DROPLET DISPENSING FROM OPEN TO CLOSE DIGITAL MICROFLUIDICS

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ABSTRACT

Droplet dispensing is one of the four fundamental operators in digital microfluidics (DMF) and functions as an in and out (I/O) port for DMF systems. Typically in closed DMF systems, the system is opened and after placing the sample droplet the system is closed to perform a test. In this paper, we introduce an appropriate technique to simplify this process by dispensing the sample droplets from an outside reservoir into the closed digital microfluidics system. The presented technique will improve the integrability of the platform with other available robotic platforms and will remove the need to open the DMF system for inserting the sample or taking out the processed sample. The paper studies the effect of the gap (between the bottom and top plates) and the volume of the reservoir droplet on the voltage required for droplet dispensing from an outside reservoir into the closed DMF platform. It is found that the required voltage for dispensing (from an outside reservoir droplet into the closed DMF system) is lower for smaller volume of the reservoir droplet. It was also found that there is a threshold gap that beyond which it is not possible to dispense a droplet into the system.

Keywords: digital microfluidics (DMF), reservoir droplet, dispensing droplets, gap, electrowetting on dielectric (EWOD)

1 INTRODUCTION

Digital microfluidics (DMF) is a recent technology proposed as an alternative for channel-based microfluidics. DMF is based on the manipulation of discrete droplets over an array of electrodes which is covered by a dielectric and a hydrophobic layer. The actuating force is electrowetting on dielectric (EWOD) which works based on the accumulation of the electric charges on the three-phase contact line (liquid-solid-gas interface) [1]. There are two types of DMF platforms: open and closed systems [2]. Each platform has its own advantages. For instance, it is easier to access the droplet in the open systems; whereas, the closed system limits the droplet evaporation [3] and facilitates droplet handling in terms of transport and splitting [4]. The closed DMF system also facilitates users with the particle manipulation techniques developed recently [5]. Despite the flexibility of the closed systems, it is difficult to place the sample on the reservoir of such systems. Reservoirs are essential element of a DMF device because they function as an in/out (I/O) port for DMF systems [6]. In the current devices, either the DMF platform is dissembled or micro-capillary needles are implemented [7] for sample injection. The latter case limits the gap between the top and bottom plates and the former case reduces the reproducibility of the device. In this paper, the open and close systems are combined to take advantage of the accessibility of the open system and functionality of the closed system.

The proposed system contains a bottom plate patterned with the actuating electrodes, partially covered with a top plate to form the closed system. The main idea is to have the sample reservoirs on the open section of the platform, and then dispense the desired volumes of the droplet into the closed section of the platform. This eliminates the need for opening the system or the use of a capillary-needle for dispensing the sample on the chip.

2 FABRICATION

The platform includes the open and the close sections which are formed by a top and a bottom plate. The bottom plate was fabricated by patterning the electrodes by standard photolithography on a copper-coated glass slide, covered by a dielectric and a hydrophobic layer. Two layers of photoresist (S1805 and S1813, MicroChem Corp.) coated consecutively on the electrodes were used as the dielectric layer, and Teflon (Teflon AF 1600, DuPont) was spun on the chip as the hydrophobic layer. The ITO-coated glass slide covered with a Teflon layer was used as the top plate. Experiments were conducted for the top plates with and without hydrophobic edges. To make the edge of the top plate hydrophobic, a Teflon layer was deposited on the edge of the top glass slide.

3 EXPERIMENTAL PROCEDURE

The bottom plate includes an array of actuating electrodes for the open section with a co-planar ground electrode parallel to the actuating electrodes, followed by an array of the electrodes for the closed section. The top plate is placed on the bottom to cover the array used for the closed section. The platform is shown in Fig. 1. The top plate is placed such that the open section includes 200 μm of the first electrode in closed section so that the droplet touches the electrode to initiate the motion into the closed section. The initial gap between the two plates was set by a 100 μm thick spacer and it was increased using a linear actuator with accuracy of ±2 μm.

DI water was used as the working fluid. A droplet was placed on the electrodes in the open section. By sequential

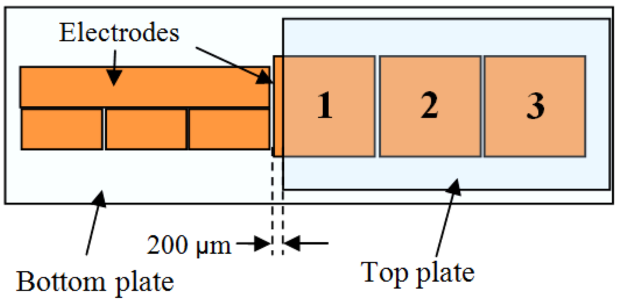

Fig. 1 schematic of the designed platform.

actuation of the electrodes in the open system the mother droplet was moved to the edge of the top plate. Afterwards the electrodes 1, 2 and 3 in the closed system (Fig. 1) were actuated sequentially to make a finger of liquid from the mother droplet over the actuated electrodes. Finally, the electrodes 1 and 2 were grounded which followed by necking the finger and cutting a droplet on the electrode 3.

A signal generator (Tektronix AFG3021B0) connected with an amplifier (TREK PZD700) was used to generate the electrical potential. A frequency of 1 kHz was set for the applied voltage for all cases of the experiments. To monitor the experimental activities an Apo-zoom microscope (Leica Z6 APO) was used which was connected to a high speed camera.

4 RESULTS AND DISCUSSION

Figure 2 shows the dispensing process of a droplet from the open to the closed section using a top plate with the hydrophobic edge (Teflon covered). A 5μL droplet of DI water was placed on the actuating electrodes on the open section of the DMF platform, and the electrodes were sequentially actuated to move the droplet toward the edge of the closed section. Because of the hydrophobic edge of the top plate the droplet does not spread on the edge when it gets in contact with the top plate. Then, the electrodes on the closed section were actuated to pull the droplet between the two plates. As a result, a part of the droplet moved between two plates and created a liquid finger. Finally, a controlled volume of the droplet was dispensed into the closed section as described in the previous section.

This process was found to be reproducible (see dispensing of the second droplet into the closed section in Fig. 3). This experiment was repeated 10 times and the difference in the volumes of these droplets was less than 5%.

The same test was performed for the top plate with the hydrophilic edge (see Fig. 4). In this case, the droplet could not be dispensed into the closed section from the sample placed in the open section (the maximum possible voltage, limited by our amplifier, was applied to the electrode (V_{p-p} = 250 volts)).

The schematic of dispensing for both top plates with hydrophobic and hydrophilic edges is depicted in Fig. 5. The case with a top plate with the hydrophobic edge is called case I and the case with a top plate with the hydrophilic edge is called case II. Dispensing was not successful for the case II due to two main effects. First, the curvature of the of the reservoir droplet (in the open section of the chip) is noticeably lower for the case II (k_2 in Fig. 5) compared to the curvature of the reservoir droplet in the case I (k_1 in Fig. 5). This means that the pressure in the droplet is lower for the case II. Therefore, when the electrode close to the edge is turned on to create a droplet finger there will be less pushing force from the reservoir droplet on the liquid going in between the top and bottom plates. As a result, the length of the formed finger will be very small. Second, the width of the finger close to the edge of the top plate for the case II (W_2 in Fig. 5) is significantly bigger than that of the case I (W_1 in Fig. 5). Due to this higher width, a higher length of the finger will be required for splitting since the high finger width hinders forming a neck and breakup of the liquid film.

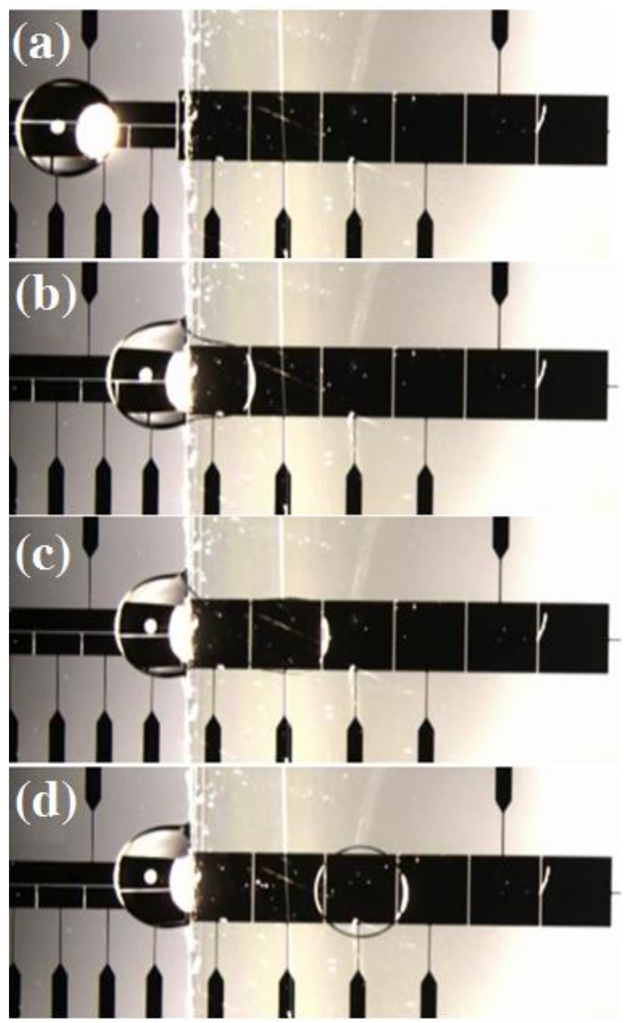

Fig. 2. Successful droplet transfer from the open to the closed DMF platform. The edge of the top plate was coated with Teflon.

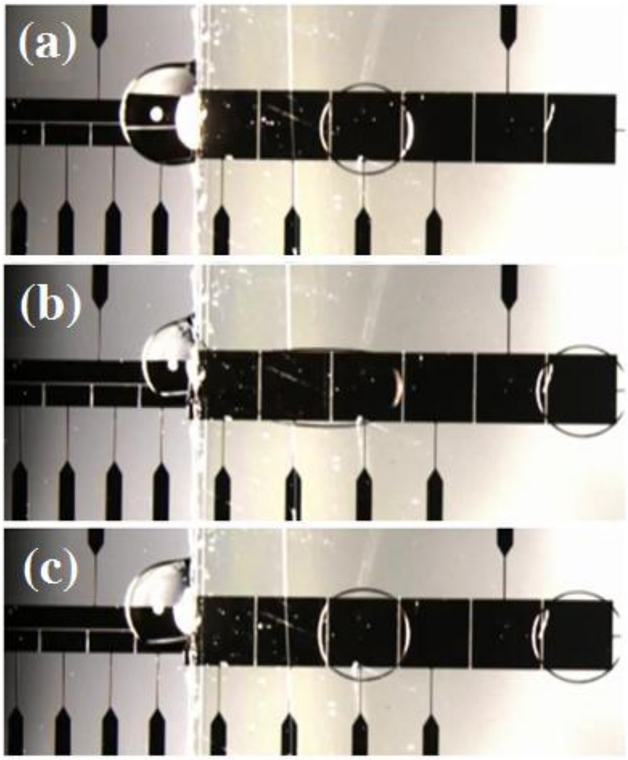

Fig. 3. Dispensing the second droplet from the same reservoir, showing the reproducibility of the dispensing process

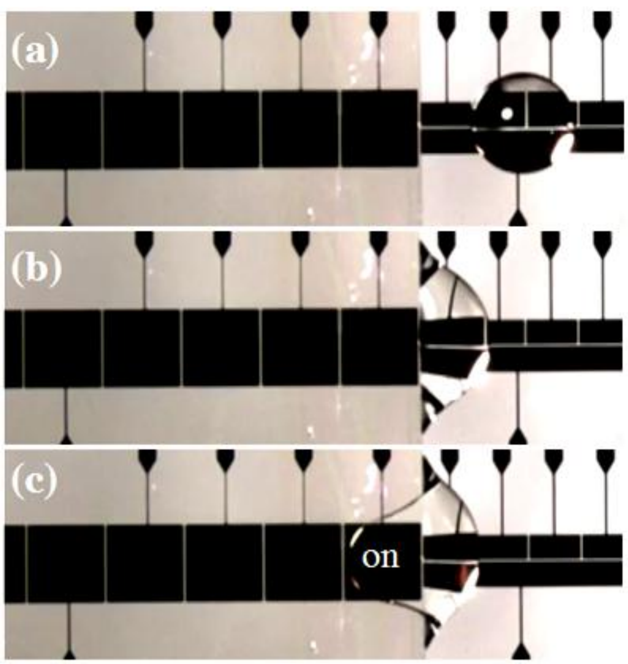

Fig. 4. Unsuccessful droplet transfer from the open to the closed DMF system. The edge of the top plate is hydrophilic

Dispensing of the droplets from open to close systems was performed for different volumes of the reservoir droplet and the gap between the two plates. Fig. 6 shows the threshold voltage (V_{th}) for dispensing a droplet from open to close system for different gap and volume of the reservoir droplet.

It is observed that the volume of the reservoir droplet directly affects the threshold dispensing voltage (V_{th}). Generally for bigger volumes of the reservoir droplet higher voltage is required for dispensing to take place. For bigger reservoir droplets the curvature of the part in the open section is smaller, and the width of the finger is fairly bigger. These two effects cause splitting to require a higher voltage as discussed above. Also, it is observed that the general trend for V_{th} versus gap size is descending. It means that for a certain volume of the reservoir droplet the required voltage decreases as the gap increases. This is due to the fact that the curvature at the liquid-gas interface in the finger front is lower for higher values of gap (Fig. 6). It means that as the gap increases the effect of surface tension (acting as the resisting force) decreases. Therefore, a lower electrowetting force, and consequently lower voltage is required to extract the liquid. However, for splitting in the closed systems, there is a gap limit beyond which it is impossible to cut a droplet [8]. Therefore, despite the fact that forming the liquid finger is easier for larger gaps, breakup of the liquid film in the finger becomes impossible for the gap values larger than the threshold values. The critical gap for the reservoir volumes of 5 μL, 10 μL, and 15 μL are 250 μm, 250 μm, 190 μm, respectively. The threshold values for of the cases of 5 μL and 10 μL are the same since a fixed interval of 30 μm was used for incrementing the gap size.

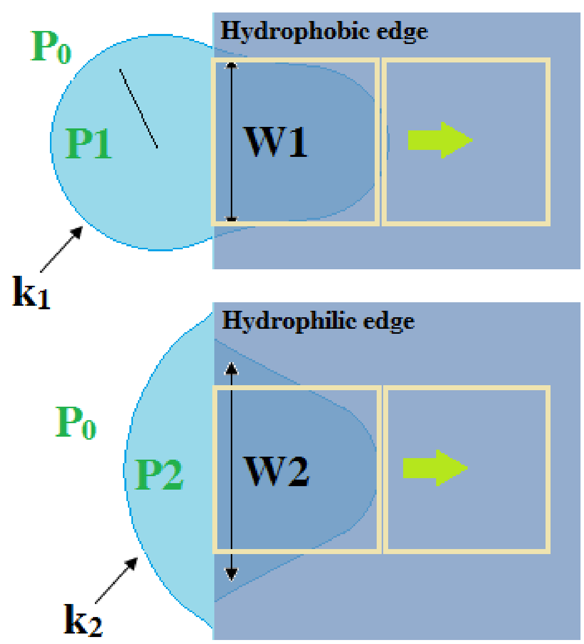

Fig. 5. Schematic of the droplet finger for both hydrophobic and hydrophilic edges of the top plate

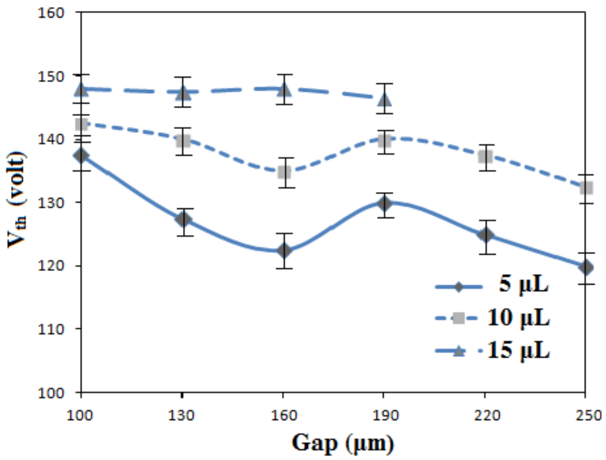

Fig. 6. Threshold voltage (V_{th}) required for droplet dispensing based on the procedure explained in the section 3 (Experimental Procedure)

5 CONCLUSIONS

This paper presents the combination of open and closed digital microfluidic platforms to facilitate droplet dispensing to the device. The open system is used as the sample reservoir since dispensing liquids is easy in this system and the closed system is used for sample manipulation and performing assays since droplet handling is easier in the closed systems. A top plate is used in the platform to cover the bottom plate partially. Present results show that the edge of the droplet must be hydrophobic to be able to extract sample droplets to the closed system from the reservoir in open section. Dispensing is performed for different gap sizes and reservoir volumes. As the gap increases the threshold voltage required for droplet extraction decreases. However, there is a threshold gap size above which droplet extraction becomes impossible. Also, for larger volumes of reservoir the threshold voltage for successful dispensing increases as the width of the base of the liquid finger increases (hindering the necking process) and the curvature of the reservoir decreases (reducing the pressure inside the droplet). This method is successful for reproducible extraction of volumes of droplets with a standard deviation of less than 5%.

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