Improving the reliability and complexity of advanced electrowetting-based digital microfluidic devices

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IMPROVING THE RELIABILITY AND COMPLEXITY OF ADVANCED ELECTROWETTING-BASED DIGITAL MICROFLUIDIC DEVICES

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ABSTRACT

While digital microfluidics based on electrowetting-on-dielectric (EWOD) appears as a highly promising technology for bioassays and clinical diagnostic, most devices demonstrated to date are still seriously limited in terms of complexity and reliability. This paper aims at presenting strategies for both (i) fabricating complex EWOD-based devices based on a low cost process and (ii) improving the throughput and reliability of droplets manipulation on the devices. We first show that SU8 photoresist can be used as a high quality dielectric to build low cost advanced devices with very limited specialized equipment. We also present a simple strategy based on the encapsulation of the droplets in a thin shell of oil that presents several key advantages for the realization of high-throughput and high reliability EWOD-based digital microfluidic devices.

KEY WORDS: Digital Microfluidics, Electrowetting-on-Dielectric, SU-8 photoresist, Droplet

INTRODUCTION

Compared to traditional microfluidic devices based on the continuous flow of liquid in channels, digital microfluidics offers a very high flexibility and dynamic reconfigurability, which are key advantages to fulfill the needs of complex bioassays [1]. In such devices, discrete liquid droplets are manipulated at will on a 2D surface by using an electrowetting-based actuation force applied locally by an array of electrodes. However, despite a very significant research effort in the last years [1], most digital microfluidic devices demonstrated to date are still too simple and lack the reliability required to perform complex bioassays. The goal of this paper is twofold: (i) to propose a low cost technique for the fabrication of complex EWOD-based microfluidic devices and (ii) to present a modification in the mode of operation of the devices that can improve drastically their throughput and reliability.

RESULTS AND DISCUSSION

Low cost fabrication of complex EWOD-based microfluidic devices

The dielectric isolating the droplets from the electrodes is well known to be one of the most critical elements of the EWOD-based microfluidic devices [1]. The high electrical potentials required to manipulate the droplets can indeed lead to dielectric breakdown and electrolysis if the dielectric is not properly chosen. Moreover, for the fabrication of complex EWOD-based microfluidic devices (as shown in figure 1 and 2), numerous steps are required for the deposition and patterning of the multiple levels of dielectric, which is not only time consuming but also typically require costly specialized equipments. By using an SU8 negative photoresist as the dielectric of the devices, we could develop a low cost fabrication technique that can be used to produce high quality advanced EWOD-based microfluidic devices (figure 2). We indeed found that SU8 photoresists not only have exceptional dielectric properties (for e.g., a 2 μm thick film can sustain more than 800 V), but also offer the advantage of being directly photo-patternable, which reduces considerable the number of steps required for the fabrication of complex devices. Finally, with process proposed herein, the dielectric layers can be deposited with no specialized and costly equipment, which could facilitate the future development of EWOD-based digital microfluidics.

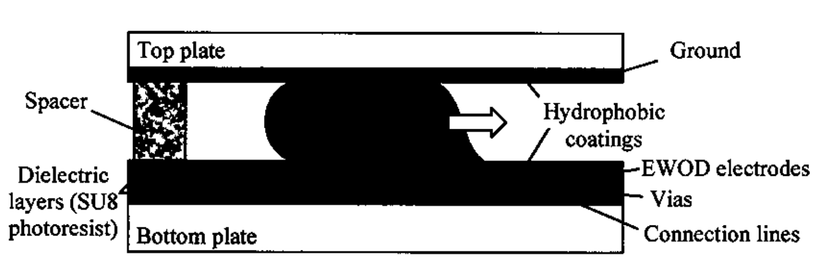

Figure 1: Side view schematics of an advanced EWOD-based microfluidic device

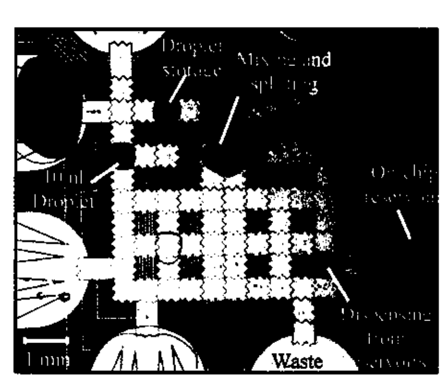

Figure 2: General layout of an advanced EWOD-based microfluidic device

Improving the throughput and reliability of EWOD-based microfluidic devices

In EWOD-based digital microfluidic devices, the aqueous droplets are typically manipulated either directly in air or in an immiscible fluid such as silicone oil. However, both techniques present important limitations. For example, while the manipulation of the droplet in a silicone oil medium prevents their evaporation, it also increases viscous drag and complicates the fabrication and handling of the devices [1]. On the other hand, much higher operation voltages are required to manipulate droplets directly in air, which can lead to a rapid degradation of the dielectric of the device [1,2].

We recently showed [3], that it is possible to improve drastically the reliability and throughput of the EWOD devices by using a simple yet powerful alternative mode of operation. As shown in figure 3a, we have investigated the effect of placing a very thin layer of oil around the droplet (instead of moving the droplet in an oil medium), which we refer to as water-oil core-shell droplets. We were able to show that, for a given operation voltage, water-oil core-shell droplets can be actuated at much higher velocities that water droplets manipulated in either air or oil (figure 4). Additionally, we found that, significantly lower operation voltages can be used to manipulate the droplets in the core-shell configuration than in air despite the absence of a continuous oil medium. Finally, all the elementary fluidic operations such as dispensing, merging, mixing and splitting droplets could be perform normally despite the presence of an oil shell around the droplets (figure 3b). Our results thus indicate that, despite being extremely simple to implement, this novel mode of operation offers an increased flexibility toward the realization of high-throughput and high reliability EWOD-based digital microfluidic devices.

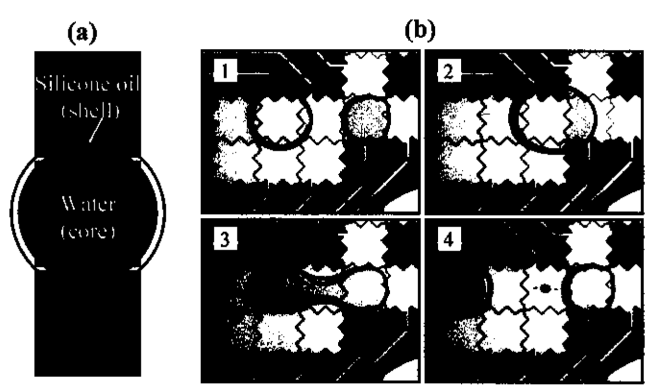

Figure 3: (a) Schematic view of a water-oil core shell droplet in a EWOD-based microfluidic device. (b) Merging, mixing and splitting of two water-oil core-shell droplets.

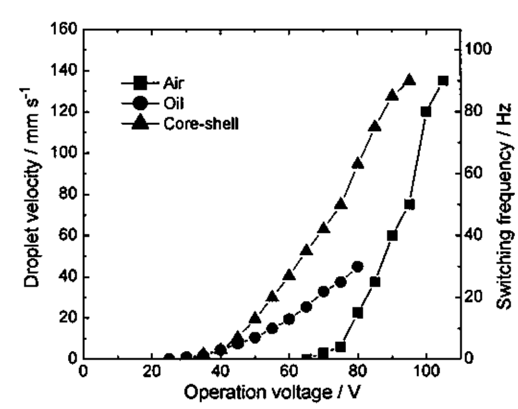

Figure 4: Effect of the operation voltage on the actuation dynamics of water droplets transported in air, in oil, and in the core-shell configuration.

CONCLUSION

We believed that both the fabrication technique and the alternative mode of operation we proposed herein offer an increased flexibility toward the realization of high complexity and high reliability EWOD-based digital microfluidic devices for biotechnological and clinical diagnostic assays.

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