The effect of reservoir liquid volume on dispensed droplet size in a microchannel using the EWOD technique

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Abstract
The present experimental study investigates the effect of the reservoir liquid volume on the dispensed droplet size in a microchannel based on electrowetting on dielectric (EWOD) technique. A crescent configuration is fabricated for the channel electrodes which provides a larger overlapping area. This leads to a higher electrowetting force between the adjacent electrodes which improves the droplet movement. In addition, special featured reservoir electrodes are patterned to facilitate the droplet dispensing. In order to examine the effect of the reservoir liquid volume on the dispensed droplet size, several experiments are performed. The dispensed droplets obtained in the experiments are in the range of 80-370 Nano litter. The channel dimensions, the size of the reservoir electrodes and the channel electrodes are fixed. Increasing the reservoir liquid volume leads to a smaller dispensed droplet.

Keywords: *dispensing- reservoir- droplet- electrowetting.*

Introduction
Microfluidics provides efficient tools for multiple research areas and more specifically biological analysis. This new technology promises to provide the benefit of high portability and controllability, faster analyses due to the shorter reactions and low fabrication cost. The digital microfluidics (DMF) is a technique used in a wide range of applications reported in the literature such as clinical diagnostics, proteomic sample preparation, DNA ligation, simple separations, and display technologies [1]. The electrowetting on dielectric (EWOD) is the most popular method used to actuate and manipulate the microdroplets in the DMF systems. In the EWOD method, the wettability of a dielectric coated metallic substrate (called electrode) to a liquid droplet is increased by using an electric potential difference between the liquid and the electrode. Individual microdroplets are dispensed, transported, merged, mixed or split into smaller segments. The droplet dispensing is one of the most difficult manipulations to be accomplished.

The size of droplet dispensed depends on numerous factors such as applied voltage, reservoir liquid volume, surface condition,the size of the reservoir electrode, the location of pinch-off and channel dimensions. Xu et al. [2] examined various shapes of electrodes in order to find a reliable and low-voltage droplet manipulation by the EWOD. For square, jagged and crescent shape electrodes, they compared the average velocity and the number of successful droplet split. Their numerical and experimental results indicated that the crescent configuration required less driving voltage. Lin et al. [3] studied the EWOD platform with multi-layer insulators in order to reduce the required voltage for droplet manipulation. In their study, the threshold voltage was compared for several insulator thickness and material, and homogeneous versus heterogeneous insulator compositions. Cho et al. [4] used the EWOD technique to dispense droplets from a reservoir by employing two side electrodes beside the main fluid path in order to have a consistent dispensing location.

In this configuration of electrodes, the liquid was pulled sideways from the main path, thereby, increasing the necking mechanism required for droplet dispensing. An assessment of long-term reproducibility of droplet dispensing in digital microfluidic devices was investigated by Elvira et al.[5]. They performed dispensing droplets from a reservoir, measuring the volume of both the droplet and the reservoir droplet, and then returning the dispensed droplet to the original reservoir. The repetition of this process was accomplished over the course of several hundred iterations. Their results indicated that the ratio between the spacer thickness and the electrode size, influences the reliability of droplet dispensing. As stated above, there are multiple parameters that influence the size of dispensed droplet from a reservoir in the EWOD method. The reservoir liquid volume is one of them which has not been clearly addressed yet. In addition, the literature on performing experiments on dispensing droplets from a reservoir into a microchannel is rare. Therefore, in this paper, the effect of reservoir liquid volume on droplet dispensing into a microchannel is experimentally investigated.

Experimental setup
The printed circuit boards (PCB) and the Fluorine Tin Oxide (FTO) glass serve as the bottom and top plates of the chip, respectively. In addition, the polyvinyl chloride (PVC) sheet forms the side walls of the microchannels. A fiberglass substrate of the grade FR-4 with a thickness equal to 1.53 mm laminated by a 30-μm-thick copper layer is used as the starting material. This board is coated by a positive photo resist. A photo mask carrier, containing the photo mask with the electrodes pattern, is placed on the photo resist and exposed to a UV beam to remove the photo resist from the areas where the copper coating should be erased. Next, the copper laminate is eliminated from the areas without photo-resist coating by acid etching. As a result, the pattern of electrodes takes form. A layer of Biaxially Oriented Polypropylene (BOPP) is used as a dielectric layer. The thickness of this layer is 25 μm. An FTO coated transparent glass slide is used as the top plate of the chip. The FTO coating has an electrical resistance of 6 Ohms/mm. Finally, the top and bottom plates, and sidewalls of the microchannel are covered with a thin hydrophobic layer. A power supply is used to generate an AC sinusoidal wave voltage. The applied voltage in the entire experiments is 450V AC. The CCD camera used in the experiments is from the Grasshopper series, Point Grey Inc. which can take up to 300 fps with a maximum resolution of 640×480 pixels. Figure 1 shows the schematic illustration of the experimental setup.

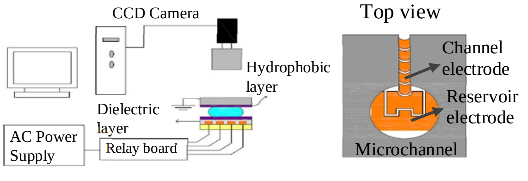

Figure 1. Schematic representation of the experimental setup and a top view of the reservoir and microchannel

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Experimental result

Several experiments are performed to examine the variation in the volume of dispensed droplets in a microchannel. Figure ***2*** illustrates droplet dispensing using a crescent channel electrode design. The reservoir electrode and channel electrodes were turn on in sequence and the liquid is pulled out of the reservoir. Then, all of the electrodes are turned off except for the channel second electrode and the reservoir electrode. When the reservoir electrode is switched on, a large force exerted on the droplet -in the opposite direction- caused droplet necking which resulted in the droplet to cut off from the reservoir. The volume of the liquid in the reservoir and dispensed droplet are measured to be 1250 nl and 230 nl respectively. These volumes are calculated from the top view area of the droplet multiplied by the height of the microchannel which is 200 µm in this experiment. All photographs were taken with a high-speed camera (frame rate: 300 fps) from the above.

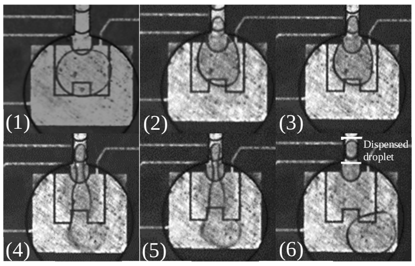

Figure 2. The captured images of droplet dispensing sequence using a crescent channel electrode design. To pull the liquid out from the reservoir, the channel electrodes are turned on in sequence (1) to (3). Then both the reservoir electrode and the second electrode in the channel are turned on which results in a narrow liquid necking as seen from sequence (4) to (5). The final dispensed droplet is observed at sequence (6).

Figure 3 shows droplet dispensing in a microchannel for three selected cases with different reservoir liquid volume. The actuation voltage, microchannel dimensions and electrode size are kept constant for the three depicted cases. As observed explicitly in the figures, increasing the reservoir liquid volume leads to a larger length of the contact line placed on the reservoir electrode that results in a greater opposing force and a smaller volume of dispensed droplet.

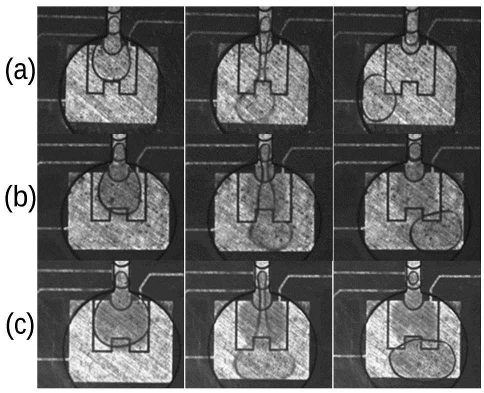

Figure 3. Sequential images of droplet dispensing for three different reservoir liquid volumes of (a) 1100 nl, (b) 1250 nl, and (c) 1570 nl. The size of the dispensed droplet for the three cases is (a) 260 nl, (b) 230 nl and (c) 80 nl.

For further evaluation of the reservoir liquid volume effect on dispensed droplet size, the experiments are performed for many cases (around 30 cases) for which the actuation Voltage and microchannel dimension are kept constant. The reservoir liquid volume, however, is varied in these experiments. A microchannel 900 µm in width and 200 µm in height is used. The results of these cases are displayed in Figure 4.

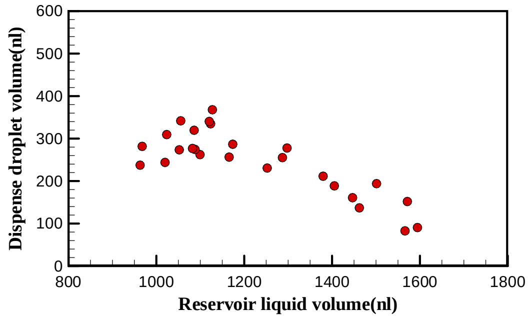

Figure 4. The volume of dispensed droplet versus reservoir liquid volume. The volumes are calculated from the top view images. All parameters remain constant except the reservoir liquid volume.

This figure demonstrates a general relationship between the volume of reservoir and dispensed droplet volume. Generally the volume of dispensed droplet is decreased by increasing the reservoir volume. This trend can be the consequence of several factors. The important factor is the pull-back force exerted by the reservoir electrode on the droplet correlated to the length of the contact line on the reservoir electrode. When the reservoir liquid volume is increased, the contact line is also increased leading to a larger electrowetting force which pulls back the droplet to the reservoir. This will lead to a smaller dispensed droplet. More data in the range of 900-1200 nl for reservoir volume (seen in Figure 4) suggests that dispensing is more successful for a certain size of microchannel and electrode.

Conclusions

In this study, dispensing a droplet from the liquid of a reservoir using the EWOD technique is experimentally investigated. A crescent shape for the channel electrodes and a special design for the reservoir electrodes is introduced to improve the droplet dispensing. The key finding of extensive experiments performed in this study is that the volume of the dispensed droplet is reduced by increasing the reservoir liquid volume. The size of the dispensed droplet is an important factor in the design of microfluidics devices.

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