Droplet Immobilization, Splitting, Metering and Aliquoting with Surface Energy Traps Created Using SU8 Shadow Mask

Yi Zhang[1] and Tza-Huei Wang[2*]

[1]Department of Biomedical Engineering, [2]Department of Biomedical Engineering, Mechanical Engineering, Sidney Kimmel Comprehensive Cancer, Center of Cancer Nanotechnology Excellence, Institute for NanoBioTechnology, Johns Hopkins University

ABSTRACT

We have developed a surface energy traps enabled magnetic droplet manipulation platform that provides a full range of droplet operations and enables complex liquid handling, thereby greatly extending the applicability of magnetic droplet platform to intricate biomolecular assays.

KEYWORDS:

surface energy trap, droplet microfluidics, magnetic actuation

INTRODUCTION

In digital microfluidics, microliter scale droplets are situated on a low-energy open surface[1]. Such droplets often function as material storage and transportation units. Sample transfers, biochemical reactions and analytes detection are accomplished by dispensing, moving, splitting and merging droplets through a number of actuation mechanisms such as magnetic force[2-4], electrowetting (EWOD)[5], surface acoustic wave [6], and dielectrophoresis[7]. Magnetic actuation is among the most popular methods. To do so, magnetizable particles (MPs) are added to the droplet to serve as the actuator. External magnetic field is then applied to control the motion of the droplets *via* MPs. In addition, MPs also function as molecule carriers for inter-droplet material transfers by providing solid substrate for molecule adsorption.

Despite its numerous advantages, magnetic actuation has certain limitations. First, whether the droplet moves along with the MPs or split from the MPs depends on the interplay between the magnetic forces on the MPs, the surface tension around the MPs plug and the drag force acted on the droplet. It often requires fine tuning of the magnetic particle and the droplet volume to achieve optimal operation[8]. Second, magnet actuated droplet is limited to basic operations such as droplet movement, merging and MPs extraction. One very important operation, which is to dispense droplet aliquots from the stock solution, has not been achieved on any magnetic droplet platforms so far.

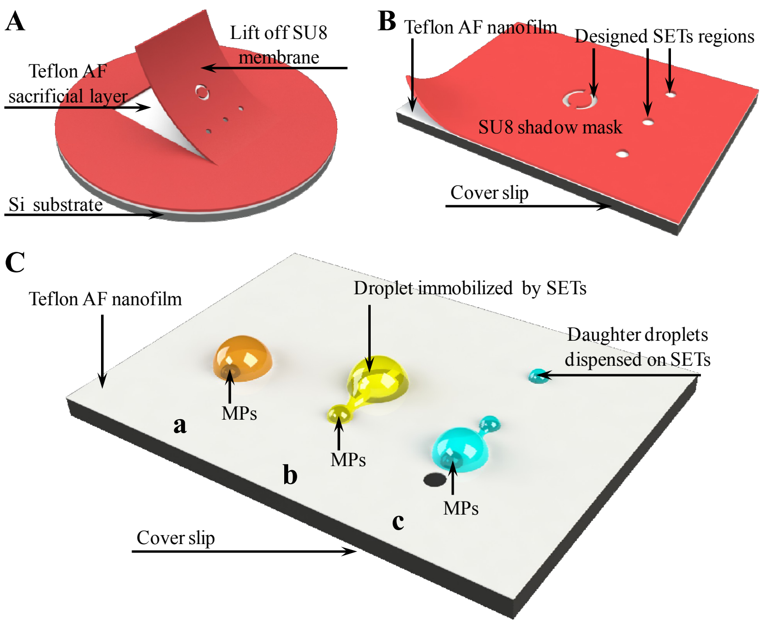

*Figure 1: Conceptual illustration of SETs-assisted magnetic droplet manipulation platform. **A)**and**B)** The SETs are patterned by selectively removing portions of the Teflon AF nanofilm using reactive ion etching through a SU8 shadow mask. **C)** The SETs-assisted platform allows common droplet operation such as **(a)** droplet moving and merging. In addition, **b)** SETs facilitates particle extraction and **c)** enables droplet dispensing, which greatly broadens the applicability of magnetic droplet systems.*

Up until now, only EWOD based droplet platforms have demonstrated the ability to dispense small droplets from the stock solution. It is a valuable tool for open surface droplet control. Nevertheless, a major drawback has greatly limited its ability to perform complex assays. Functionalized micro particles are usually required to isolate analytes of interest in biochemical reactions through solid phase extraction. EWOD alone is not able to separate the particles from the droplet. Usually a secondary mechanism is in place to facilitate the particle extraction. Commonly used methods include dielectrophoresisand magnetic force. The additional mechanism further complicates the already convoluted system, rendering it less portable and less desirable for biomolecular sensing.

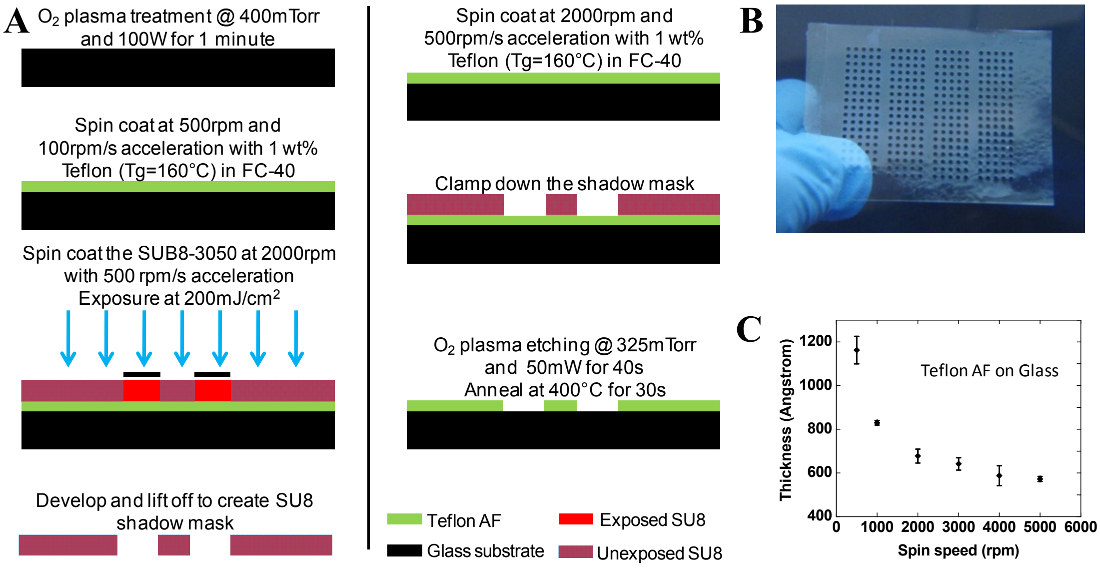

*Figure 2: **A)** Workflow for creating SU8 shadow and patterning SETs with the SU8 shadow mask. **B)** Picture of SU8 shadow mask. **C)** Thickness of Teflon AF on v.s. spin speed. The SU8 shadow mask is reusable. The entire SETs patterning process completes in less than 2 min.*

EXPERIMENTAL

Having understood the limitations of existing droplet manipulation methods, we propose a novel surface energy traps (SETs)-assisted droplet manipulation platform (**Fig. 1**). SETs are high-energy islands surrounded by regions of low surface energy. They function by altering the surface wetting property. SETs are patterned by O_2 plasma etching of Teflon nanofilmthrough a SU8 shadow mask, which is lithography defined and lift-off from a sacrificial layer (**Fig. 2**). The shadow mask protects the Teflon AF nanofilm meanwhile exposes the SETs regions. The unexposed regions maintain their low-energy coating while the exposed regions are etched and rendered hydrophilic. As a result, SETs possess high surface energy and trap liquid within their boundaries.

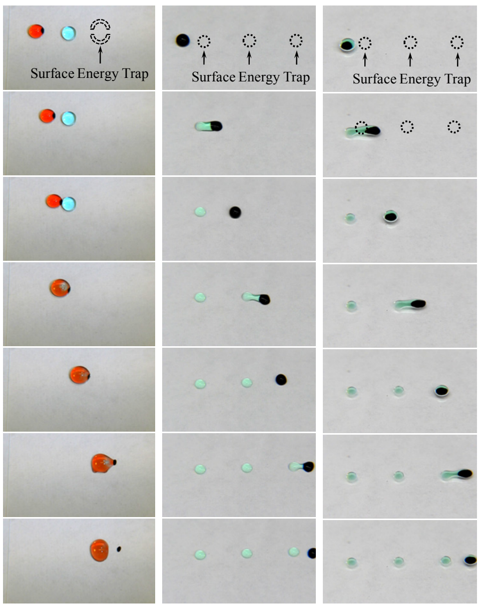

Figure 3:Demonstration of droplet manipulation of the SETs-enabled platform. (A) Droplet moving, merging and particle extraction. B) Droplets dispensing in air. C) Droplet dispensing in oil.

RESULTS AND DISCUSSION

The platform allows common droplet operation including droplet moving and merging. In **Figure 3a**, the orange droplet is moved to merge with the blue droplet using magnetic actuation with magnetic particles (MPs). SETs are first demonstrated for easy MPs splitting. The SET holds the merged droplet in position whereas the MPs plug overcomes the surface tension and splits from the droplet (**Fig. 3a**). In addition, droplets of pre-determined volumes can be metered and aliquoted from the parent droplet using SETs (**Fig. 3b-c**). By adjusting the size of the SET, the surface tension along the SET contact line becomes weaker than the capillary force around the MPs plug. As a result, MPs plug does not split from the droplet. Instead, a daughter droplet is metered and aliquoted from the parent droplet. The SET does not only operate in air (**Fig. 3b**) but also in oil (**Fig. 3c**) environment, indicating potentially broader applications.

Whether the MPs plug splits from the droplet or daughter droplets are dispensed from the parent droplet is the interplay between the MPs amount, droplet volume and SET size. A 3D phase diagram is created based on the observations under various conditions (**Fig. 4**). The phase diagram helps understand the working principle of SETs and facilitate the SET design. Combination of SETs of different sizes can be arranged for more complex tasks.

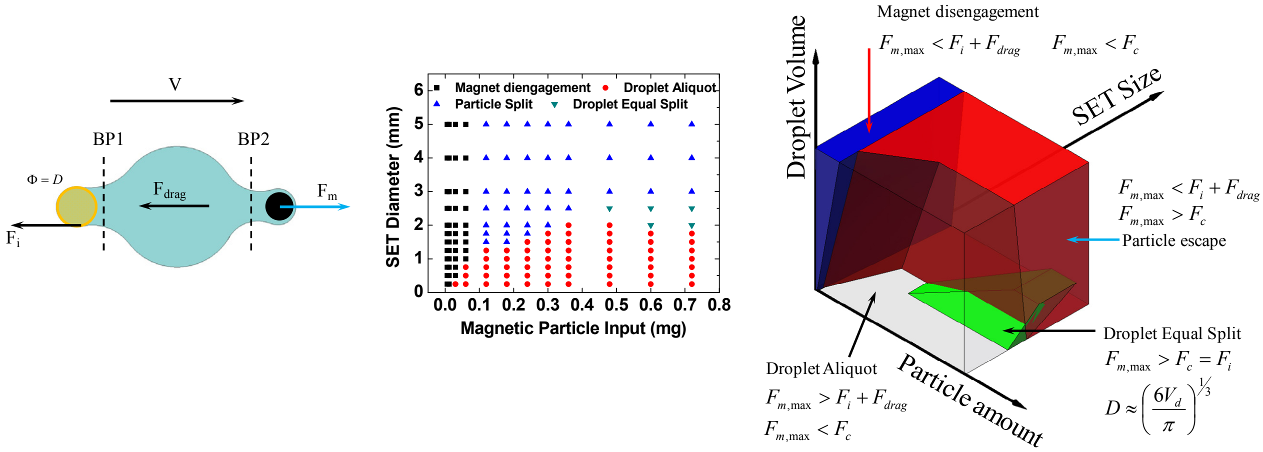

*Figure 4: **A)** The effect of SETs is the interplay between surface tension, magnetic force and drag force, as well as SETs sizes and MPs amounts. **B)** Four events are observed under various conditions: 1. the magnet disengages from the MPs; 2. the MPs plug splits from the droplet and escapes; 3. the SET meters an aliquot from the droplet; 4. the droplet splits equally between the SET and the MPs plug. **C)** The four events observed under various conditions are constructed in a 3D phase diagram.*

ACKNOWLEDGEMENTS

The authors would like to thank the funding support from NSF and NIH.

CONTACT

*Correspondence should be addressed to Dr. Tza-Huei(Jeff) Wang, Tel: (001)-410-516-7086, email: thwang@jhu.edu

REFERENCE

[1] X. Casadevall i Solvas and A. deMello, "Droplet microfluidics: recent developments and future applications," *Chemical Communications,* vol. 47, pp. 1936-1942, 2011.

[2] J. Pipper, M. Inoue, L. F. P. Ng, P. Neuzil, Y. Zhang, and L. Novak, "Catching bird flu in a droplet," *Nature Medicine,* vol. 13, pp. 1259-1263, 2007.

[3] J. Pipper, Y. Zhang, P. Neuzil, and T. M. Hsieh, "Clockwork PCR including sample preparation," *Angewandte Chemie-International Edition,* vol. 47, pp. 3900-3904, 2008.

[4] Y. Zhang, S. Park, K. Liu, J. Tsuan, S. Yang, and T.-H. Wang, "A surface topography assisted droplet manipulation platform for biomarker detection and pathogen identification," *Lab on a Chip,* vol. 11, pp. 398-406, 2011.

[5] S. K. Cho and H. Moon, "Electrowetting on dielectric (EWOD): New tool for bio/micro fluids handling," *Biochip Journal,* vol. 2, pp. 79-96, Jun 20 2008.

[6] Z. Guttenberg, H. Muller, H. Habermuller, A. Geisbauer, J. Pipper, J. Felbel, M. Kielpinski, J. Scriba, and A. Wixforth, "Planar chip device for PCR and hybridization with surface acoustic wave pump," *Lab on a Chip,* vol. 5, pp. 308-317, 2005.

[7] S. K. Fan, T. H. Hsieh, and D. Y. Lin, "General digital microfluidic platform manipulating dielectric and conductive droplets by dielectrophoresis and electrowetting," *Lab on a Chip,* vol. 9, pp. 1236-1242, 2009.

[8] Z. Long, A. M. Shetty, M. J. Solomon, and R. G. Larson, "Fundamentals of magnet-actuated droplet manipulation on an open hydrophobic surface," *Lab on a Chip,* vol. 9, 2009.