

# ANALYSIS OF A SUPERHYDROPHOBIC MICROLENS ARRAY SURFACE: AS A MICROCHANNEL WALL FOR PRESSURE DROP REDUCTION

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## ABSTRACT

This paper reports an analysis of a superhydrophobic microlens array (SMA) surface as a microchannel wall with a reduced pressure drop. To explore the pressure drop reduction in a microchannel, simulations were conducted using an SMA channel wall. Additionally, a magnetic-force-driven speed test verified that friction force on a SMA surface is less than on a flat surface. These results are useful to reduce the power consumption in various microfluidic applications.

**KEYWORDS:** Superhydrophobic, Microlens array, Microchannel, Pressure drop reduction

## INTRODUCTION

We previously reported a perfectly ordered microlens array [1, 2] for large area superhydrophobic surfaces. We recently achieved a contact angle of  $165^\circ$  and a low contact angle hysteresis of  $3^\circ$  on a polydimethylsiloxane (PDMS) microlens array with the aid of a Teflon (polytetrafluoroethylene) coating [2]; these figures indicate little static friction force for a water droplet on this surface. We have also studied drag force reduction on the superhydrophobic microlens array (SMA) in this paper.

## FABRICATION PROCESS

The fabrication process of the SMA is described in Figure 1. A mold of photoresist microbowls was made by 3D diffuser lithography [3]. After being poured and cured, the PDMS elastomer was peeled from the mold. Finally, a 500-nm-thick layer of Teflon AF2400 was coated on the SMA using FC-40 (perfluorocarbon). The Teflon solvent evaporated overnight at room temperature. Figure 2(a) shows a scanning electron microscopy (SEM) image of the fabricated SMA, which has a height and diameter of  $10\mu\text{m}$ . A photograph of a water droplet on the SMA is shown in Figure 2(b).

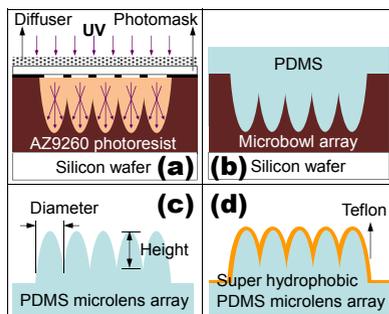


Figure 1. Process flow of the superhydrophobic PDMS microlens array. (a) 3D diffuser lithography. (b) Solidification of PDMS for a replica of the photoresist microbowl mold. (c) Separation of PDMS from the mold. (d) Teflon (500nm) spin-coating on the PDMS microlens array.

## SIMULATION RESULTS

To investigate the feasibility of applying the SMA in a microchannel wall, we simulated pressure drops in the microchannel structure shown in Figure 3 using CFD-ACE+ (CFD Research Co., Huntsville, AL). The microchannel is composed of three regions with the same length and width. Water flows on a SMA surface at the center region as well as on flat PDMS surfaces near the inlet and outlet. For short-loop verification, simulation was performed on a rectangle-shaped micropillar array instead of the curved microlens array for various effective contact areas, as shown in Figure 4. The outlet was at atmospheric pressure, and an additional 10kPa of pressure was applied at the inlet. Figure 5 shows significant pressure drop reduction rates [4] from employing the SMA at the bottom wall, even for the enlarged effective contact area. This reduction in pressure drop results from the fact that the water can slip over the SMA due to its superhydrophobicity and trapped air among the adjacent microlenses, while the water is under a no-slip condition on the flat surfaces, as illustrated in the insets of Figure 5.

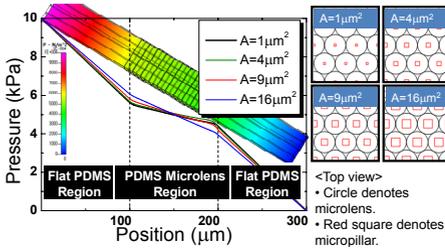


Figure 4. Simulation results of pressure drop through the proposed microfluidic channel with various effective contact areas of the microlens array.

## EXPERIMENTAL RESULTS

In order to verify the drag force reduction on the SMA, a speed test using mini-boats driven by magnetic force was performed on a water surface, as shown in Figure 6. The respective masses of the flat PDMS and the SMA mini-boats are 70mg and 73.2mg. Each mini-boat is 1cm<sup>2</sup>. A staple (62mg) was mounted on the mini-boats to

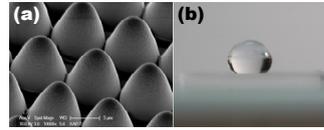


Figure 2. (a) SEM image of the fabricated microlens array. (b) A water droplet (~10 $\mu$ l) on the superhydrophobic microlens array (contact angle: 165 $^\circ$ ).

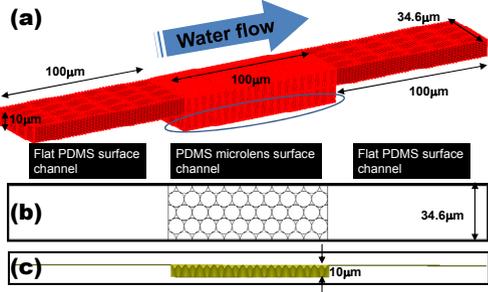


Figure 3. Microchannel structure used for simulation. (a) Geometrical dimensions of the microchannel. (b) Top view of the microchannel. (c) Side view of the microchannel.

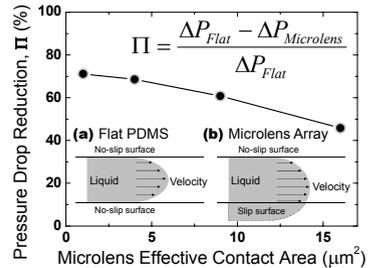


Figure 5. Pressure drop reduction rate versus effective contact area of the microlens array

allow the boats be driven by the magnetic force arising from a permanent magnet (8kGauss) located at the opposite side of a starting line in a water container. The boats were carefully aligned on the same starting line. The traces shown in Figure 6 were recorded at 300frames/sec with a digital camcorder. The displacements were analyzed using the recorded traces and then the accelerations were extracted as shown in Figure 7. It is noteworthy that the SMA mini-boat moved faster than the flat PDMS boat, despite the fact that the SMA mini-boat is slightly heavier than the flat boat, providing further evidence of the drag force reduction.

## CONCLUSIONS

A low-friction SMA surface is important to reduce power consumption in various microfluidic applications such as microfluidic large-scale integration [5] and artificial blood vessels.

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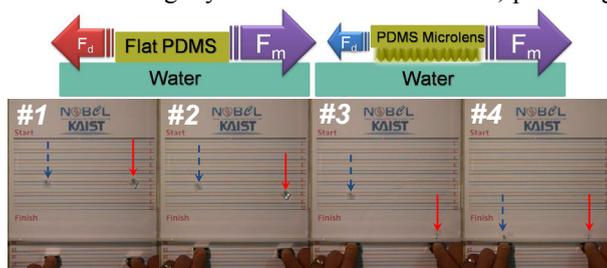


Figure 6. Captured images of the flat PDMS (blue dashed arrow) and the microlens PDMS (red solid arrow) mini-boats driven by magnetic force ( $F_m$ ). The time interval between adjacent frames is 1.6 sec.

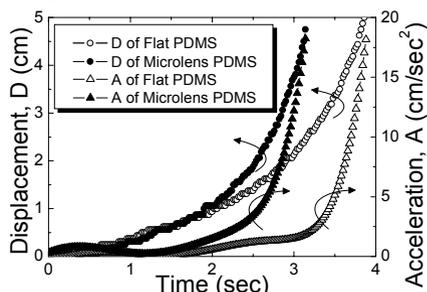


Figure 7. Displacements and accelerations of both mini-boats as a function of time.