FAST SURFACE-TOPOGRAPHY-DRIVEN DROPLET TRANSPORTATION ON THE MAGNETIC ELASTOMER WITH A SUPERHYDROPHOBIC SURFACE

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ABSTRACT

For fast droplet transportation on an open surface, we developed the surface-topography-driven droplet transportation process using a magnetic elastomer with a superhydrophobic surface. Because the superhydrophobic surface has a high contact angle and low contact angle hysteresis, a droplet can easily roll off on the tilted surface. By taking advantage of the superhydrophobic characteristics of the surface, a droplet was moved on the surface of the device through local change in topography by the magnetic actuation. As far as we know, it is the first time to apply this concept to droplet transportation.

KEYWORDS

superhydrophobic surface, magnetic elastomer, open surface digital microfluidics, droplet transportation, surface-topography-driven droplet motion control.

INTRODUCTION

Movement of liquid microdroplets is one of the important issues in microfluidics, especially in open-surface digital microfluidics (OSDMF) which doesn't have channels and is based on micromanipulation of discrete droplets. There are three main types for droplet motion control in the OSDMF: electrowetting-on-dielectric(EWOD) [1], magnetofluidics [2] and wire-guided manipulations [3]. In these systems, EWOD needs expensive and complicated procedure to fabricate the devices. In the magnetofluidics, superparamagnetic particles should be designed not to contaminate biological or chemical reagents in a droplet. In the wire-guided manipulation, the diameter of the wire should be selected depending on the volumes of droplets to be transported. Besides, all these systems have a constraint in the size of a droplet to transport.

We developed a new device for the transportation of droplets using a magnetically actuating elastomer with a superhydrophobic surface. Because the superhydrophobic surface has a high contact angle and low contact angle hysteresis, a droplet can easily roll off on the tilted surface. By taking advantage of the superhydrophobic characteristics of the surface, a droplet was moved on the surface of the device through local change in topography by the magnetic actuator. Fast transportation of water droplets were performed on the devices. The stable moving speed of the droplet was higher than 8 cm/s. In addition, the direction and speed of droplet motion could easily be controlled by changing the surface topography using magnetic force. This speed is comparable with that of a self-propelling Leidenfrost liquid droplet on hot brass surface with rachetlike topology among the fastest processes reported. But in our device, no vaporization is required to move droplet on the magnetic elastomer device compared to self-propelling Leidenfrost liquid droplet movement. The superhydrophobic magnetic elastomer actuator may find its applications in droplet-based microfluidics and lab-on-a-chip systems.

EXPERIMENT

Our device consists of two main parts. One is a magnetic elastomer (3 layers) and the other is a superhydrophobic surface, as shown in Scheme 1. The magnetic elastomer actuator plate consisted of 3 layers. For the first layer, silicone elastomer base, silicone elastomer curing agent (Dow corning , Sylgard 184) and silicone oil (Dow corning corporation, 200 fluid, 50 cSt, Sigma-Aldrich) were mixed. Their ratio was 81 wt%, 2 wt%, and 17 wt%, respectively. After degassed under vacuum, the mixture was poured into a petridish and cured in an oven (70 ℃, 2 h). The final thickness of the first layer was about 3 mm. For a second layer, silcone elastomer base (39 wt%), curing agent (1 wt%) and Fe powder (60 wt%) were fully mixed. After degassing, the mixture was poured on the first layer and cured in an oven (70 ℃, 3 h). The final thickness of the second layer was about 3 mm. For a last thin protecting layer, silicone elastomer base (91 wt%), and curing agent (9 wt%) were mixed. The rest of procedure was same as above. The final thickness of the third layer was 0.3 mm. Fig. 1a shows the side-view of the magnetic elastomer actuator.

The superhydrophobicity was given to the elastomer surface by rendering a hierarchical morphology based on a solvent/non-solvent method with isotactic polypropylene (i-PP). A solution for superhydrophobic coating was applied employing the procedure by Erbil et al.[4] The surface of the magnetic actuating elastomer plate was coated by spraying the solution with an airbrush. As shown in Fig. 1b, the superhydrophobic surface had a contact angle of 157° ± 2° and a maximum sliding angle of a water droplet (5 μL) smaller than 5° (from measurement on 15 different spots of the surface). The surface roughness in micro and nano scale could be verified by a scanning electron microscope (SEM), as shown in Fig. 1c. Submicrometer-sized wrinkles were observed on the micrometer-sized globules.

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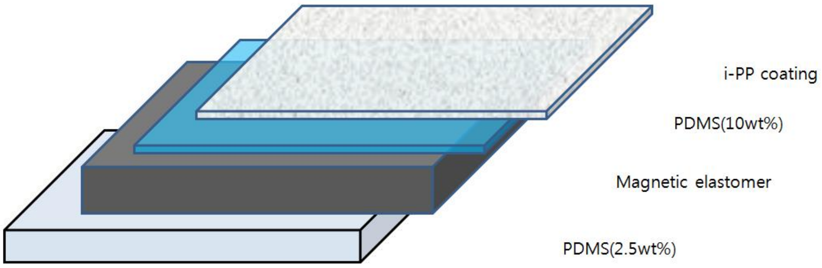

Scheme 1. Scheme of the superhydrophobic magnetic elastomer plate. The plate consists of magnetic elastomer (soft PDMS(2.5 wt%), magnetic elastomer, hard PDMS(10 wt%)) and a superhydrophobic surface(i-PP coating)

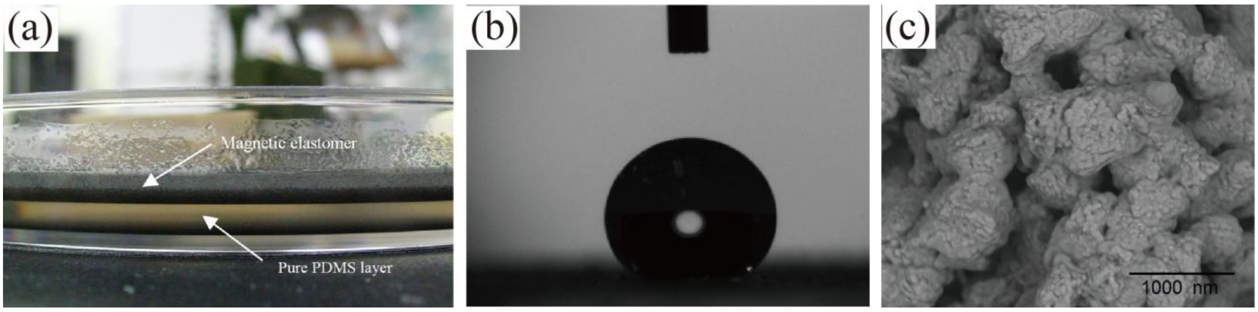

Figure 1. a) Side view of the magnetic elastomer plate. b) Contact angle measurement of a water droplet (9.66 μl) on the magnetic elastomer with superhydrophobic surface. c) SEM image of the superhydrophobic surface.

RESULTS AND DISCUSSION

Iron particles are impregnated in the second elastomer layer of the device. These particles are attracted to a magnet generating a magnetic field. The attracted particles in the dense polymer network lead to the deformation of elastomer. It implies that the magnetic attractive force of the particles will be equilibrated with an elastic force of the elastomer. Therefore, a mini bowl, shown in Fig. 2a, will be locally created on the surface when there is a magnet under the device. Fig. 2a is for the case without superhydrophobic coating for visibility. The shape of the mini bowl could be identified by an alginate gel molding. Fig. 2b shows a cross-section of the molded alginate gel. When three neodymium magnets stacked for strong magnetic field are used under the device, the depth and the diameter of the mini bowl was about 1.3 mm and 22.4 mm, respectively, as shown in Fig. 2b. Each magnet has a diameter of 2 cm and a thickness of 1cm with a magnetic flux density of 0.47 Tesla. From the figure, the slope angle of the mini bowl could be obtained as approximately 6.6° assuming that the slope of the minibowl is linear. It should be mentioned that the slope angle of the mini bowl needs to be higher than the sliding angle of the droplet on the surface in order that the droplet rolls off on the surface. The superhydrophobic surface has a maximum sliding angle of 5°. Thus, the droplet can sufficiently roll off in the mini bowl.

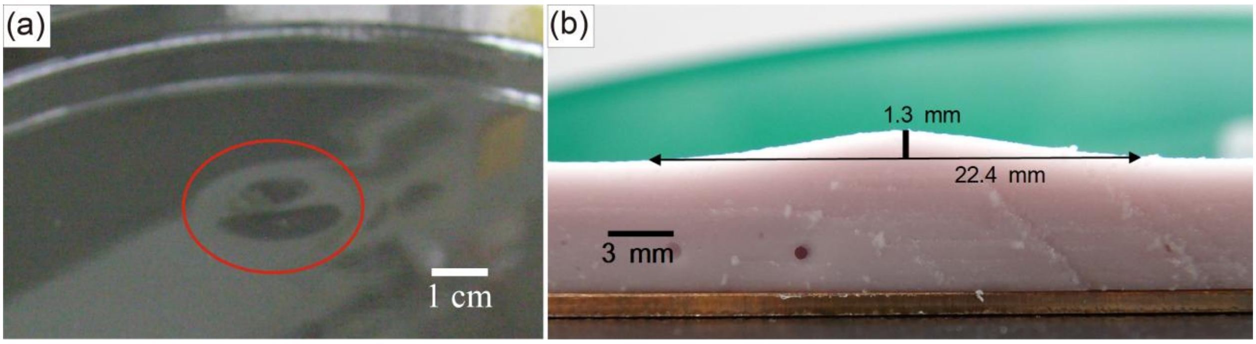

Figure 2. a) Local topography change created by a magnetic force. b) Cross-section view of an alginate gel with the shape of the mini bowl.

The position of the mini bowl can be manipulated by controlling the position of a magnet underneath the superhydrophobic magnetic elastomer plate. It implies that a droplet also can be manipulated in synchronization with the magnet, because the droplet rolls off toward the center of the mini bowl, as shown in Fig. 3a.

Fig. 3b shows a series of images during the transportation of droplet on the plate. For clarity, the water droplet was marked with a pink box. The magnet was manually operated under the plate. The stable velocity of the droplet could be higher than 8cm/s. The maximum speed of the water droplet would be much higher than 8 cm/s without sudden acceleration.

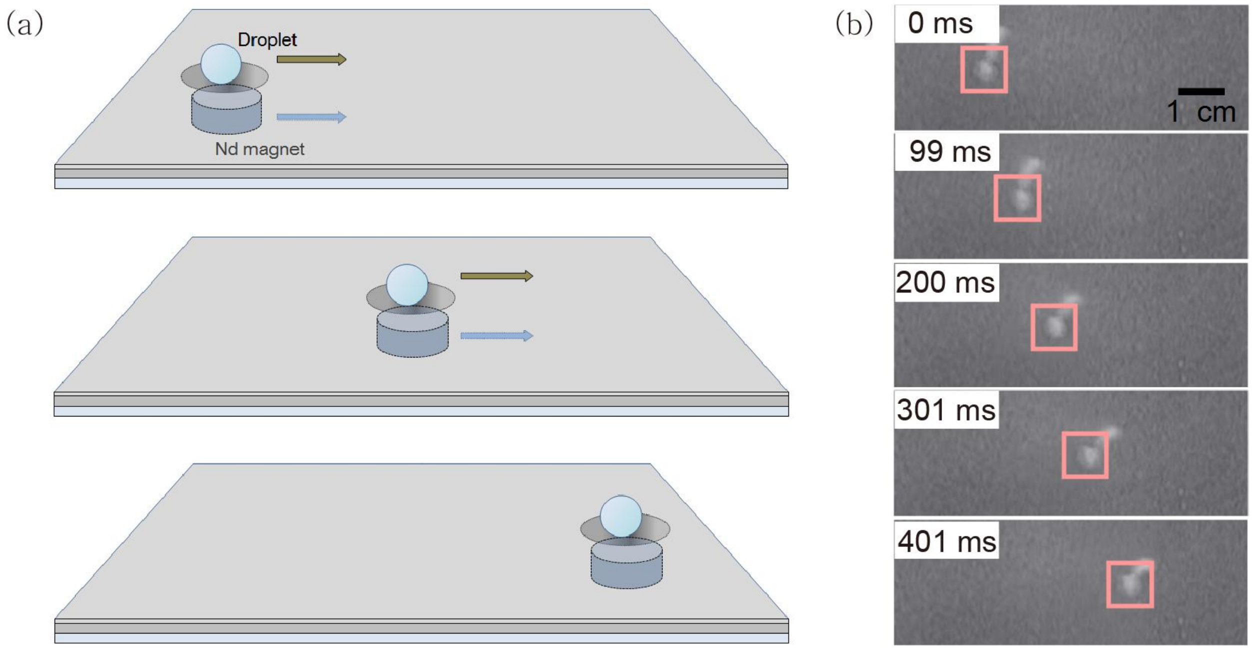

Figure 3. a) Schematic diagram of a droplet transportation on a superhydrophobic magnetic elastomer plate b) A series of images during the transportation of a water droplet (in a pink box) on the device.

CONCLUSIONS

We developed a new device for the transportation of droplets using a magnetically actuating elastomer with a superhydrophobic surface. The superhydrophobic surface was prepared employing a solvent/non-solvent method with isotactic polypropylene. Because the superhydrophobic surface has a high contact angle and low contact angle hysteresis, a droplet can easily roll off on the tilted surface. By taking advantage of the superhydrophobic characteristics of the surface, a droplet was moved on the surface of the device through local change in topography by the magnetic actuator. Fast transportation of water droplets were performed on the devices. The moving speed of the droplet was higher than 8 cm/s. In addition, the direction and speed of droplet motion could be easily controlled by changing the surface topography using magnetic force. Instead of manual operation, a magnet controller with computer-controlled actuators would enable the complex and elaborate manipulation for droplets. We expect that this kind of novel droplet manipulation could open up new possibilities for droplet transportation system and open surface digital microfluidics.

REFERENCES

1. M. G. Pollack, R. B. Fair, and A. D. Shenderov, *Electrowetting-based actuation of liquid droplets for microfluidic applications*, Appl. Phys. Lett. 77, 1725 (2000).
2. Ana Egatz-Gómez, Sonia Melle, M. Márquez et al., *Discrete magnetic microfluidics*, Appl. Phys. Lett. 89, 034106 (2006).
3. J. Y. Yoon and D.J. Yoo, *Backscattering particle immunoassays in wire-guide droplet manipulations*, J. Biol. Eng., 2, 15 (2008).
4. H. Y. Erbil, A. L. Demirel, Y. Avci, and O. Mert, *Transformation of a Simple Plastic into a Superhydrophobic Surface*, Science, 299, 1377 (2003).
5. H. Linke, B. J. Alemán, L. D. Melling, M. J. Taormina, M. J. Francis, C. C. Dow-Hygelund, V. Narayanan, R. P. Taylor, and A. Stout., *Self-Propelled Leidenfrost Droplets*, Phys.Rev.Lett., 96, 154502 (2006).

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