DELAYED LEIDENFROST PHENOMENA ON BIOTEMPLATED NANOSTRUCTURED SURFACES

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ABSTRACT

Using the *Tobacco mosaic virus* (TMV) as a nanoscale template, superhydrophilic surfaces have been fabricated and characterized showing a delay of the Leidenfrost phenomena during droplet cooling. In this work, we show that the Leidenfrost point (LFP) can be delayed by over 100°C with the addition of TMV nanostructures, and up to 250°C by using dual-scale hierarchical structures. Additionally, increases in heat transfer by nearly three orders of magnitude have been achieved as compared to flat samples at similar temperatures.

INTRODUCTION

The Leidenfrost point is the temperature at which a liquid will begin film boiling and is commonly seen when a droplet of water is placed in a hot frying pan. The droplet slides around, hovering on a cushion of vapor without wetting the surface. Eliminating this phenomenon is important in high-temperature processes where liquid-to-surface contact is critical, such as replacing nuclear reactor coolant after loss-of-coolant incidents [1]. This *Late News Paper* reports the first demonstration of delayed Leidenfrost effect using nanostructures that can be applied to a variety of surfaces using a simple yet powerful biotemplating technique.

FABRICATION

By manipulating interfaces with nanostructures, substantial increases in heat transfer can be achieved. However, traditional nanofabrication methods are difficult to integrate with real-world cooling schemes. The current work uses a simple room temperature nanofabrication process, using the self-assembly and mineralization of the TMV to create superhydrophilic surfaces for enhanced heat transfer. By sequentially submerging a surface in three room temperature solutions (TMV suspension, catalyst, and electroless nickel solution) conformal virus-templated nickel coatings are created. A similar fabrication method has been previously reported at Hilton Head 2010 and Transducers 2011 for superhydrophobic water-repellent surfaces [2] and 3D microbattery electrodes [3]. This work reports superhydrophilic surfaces for increased wetting and phase-change heat transfer. This process requires no special equipment and can be easily extended to both micro and macroscale manufacturing. Figure 1 shows SEM images of virus-templated nanostructures, and a hierarchical surface with SU-8 pillars coated with TMV. In this work, flat nickel surfaces (contact angle of 80°), TMV nanostructured surfaces (<10°), and hierarchical surfaces with post heights of 20 μm and 40 μm (~0°) were fabricated and tested.

Figure 1: SEM images of (a) nickel-coated TMV nanostructures at two magnifications and (b) hierarchical structures comprised of SU-8 posts coated with TMV nanostructures.

EXPERIMENTAL RESULTS

The evaporation of 6 μL water droplets on heated surfaces was measured using high-speed imaging to determine the LFP, the temperature corresponding to the longest evaporation time. Figure 2 shows the evaporation time versus surface temperature for each sample. As the surface temperature is increased the evaporation time decreases until the onset of film boiling, at which point the time to evaporate begins to increase for each sample. As compared to the flat sample (LFP=200°C), the nanostructures offset LFP by 100°C, the 20 μm hierarchical samples offset LFP by 175°C, and the 40 μm hierarchical samples offset LFP by 250°C. We believe the posts bridge the vapor film and capillary pressure maintains the wetted surface. Figure 3 shows high-speed imaging of droplet-

Figure 2: Experimental results of droplet evaporation time as a function of surface temperature for each sample, showing an offset in LFP with the addition of nano and microstructures. The LFP is defined as the surface temperature at the largest evaporation time.

Figure 3: High-speed imaging of droplet-surface interactions at $T_{\text{Surface}}=200^{\circ}\text{C}$ for (a) flat nickel surface, (b) nanostructured TMV surface, and (c) hierarchical surface with $40\text{ }\mu\text{m}$ tall posts. It can be seen that the flat surface is undergoing the Leidenfrost phenomena, where the droplet does not wet the hydrophilic surface because of a thin vapor layer generated by the slow evaporation of the droplet. The nanostructured surface shows similar behavior but periodically bridges this vapor layer, leading to faster evaporation and droplet deformation. The hierarchical sample immediately wets and vaporizes the droplet quickly.

interactions at $T_{\text{Surface}}=200^{\circ}\text{C}$. The flat surface (Fig.3a) undergoes classical Leidenfrost behavior, bouncing on the surface and not wetting. Droplets initially bounce on the nanostructured surface (Fig.3b), but eventually (at $t=72\text{ms}$) bridge the vapor layer causing a violent rupture. This process continues until the droplet has evaporated. Figure 3c shows the droplet immediately wetting the hierarchical sample and evaporating in under 100ms.

Knowing the time to evaporate a fixed volume of water, the heat transfer rate per droplet is calculated. Figure 4 shows heat transfer rates above and below the LFP for flat surfaces. It can be seen that at $T_{\text{Surface}}=100^{\circ}\text{C}$, the structured samples increase heat transfer by a factor of five-to-eight. At $T_{\text{Surface}}=250^{\circ}\text{C}$, the structured surfaces increase heat transfer by almost three orders of magnitude.

CONCLUSION

This work demonstrates the feasibility of using biotemplated nanostructures based on the TMV for delaying LFP. Offsets of 250°C and a nearly three order of magnitude increase in heat transfer have been demonstrated.

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Figure 4: Heat transfer rate per droplet for each sample for (a) $T_{\text{Surface}} = 100^{\circ}\text{C}$ and (b) $T_{\text{Surface}} = 250^{\circ}\text{C}$ (on a log scale), showing substantial increases in heat transfer with nano/microstructures.

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