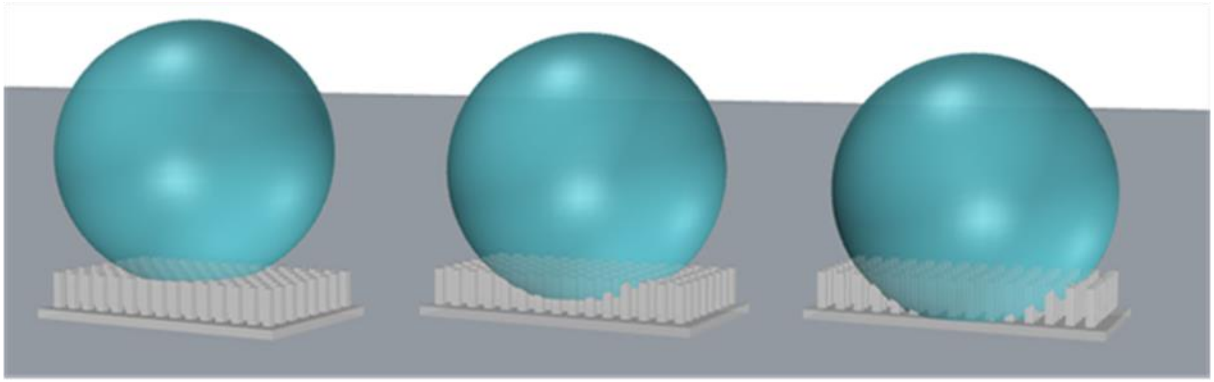
Optical Metrology of Characterizing Superhydrophobic States on Patterned Substrates

Deming Meng, Yifei Wang, Hao Yang, Buyun Chen, Pan Hu, Boxiang Song, Yunxiang Wang, Tse-Hsien Ou, Zerui Liu, Ximing Zheng, Yichen Gong and Wei Wu*
Department of Electrical Engineering, University of Southern California, Los Angeles, CA 90089
* wu.w@usc.edu

Superhydrophobic surfaces have many applications due to the high repellent property. When superhydrophobic surfaces are immersed under the liquid, sometimes air will be trapped between the liquid and the surface depending on the surface energy coefficient, superhydrophobic structure and the surface treatment. Depending on the air distribution shape trapped between the liquid and the surface, the liquid can be divided into several states: Wenzel state, Cassie-Baxter state and some sub-state between Wenzel and Cassie-Baxter state (Figure 1 a, b&c). Different states will lead to totally different properties so that distinguishing the state is essential. Until now, no in-situ, non-destructive and accurate technology has been invented, which introduces huge difficulties into the superhydrophobic surfaces research and applications. Here we developed an optical technology to characterize the state of superhydrophobic surface.

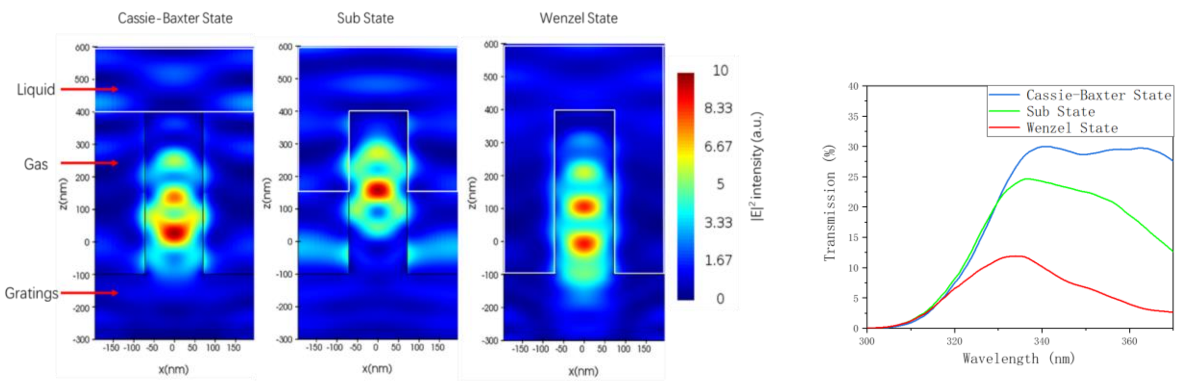
The in-situ, non-destructive and accurate optical technology was invented based on that different superhydrophobic states could cause difference optical responses with the superhydrophobic surfaces. If an optical mode sensitive to the liquid-gas boundary exists, this small difference will produce obvious optical effects. Here, the 2-dimensional gratings will be used as the examples. As the state changes, the optical resonance will change as the refractive index in gaps changing. The simulation results of the Cassie-Baxter state, Wenzel state and the sub-state (Figure 2a, b &c) show that we have succeeded achieving the design goal: optical responses at 340 nm wavelength are very sensitive to the superhydrophobic states, therefore, produces huge difference in optical characteristics. Figure 2d shows the simulation results of 0^{th} order diffraction transmission spectrum of Cassie-Baxter state, sub state and Wenzel state. Those simulation data show that the design goal has been successfully achieved: optical responses at 340nm wavelength are very sensitive to the different superhydrophobic states, therefore, produce huge difference in optical characteristics.

The 2-D gratings were fabricated by combining interference lithography and nanoimprint lithography and then a self-assembled monolayer was coated on the surface as the hydrophobic treatment. Fabricated 2-D gratings SEM picture is shown in figure 3a. When liquid is added onto the 2-D nano gratings surface, different states can be distinguished clearly by transmission spectra. Liquid with different surface tension coefficient may lead to different states on the superhydrophobic surface. By tuning the concentration of ethanol in water solution, we can tune surface tension without significant change in refractive index, and hence realize different states on patterned surface (Figure 3b). Figure 3c shows the transmission spectra of the different surface tension coefficient liquid in experiment. The experimental data fits well with the simulation data and it proves the feasibility of this new optical technology.



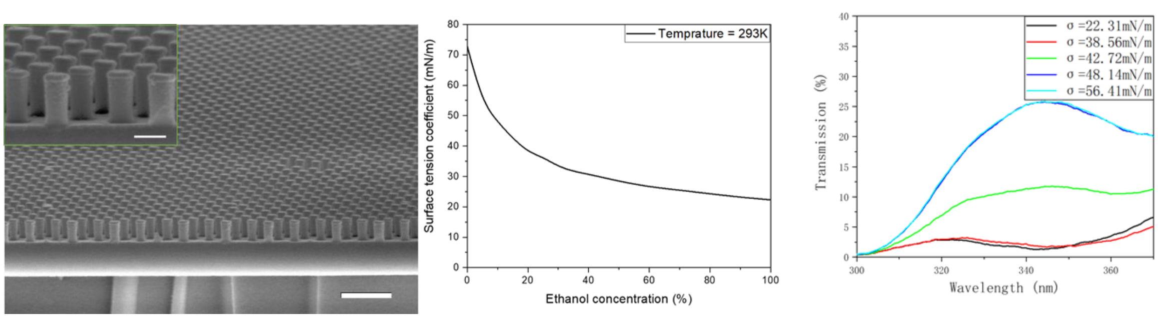
(a) (b) (c)

Figure 1: Schematics of three different superhydrophobic states. (a) Cassie-Baxter state. Liquid stands on the superhydrophobic surface. (b) Sub state between Cassie-Baxter state and Wenzel state. (c) Wenzel state. No air is trapped between the liquid and superhydrophobic surface.



(a) (b) (c) (d)

Figure 2: a, b&c show electrical field distribution (cross section view) of three different superhydrophobic states at 340nm. White line shows the boundary of liquid and gas. (a) Cassie-Baxter state. (b) Sub state. (c) Wenzel state. (d) Transmission spectra of Cassie-Baxter state, sub state and Wenzel state.



(a) (b) (c)

Figure 3: (a) SEM images of fabricated 2-dimensional gratings. Inserted image is zoom-in view. Scale bars of the zoom-out and zoom-in images are 1um and 250nm. (b) Surface tension coefficient versus ethanol concentration in ethanol water solution. (c) Transmission spectra of superhydrophobic surfaces covered by different surface tension coefficient liquid.