

Nanoparticle Dispersion in Superhydrophilic Nanostructures

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Nanostructures can lead to novel properties that can not be found in macroscale materials and have been employed for a wide range of applications. The wetting properties of nanostructured surfaces are particularly interesting and can be engineered by the structure geometry and surface chemistry. Examples include hydrophilic wicking structures to increase heat transfer [1,2] and hydrophobic structures for self-cleaning and waterproofing [3]. Recent work have also examined using surface nanostructures for antiviral effects [4]. In all these applications, the wicking of suspended nanoscale elements in hydrophilic nanostructures is critical and currently not well understood, especially when their length scale approaches the structure features. Identifying the dispersion mechanisms for particles of various sizes during fluid transport in nanostructures will provide insight into their response to particulates and viruses.

In this work, superhydrophilic nanostructures with periods of 300 nm are fabricated using laser interference lithography (IL) on a silicon substrate to examine the dispersion of nanoparticles during wicking. The fabrication process includes spin-coating a photoresist and antireflection coating on a silicon substrate, as illustrated in Figure 1. The coated substrate is patterned using Lloyd's mirror IL and then etched into the silicon substrate using O₂ and HBr ICP-RIE. The fabricated surface is cleaned using oxygen plasma to increase the surface energy, thereby making the surface more hydrophilic and enhancing wicking through the structure. Polystyrene (PS) nanoparticles with 200 and 500 nm diameters are used to examine the dispersion as the water wicks through the fabricated nanostructure. Solutions are prepared by mixing deionized (DI) water and the nanoparticles to create .05% nanoparticle concentration. Optical microscopes are first utilized to observe the spreading and drying of the droplets as they wick through the nanostructured surface. During the drying process particles aggregate on the edge of wetting front, causing visible rings of particles to form on the nanostructure. As the droplet evaporates it reduces in diameter periodically due to the balance of surface tension and the fluid pressure exerted by wicking. This effect causes concentric rings of particles to form at each point where the diameter stayed constant. After the DI water completely evaporated, scanning electron microscope (SEM) imaging is used to examine the particle assembly patterns to determine the dispersion mechanisms.

Preliminary results demonstrate the difference in the dispersion methods for the two particle sizes on the superhydrophilic nanostructure. We observe that the 500 nm PS particles did not appear to be carried past the boundary of the wetting/wicking fronts and the assembly resulted in a sharply defined outer edge. This effect is observed in the SEM image shown in Figure 2(a), where 500 nm particles form a monolayer assembly on top of the nanostructures. Different effects can be expected for smaller particles which can fit between the periodic nanostructures in the wicking region. As shown in the SEM image shown in Figure 2(b), the 200 nm particles are able to disperse within the nanostructures due to wicking forces and are embedded after drying to leave a less defined boundary. We will present the fabrication and testing results on particles smaller than 100 nm, which can be expected to be carried further through the structure by passing between the features of the nanostructure. The effectiveness of these superhydrophilic nanostructures on filtering and spatially separating various particles sizes will also be examined and presented.

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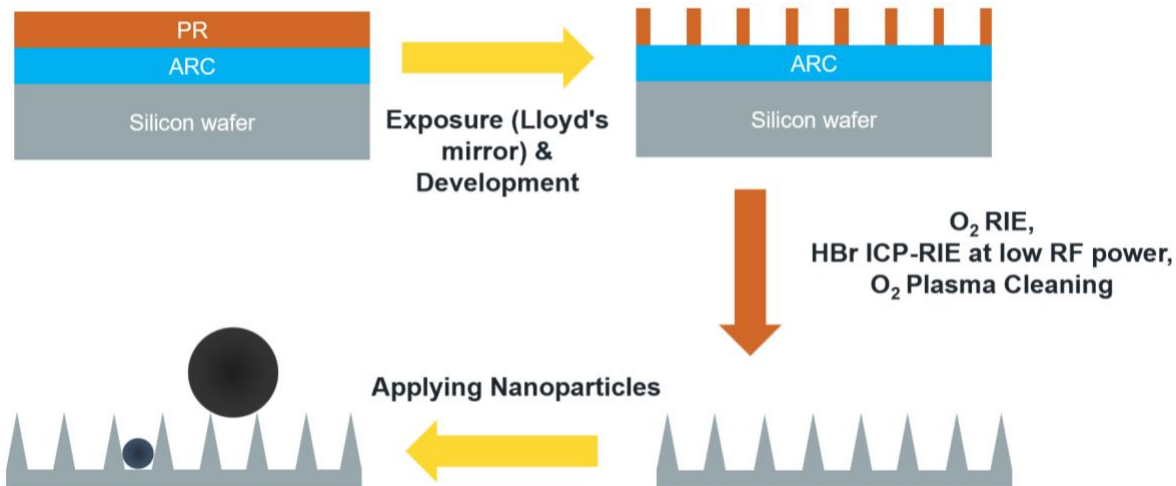


Figure 1. Schematic of the fabrication process. The silicon substrate is coated with antireflection coating (ARC) and photoresist (PR) and then patterned using IL. That pattern is then transferred into the silicon substrate using RIE to create nanocone structures.

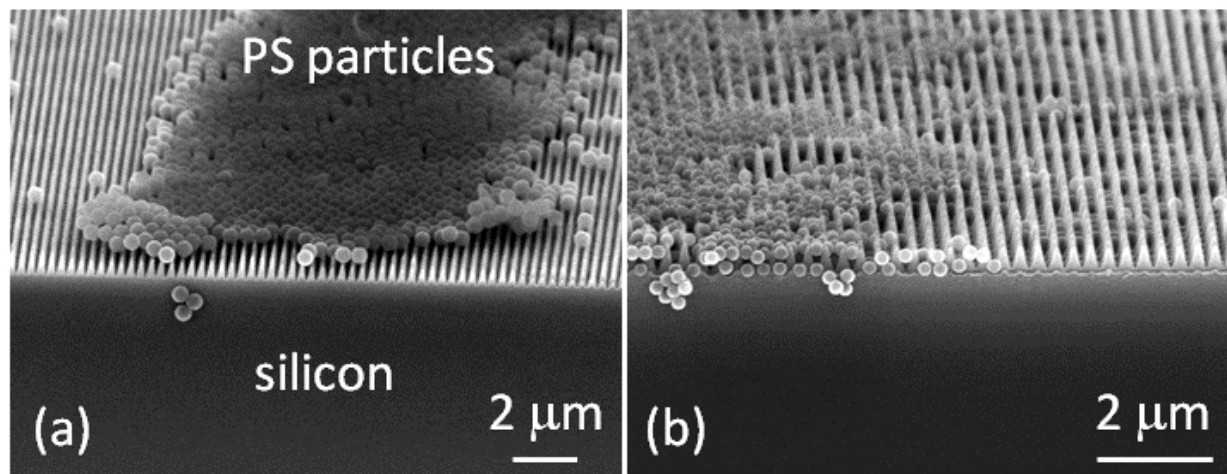


Figure 2. Cross-section SEM images of the boundary between the wicking and wetting fronts for water with (a) 500 nm and (b) 200 nm polystyrene (PS) particles on superhydrophilic nanostructures.

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