently grafted slippery surfaces (AGSs) by grafting PDMS brushes on ASs, which showed outstanding anisotropic omniphobic sliding behaviors facilitating the transportation of droplets (in air) and bubbles (underwater) (**Picture 1**).




***Picture 1:*** *Preparation of anisotropic covalently grafted slippery surfaces AGSs by grafting PDMS on anisotropic surfaces (ASs)*

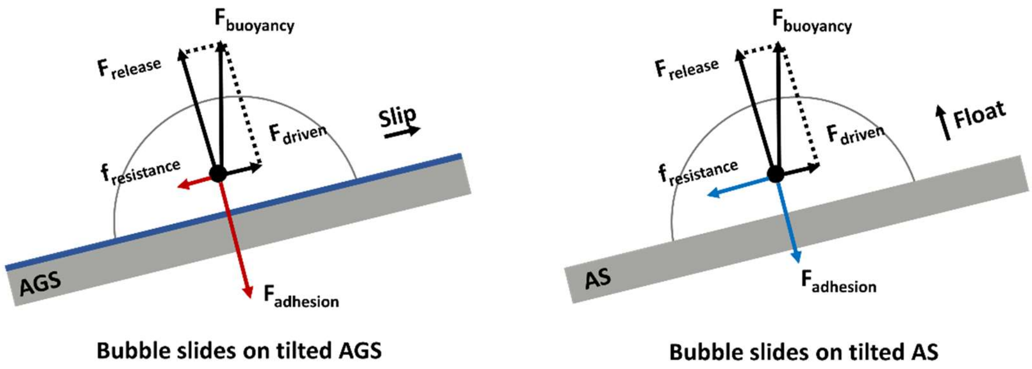
The wettability and slippery property of AGSs with different spaces (lapping sizes) between the microgrooves were studied. **Picture 2A** shows that with increasing space between the microgrooves the water contact angles (CAs) in the perpendicular direction ($CA_{\perp}$) first increased, and then slightly decreased. However, the CAs in the parallel direction ($CA_{//}$) are almost constant. The $CA_{\perp}$ and the $CA_{//}$ of air bubbles on AGSs displayed a similar tendency to that of the water droplets (**Picture 2B**).




**Picture 2:** *CAs changes on AGSs with increasing lapping size, for 5 µL water droplets in air (A) and 5 µL air bubbles underwater (B). SAs changes on the AGSs with increasing lapping size, for (C) 5 µL water droplets in air and (D) 5 µL air bubbles underwater*

They attributed the larger CAs to the rougher surface with micro/nanostructure, and the different energy barriers in the two directions resulted in the larger values for $CA_{\perp}$ compared to $CA_{//}$. Besides, they proposed that the surface structure does not hinder the spreading of water dropletts and air bubbles in the parallel direction, leading to almost unchanged $CA_{//}$ of water and air bubble on different AGSs. Furthermore, as **pictures 2C** and **2D** show, droplets and bubbles can slide well on the tested AGSs, indicating that the liquid like PDMS brushes endowed slipperiness to all AGSs. The $SA_{//}$ values are smaller than the $SA_{\perp}$ values for both droplets and bubbles, which could be caused by the differences of motion energy barrier in the three-phase contact line (TCL) while the droplets or bubbles slide in different orientations towards the lapping structure.

Also the dynamic adhesive force between bubbles and AS/AGS was studied. PDMS brushes enhanced the adhesion between bubbles and the surface (from 138.6±11.2 µN to 239.3±13.6 µN), thus improving the bubble storage capacity. **Picture 3** shows different forces in an equilibrium state where PDMS brushes enhanced the $F_{adhesion}$ and decreased the $f_{resistance}$, leading to the growth and coalescence of bubbles. With increasing bubble volume $F_{driven}$ progressively increased and exceeds $f_{resistance}$ due to the rising $F_{adhesion}$ and bubble volume, thus generating bubbles sliding on AGSs. However, low $F_{adhesion}$ and high $f_{resistance}$ on AGs resulted in a bubble release instead of bubbles sliding.




**Picture 3:** *Force analysis of the bubbles on AGS and AS*

In addition, the sliding angles (SAs) of droplets and air bubbles kept unchanged even when placed in air or immersed underwater for 240 d, indicating remarkable long-term stability. The AGSs showed a good slipperiness in solution of pH 3-11 and presented an excellent durability towards organic liquids.

Overall, the authors designed omniphobic AGSs with highly superior stability by grafting liquid-like PDMS molecular brushes on PDMS. The AGSs presented an excellent stability for the directional transportation of droplets and air bubbles dramatically outperforming the traditional SLIPSs. A large research interest in designing versatile slippery surfaces for the directional transportation of liquid droplets and air bubbles can be assumed for the future.

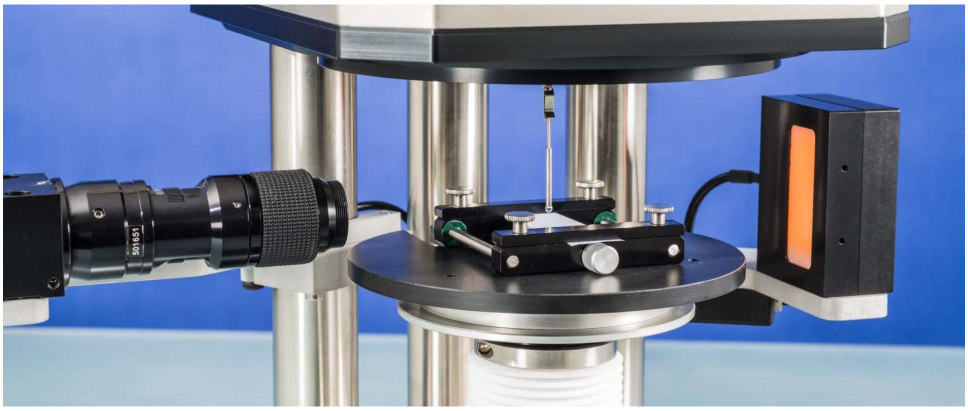
An optical contour analysis system OCA and a dynamic contact angle measuring devices and Tensiometer DCAT (DataPhysics Instruments GmbH, Germany) was used in this research.

For more information, please refer to the following article:

**Stable Omniphobic Anisotropic Covalently Grafted Slippery Surfaces for Directional Transportation of Drops and Bubbles**; Xuan Wang, Zubin Wang, Liping Heng, and Lei Jiang; *Adv. Funct. Mater.* **2020**, 30, 1902686; DOI: 10.1002/adfm.201902686

## Adhesive Force Measurements of gas bubbles under water with DCAT

Adhesive forces of liquids in air phase or of gas bubbles under liquid phase can be analysed with the Dynamic Contact Angle measuring devices and Tensiometer DCAT 25 with video upgrade.



This system combines a force measurement to determine the force of adhesion and an optical system to determine the area of contact between the liquid/gas and solid phase for each force that is measured. Like this a force per area can be determined. The measurement procedure involves a liquid or gas bubble being pushed onto a solid substrate under air or liquid and being pulled of from it again.