

FIG 1. (a) Frozen coalescing droplets and (b) frozen amorphous droplets (blue) nucleating ice crystals (red) from the interface.

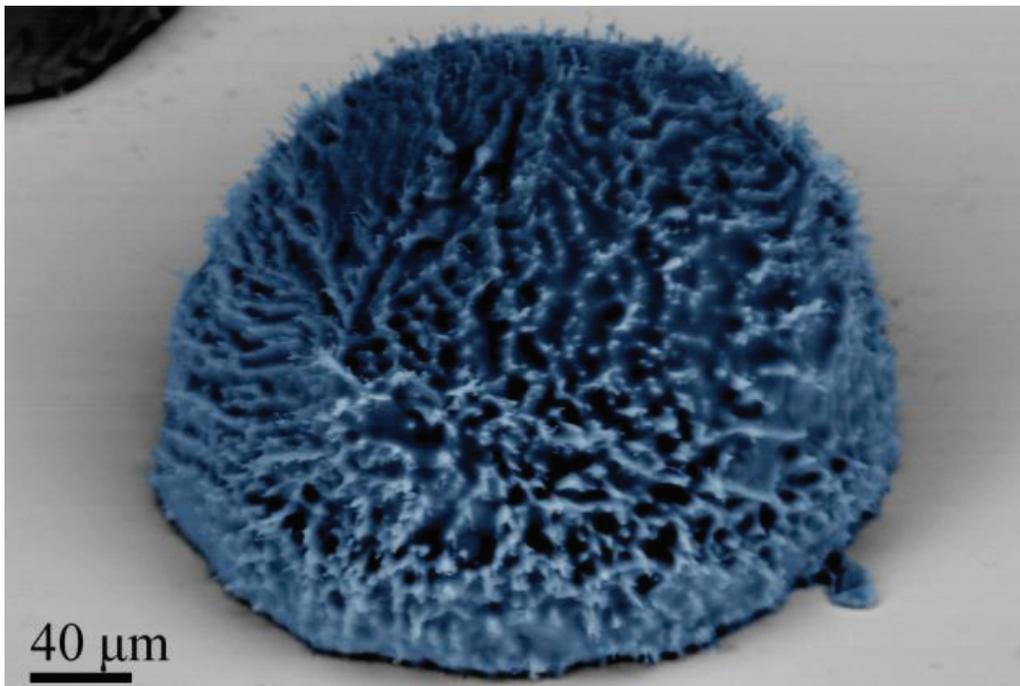


FIG 2. Frozen droplet with disrupted solid-vapor interface created by rapid freezing.

## Liquid Freezing Dynamics on Hydrophobic and Superhydrophobic Surfaces

Nenad Miljkovic, Ryan Enright, and Evelyn N Wang

Device Research Laboratory, Massachusetts Institute of Technology, Cambridge, MA, USA

False color environmental scanning electron microscope (ESEM) images of water freezing on smooth ( $\theta_e \approx 120^\circ$ ) and nanostructured ( $l \sim 50$  nm,  $\theta_e \approx 170 - 180^\circ$ ) hydrophobic surfaces are presented. To obtain the freezing dynamics of water droplets, the vapor pressure in the ESEM chamber was set to 800 Pa. The images were obtained with a beam potential of 20 kV and variable probe current. The surface temperature was initially set to  $5 \pm 1.5^\circ\text{C}$  using a cold stage, resulting in water droplet condensation. After a period of time, the surface temperature was decreased to  $-20 \pm 1.5^\circ\text{C}$ , rapidly freezing the condensed droplets. The three images capture the freezing dynamics on hydrophobic and superhydrophobic surfaces. Figure 1a shows a snapshot of droplet coalescence between a large droplet (left) and a smaller droplet (right) on a nanostructured

surface. Due to rapid freezing (Figure 1b), ice droplets maintained an 'amorphous' spherical structure (blue). Subsequent deposition of ice preferentially initiated on the droplet interface and formed crystallographic ice (red). Figure 2 shows a larger scale droplet ( $R \sim 100$   $\mu\text{m}$ ) undergoing rapid freezing with notable protrusions. The heat flux ( $q'' \sim 1$  GW/m<sup>2</sup>) due to the latent heat of freezing could not be removed rapidly enough to match the velocity of the freezing front ( $v_f \approx 1500$  m/s), resulting in evaporation and ejection of the liquid (protrusions) from the droplet interface. These distinct freezing droplet behaviors can significantly alter dynamics of phase-change phenomena on these surfaces. The visualizations provide insight into these complex droplet-surface interactions, which are important for the development of de-icing surfaces.