nustem

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Ice Protection using Sound Wave Strategies

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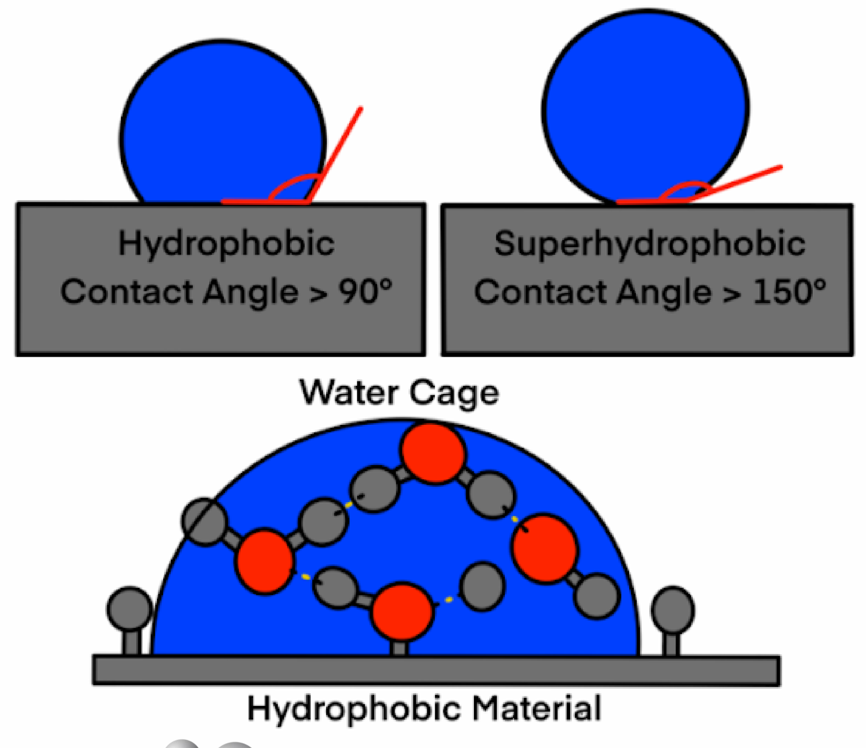
Cramlington Learning Village

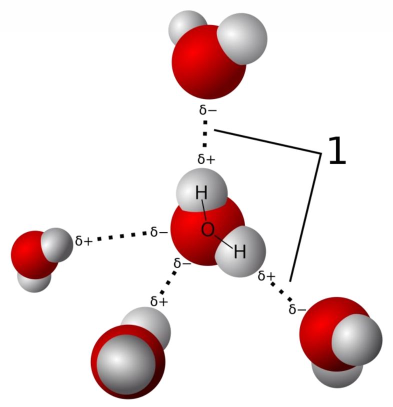
What are Hydrophobic Materials ?

Hydrophobic materials are a type of smart material that naturally repel water. These materials are non polar which causes a disruption to the hydrogen bonding in water. These hydrogen bonds are arranged tangentially to such a surface to minimize disruption leading to a structured water cage around a non polar surface yet have limited mobility. Hydrophobic surfaces are defined by the geometry a water droplet makes between its edge and surface underneath it, called the contact angle. If the droplet is more spherical and has minimum surface contact at angle greater than 90°, it is defined as hydrophobic. Angles greater than 150° are considered superhydrophobic and are examples of the lotus effect

To make a material more superhydrophobic creating nanopatterns on its surface can increase the contact area amplifying the effect. Nanopatterns with many ridges, crevices and bumps which are only a few nano metres have brought in a new generation of superhydrophobic materials.

Similar to superhydrophobic, Icephobic materials can repel and stop the formation of ice on its surface. When cold water hits a surface nucleation and freezing is more likely to occur due to contact pinning. However adding a thin oil layer means contact pinning cannot occur and nucleation is less likely so the water droplet remains in its liquid form. In which the property can be attributed to the structure of the surface which has low surface energy, in turn low adhesion and the easy removal of the ice.





Hydrogen bonding present in a water molecule.

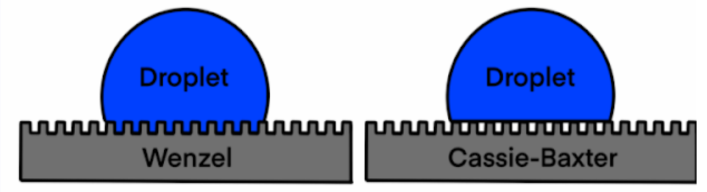
The lotus effect is named after the same superhydrophobic effect observed on the lotus flower.

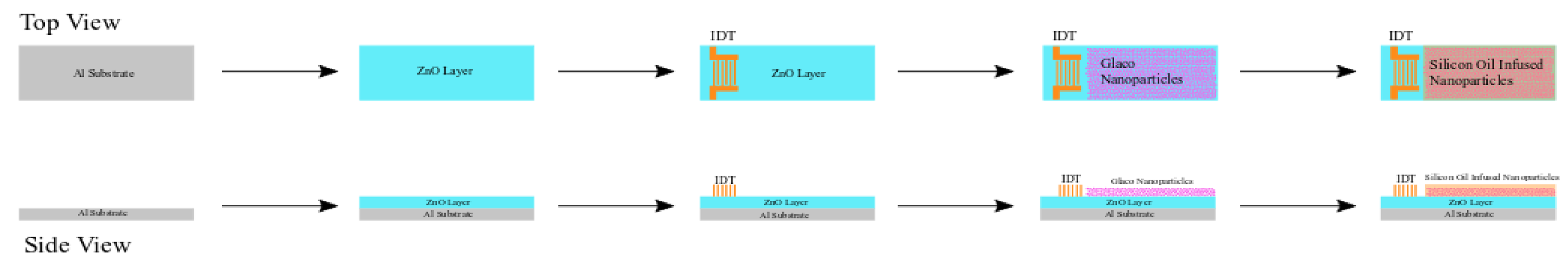
The 2 states of liquid droplets

The liquid droplets can occupy 2 states:

- Cassie-Baxter State (C-B): A bridging between the tips of the surface, on a superhydrophobic surface, where it occupies an almost spherical shape. Increases hydrophobicity with minimum contact area and highly mobile droplets.
- Wenzel State: A droplet can transition into this state with the liquid penetrating between the surface features. The Wenzel state has a large contact area and low mobility.

The transition of C-B to Wenzel state has been of interest recently to develop surfaces with controlled wettability (the ability of a liquid droplet to maintain contact surface with a solid via adhesion). The C-B state is more favourable as it lies above the pores present on the material.





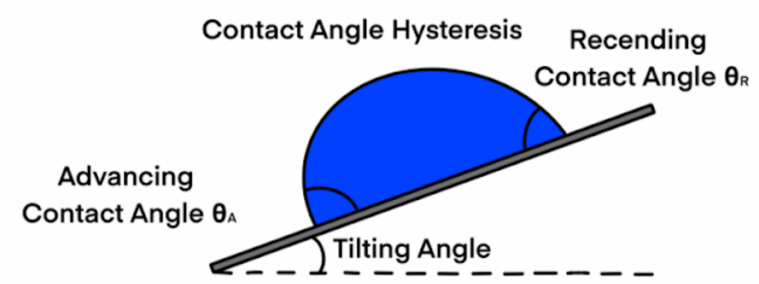
The process of forming SLIP surfaces with a SAW device.

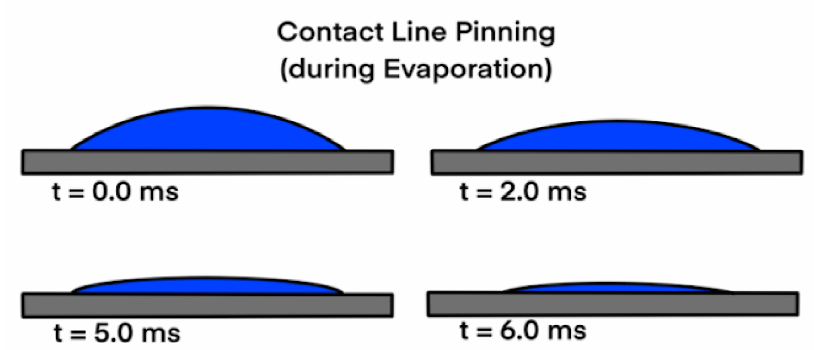
What are SAW Waves ?

SAW (Surface Acoustic Wave) is the propagation of a wave front parallel to the surface it is applied to, generated via applying a radio frequency signal to interdigital transducers (IDT) which are patterned on top of a piezoelectric substrate. This happens at the excitation centre and spreads out along the surface of the solid material not too dissimilar to an earthquake. The addition of the SLIP surfaces mean SAW waves are less likely to be damped due to the air pockets so the maximum amount of energy known as threshold power is obtained to get the liquid droplet moving.

What is a SLIP surface ?

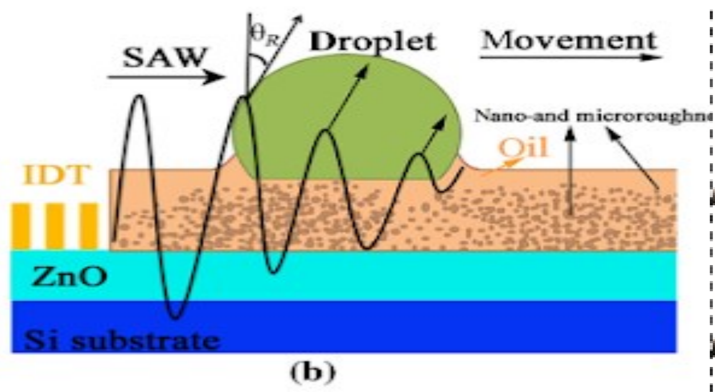
A new type of liquid state was developed using SLIPS (Slippery liquid-infused porous surfaces). SLIP are thin porous (micrometer/nanometer scale) surfaces infused with a non-volatile, hydrophobic lubricating liquid. This textured surface has a high surface area meaning it is energetically favourable for the lubricant to form a thin oil film (the oil layer needs to be thin to reduce damping and energy loss when the SAW wave interacts with the droplet) across the solid surface. The water droplet rests on this lubricating layer and not the solid surface, therefore lowering contact angle hysteresis (difference between advancing and receding contact angles) and removing contact line pinning (outer edge of liquid drop remains stationary during evaporation) resulting in a highly mobile droplet rather than a sticking droplet.

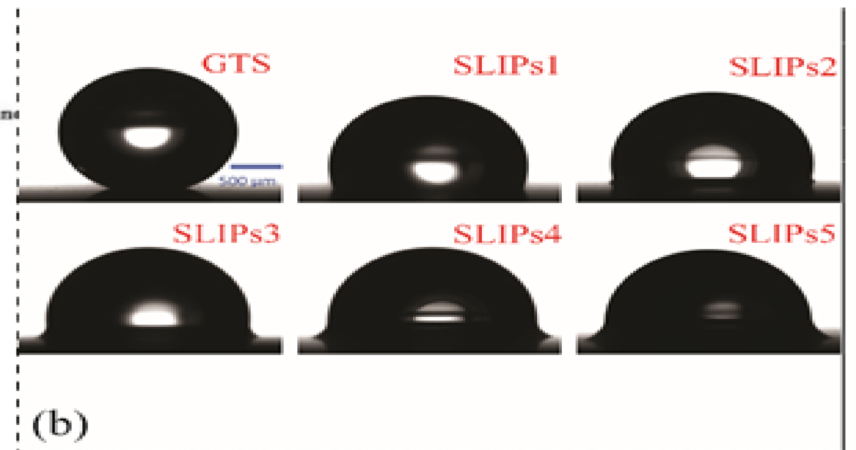


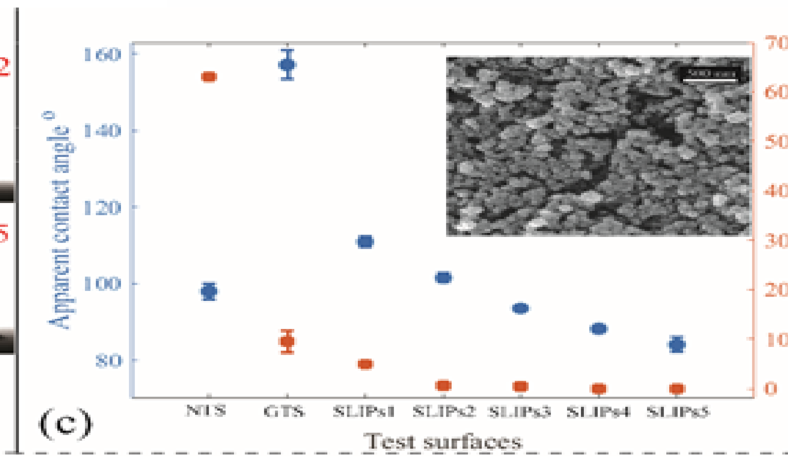


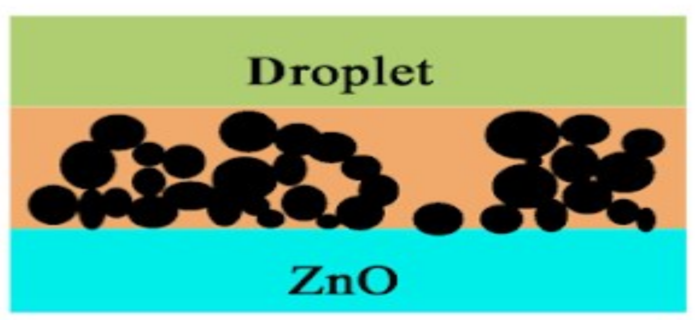
What is the Experiment ?

The experiment itself uses a propagating SAW wave which comes into contact with the droplet on a zinc oxide (ZnO) layer (which is piezoelectric to help transfer the wave), with the SLIP surface above it, in which a leaky SAW wave with a decaying amplitude is launched and dissipated into the droplet. The energy and momentum of the longitudinal wave dissipated into the body provide a pressure or force in the same direction of propagation of the sound wave. This is the basis for droplet movement and a transition between C-B to Wenzel state depending on conditions and frequencies used. It showed that by reducing contact angle hysteresis and increasing droplet mobility without increasing the contact angle more towards 180°, can increase droplet mobility and a large contact area for SAW wave interactions. This is a highly efficient energy and momentum transfer of the SAW wave energy.









(b) Droplet shape after 0-5 coatings of an oil layer. Using a SLIP surface with an oil layer has a maximum theoretical contact angle of 104.5° and with increasing oil layers, a lowest of 75°-80° which means it is no longer hydrophobic after 5 coatings of the thin oil layer.

(c) Apparent contact angle and contact angle hysteresis/sliding angles (CAH/SA) of different surfaces.

Conclusion

In conclusion a method has been devised using SAW technology and SLIP surfaces to allow high velocity movement of liquid droplets, while retaining a large contact area for SAW energy to dissipate into the object. The SLIP surface has been designed to be much thinner than the SAW wavelength to reduce damping and loss of energy. The SLIP surfaces on SAW devices are easy to fabricate, reproducible and inexpensive which is promising for the future of droplet microfluidics. This applies to anti-icing in which the surfaces are icephobic and allows for the possibility of de-icing, in many applications such as engines, biomedical sectors and solar panels.

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