Understanding and Controlling Wetting Phenomena at the Micro/Nanoscale

by

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ABSTRACT

Understanding and controlling wetting phenomena at the micro/nanoscale is currently a subject of great interest. Inspired by nature, the goal of this dissertation is to study the wetting phenomena at the micro/nanoscale by designing and synthesizing structures with desired size and function, and then to translate this knowledge for novel applications such as in surface self cleaning, microfluidics, and energy management. In this dissertation, we systematically investigated the effects of roughness on the static and dynamic wetting properties and how to dynamically control the wettability of rough surface by using electrowetting and electrochemical means.

Specifically, in the first part of this dissertation, we first designed and created two classes of superhydrophobic surfaces, one with microscale roughness and the other with nanoscale feature. Both can achieve very high static contact angle of up to 165^{o}. For the pure carbon nanotube film (with nanoscale roughness), although it exhibits a superhydrophobic property, it suffers from a large sliding angle. Significant decrease of sliding angle on the carbon nanotube film was achieved by using two-scale roughness, in which a more robust Cassie state is maintained.

We investigated impact dynamics of water droplets on surfaces with nanoscale roughness and microscale feature, respectively. Even with the same static contact angle, dynamic impact behaviors on those two surfaces are quite different. This is because the critical pressure for Cassie to Wenzel transition on the surface with nanoscale roughness is much higher than the surface with microscale roughness. Further analysis indicated that the response of the droplet on the surface with microscale roughness was governed

by surface porosity, diameter of pillars, coating property, and impacting velocity of the droplet.

In the second part of this thesis, we investigated how to dynamically control the wettability of the as-fabricated superhydrophobic surfaces with microscale roughness using electrowetting means. By meticulous design of porosity, aspect ratio and coating materials, we demonstrated that it is possible to achieve partial reversibility of wetting and dewetting transition on rough surfaces.

For the carbon nanotube membrane with nanoscale roughness, we discovered that its wettability was strongly polarity dependent. At a critical bias (1.7V), with the membrane acting as the anode, there was an abrupt transition from a super-hydrophobic to hydrophilic state. For a negative bias applied to the membrane, two orders of magnitude higher bias was required for the transition. Using first principles density functional theory, we showed that the strong polarity dependence of wetting was due to electro-chemical oxidation of the nanotube which modifies the nanotube's surface energy. We also demonstrated several exciting applications of this technology such as directional control of water flow by reversing the polarity of the applied bias and achieving extreme hydrophobic-to-hydrophilic spatial contrast on the membrane surface. This simple electrochemically controlled wetting and transport phenomena could find various applications in transport and separation technologies.