Electrically Controlled Switchable Adhesion of Dual Nanometer and Micrometer Structured Surfaces*

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We report on the development of dynamically switchable adhesion surfaces containing artificially fabricated structures of micro-scale and superimposed nano-scale features. The aim of developing this type of surface was to create a surface that could be switched by external stimulus from a Cassie state with low adhesion to a Wenzel state with high adhesion and also to be able to switch back once the stimulus was removed. We will present results from a comprehensive study investigating the wetting properties of different combinations of nano-scale and micro-scale geometries.

The use of textured surfaces to achieve superhydrophobicity can be routinely found in nature. Many plant leaves, bird feathers, insect wings and insect legs take advantage of micron and/or nanometer-scale features to modify the wetting state. The best known example is the lotus plant, with leaves, having a double structure of micron-sized nubs with nano-scale asperities superimposed, that exhibit superhydrophobic, self-cleaning properties where water beads up into droplets and easily rolls off the leaves' surfaces. A second example is the rose petal, also made up of dual micro and nano-scale structures of roughly the same scale as the lotus leaf, but its structures are arranged in such a way to allow water to bead up into droplets but instead of rolling off, adhere to the surface.

To study parameters that affect switchable adhesion a variety of different geometries were fabricated. Nanometer-scale lines, posts, and holes were fabricated and combined with micron features consisting of parallel streets, islands, or checkerboard patterns of varying linewidths and pitches. Figure 1 shows scanning electron microscopy (SEM) images of selected combined nano- and microscale surfaces. Each different geometry was modified with three different organic hydrophobic films (PDMS, CYTOP, and Teflon AF) conformably grafted onto the nanostructured surface to study the effect that surface energy had on the wetting state for a fixed geometry. Many combinations of dual-textured surfaces were found to be superhydrophobic and water droplets on these surfaces could be electrically controlled to switch from a Cassie state to a Wenzel state. The ability to reversibly switch between these wetting states was found to be a strong function of the specific combination of surface geometries.

Selected surfaces consisting of parallel corrugations can undergo reversible adhesion. The surface is initially in a superhydrophobic (contact angle > 150°) Cassie state that, in response to electrical control, switches to a Wenzel state having high adhesion. When the electric field was removed, spontaneous dewetting occurred along the corrugations as the droplet transitioned from the Wenzel state back to a Cassie state. An example of this process is shown in Figure 2. One of the key findings of this work is geometry that provides a dynamic pathway for the contact line to freely propagate with little to no energy barriers is critical for the transition from a Wenzel state back to a Cassie state.

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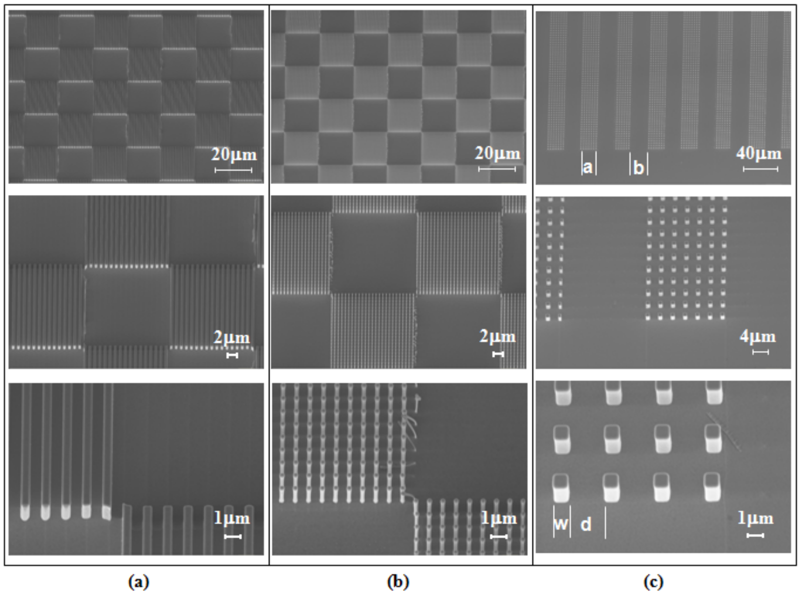

Figure 1. Scanning electron microscopy images taken at different magnifications. (a) Images of the combined nano-scale feature: Dense Lines, *w* = 600nm, *d* = 600nm and the micro-scale feature: Checkerboard 20/20, *a* = 20μm, *b* = 20μm. (b) Images of the combined nano-scale feature: Dense Posts, *w* = 400nm, *d* = 400nm and the micro-scale feature: Checkerboard 20/20 *a* = 20μm, *b* = 20μm. (c) Images of the combined nano-scale feature: Iso Posts-10000/2000, *w* = 1000nm, *d* = 2000nm and the micro-scale feature: Lines 20/20 *a* = 20μm, *b* = 20μm.

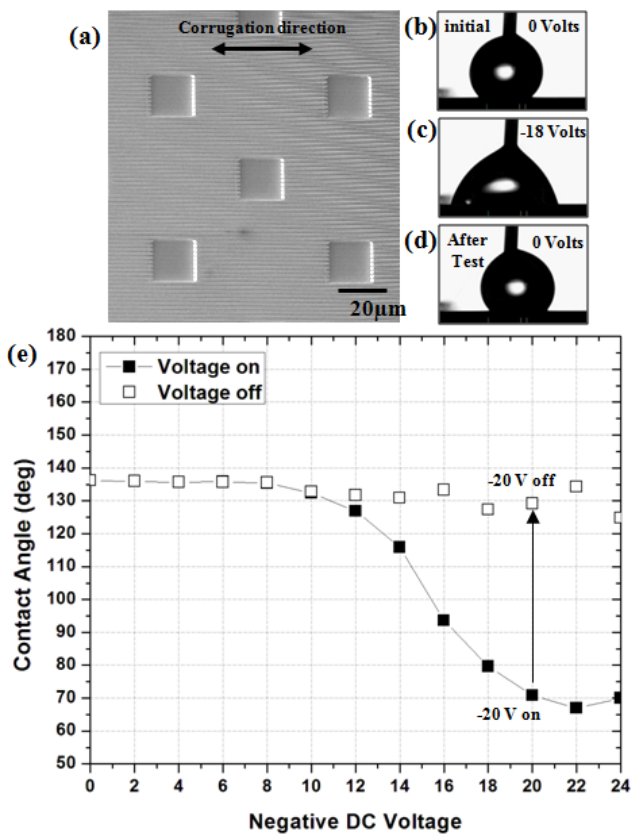

Figure 2. (a) SEM image of the 1000-nm wide corrugations with spacing-to-width ratio = 1:1 patterned into the checkerboard pattern *pitch* = 20 μm, *width* = 60 μm. (b) Side view of droplet on surface prior to electrowetting actuation. (c) View of droplet with -18 V dc applied. (d) View of droplet immediately after the potential has been removed. (e) Plot of contact angle vs. negative dc voltage. Measurements parallel with corrugations.