Jumping Droplet Dynamics on Scalable Nanostructured Superhydrophobic Surfaces

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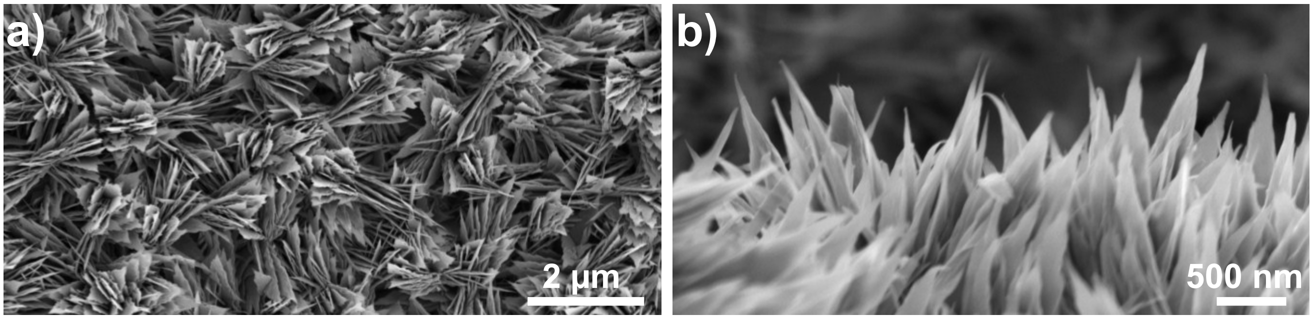

FIG 1. Field emission scanning electron microscopy images of a nanostructured copper oxide (CuO) surface with (a) top view, (b) side view. The sharp, knife-like CuO structures have characteristic heights, $h \approx 1$ µm, solid fraction, $\varphi \approx 0.023$, and roughness factor, $r \approx 10$.

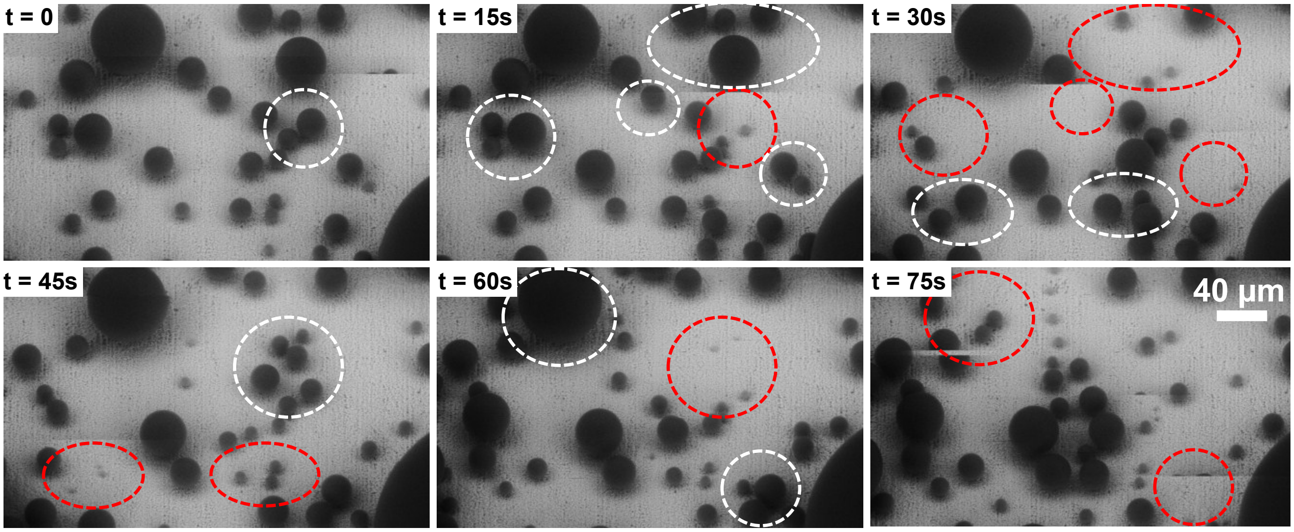

FIG 2. Time-lapse images captured *via* environmental scanning electron microscopy (ESEM) of water condensation on the nanostructured CuO surface. White dotted circles highlight areas of the surface with droplets just prior to coalescence and subsequent jumping, while red dotted circles highlight areas of the surface right after droplet jumping (P_v = 860 ± 43 Pa, T_s = 4.5 ± 1.5 °C).

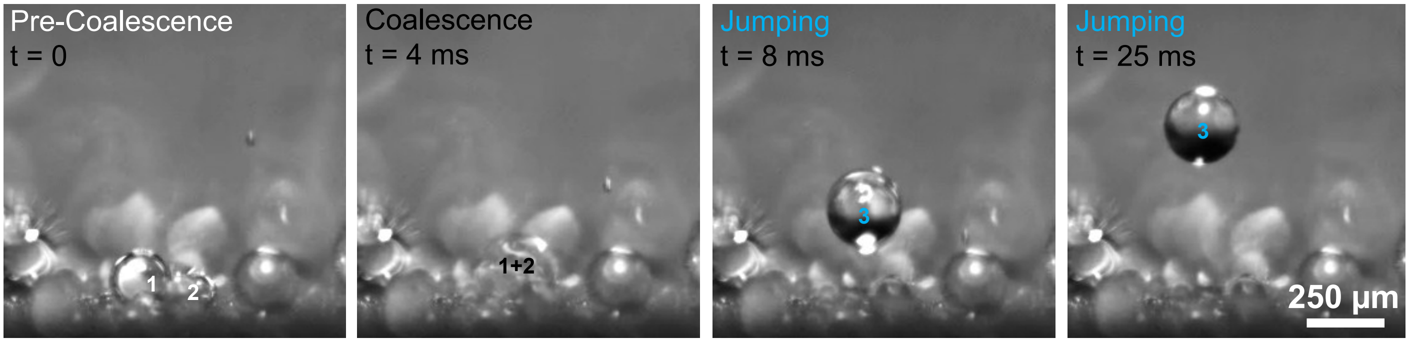

FIG 3. Time-lapse images captured *via* high speed camera of water condensation on the nanostructured CuO surface. Droplet 1 and 2 initially grow independently until coalescing and then jumping from the surface (P_v = 3500 ± 175 Pa, T_s = 26 ± 0.2°C).

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Environmental scanning electron microscope (ESEM) and high speed images of coalescence-induced droplet jumping on a nanostructured superhydrophobic copper oxide (CuO) surface are presented. Nanostructured CuO films were formed by immersing clean copper sheets into a hot (96 ± 3 °C) alkaline solution composed of $NaClO_2$, NaOH, $Na_3PO_4 \bullet 12H_2O$, and DI water (3.75 : 5 : 10 : 100 wt.%). During the oxidation process, a thin (<200 nm) Cu_2O layer was formed that then re-oxidized to form sharp, knife-like CuO oxide structures (Figure 1). Hydrophobic functionalization was obtained by depositing a fluorinated silane (trichloro(1H,1H,2H,2H-perfluorooctyl)silane) from a vapor phase. Individual droplet growth on the nanostructured CuO surfaces was characterized using an ESEM (Figure 2). The images were obtained with a beam potential of 20 kV and variable probe current. Droplets nucleated within the nanostructures and, while growing beyond the confines of the structures, their apparent contact angle increased as they developed a balloon-like shape with a liquid bridge at the base. Once droplets grew to diameters large enough to coalesce with neighboring droplets ($R \approx 7$ µm), frequent out-of-plane jumping droplets were observed. To gain further understanding on jumping velocity, droplet jumping was studied in a pure saturated environment with a high speed camera. Recordings were taken at 2000 FPS. Figure 3 shows a time lapse of a coalescence event between two droplets. As the droplets coalesce, excess surface energy is converted into kinetic energy resulting in droplet jumping. The visualizations provide insight into these complex droplet-surface interactions, which are important for the development of enhanced phase change surfaces. In addition, these CuO surfaces offer ideal condensation behavior in terms of emergent droplet morphology and coalescence dynamics.