Introducing a Digital Micropump for Driving a Droplet in a Microfluidic Channel

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ABSTRACT

A novel device for pumping a column of liquid in a microchannel, integrated on a digital microfluidic (DMF) platform, is presented. Electrowetting on dielectric (EWOD) method is used to actuate frequently a droplet (referred to as the piston droplet) on an array of electrodes. A column of liquid (referred to as the pumped droplet) is pumped in a microfluidic channel by the pressure generated by actuating the piston droplet. A signal modulation technique is developed and used in order to control the flow rate of the liquid column in the microchannel. Different flow rates of the pumped liquid were achieved by controlling the actuation time of the signal used for actuation the piston droplet.

Keywords: digital microfluidics (DMF), droplet manipulation, Electrowetting on dielectric (EWOD), SU8 microchannel, Micropump.

1 INTRODUCTION

Recent efforts have focused on replacing the conventional macro-systems with lab-on-chip (LOC) systems to enhance transport, reaction and manipulation of different fluid sample [1]. The first generations of LOC systems include microchannels for transporting fluid [2]. These systems referred to as continuous microfluidics [3] require peripheral devices to process and analysis biofluids [4]. A variety of detection methods have also been developed and integrated into continuous microfluidic platforms over the past decades [5-7]. However, to manipulate the fluids in microchannels in continuous microfluidic devices it is required to use external elements and moving parts such as pumps and valves. These cumbersome devices hinder the portability and integrability of the continuous platform.

Digital microfluidics (DMF) is a relatively new type of microfluidic systems using planar electrode arrays to manipulate individual droplets for performing different fluidic operation in micron scales [8]. For its unique advantages (including reduced sample size, rapid analysis, ease of fabrication, portability, and low cost [8,9]) DMF has shown a great potential to improve conventional bio-chemical laboratory operations ranging from DNA purification to cell culture and single cell analysis [10]. To take advantage of the features of both platforms, the integration of continuous and DMF systems has attracted attentions [8].

This paper presents a novel technique to manipulate a column of liquid in microchannels on a DMF platform. For this purpose, an array of electrodes is fabricated on a glass substrate covered with dielectric and hydrophobic layers. To integrate a microchannel on DMF platform, two thin walls of SU8 are fabricated on two sides of electrodes and a top plate is mounted on top of the SU8 walls (the details of the fabrication process is described in Section 3). An array of electrodes is used to actuate a droplet in the microchannel. It is shown that the fabricated device is capable of pumping a column of liquid in the SU8 microchannel. In essence, a target droplet (referred to as the pumped droplet) is pumped by actuating the secondary droplet (referred to as the piston droplet) in a microfluidic channel using the electrowetting on dielectric (EWOD) method. In order to control the flow rate of the liquid column in the microchannel, a signal modulation technique is developed and utilized. Different flow rates of the pumped liquid were achieved by controlling the actuation signal of the piston droplet.

2 EXPERIMENTAL SETUP

The schematic diagram of the experimental setup is shown in Fig. 1a. A signal generator is used to create an AC square wave signal. A voltage amplifier is used to amplify the output of the signal generator. High voltage signal from the amplifier output is then sent to an interface circuit designed to switch the signal on and off by the operator. The modulated output high voltage signal from the interface circuit is used to drive the DMF platform. The detail of the interface circuit is displayed in Fig. 1b.

3 FABRICATION PROCESS

The integration of a microfluidic channel on a DMF platform was achieved by the fabrication process shown in Fig. 2. First, a series of electrodes on a copper-coated glass substrate was patterned using the S1805 positive photoresist and the standard photolithography technique. Each of electrodes has a surface area of 2 mm × 2 mm. To create the sidewalls of the channel, the SU8 negative photoresist was spun on the chip and then the mask with a straight channel pattern was aligned on the chip and exposed to UV. The process was followed by developing the SU8 layer in the developer solution. The S1813 positive photoresist was then spun on the chip as a dielectric layer. An ITO glass was

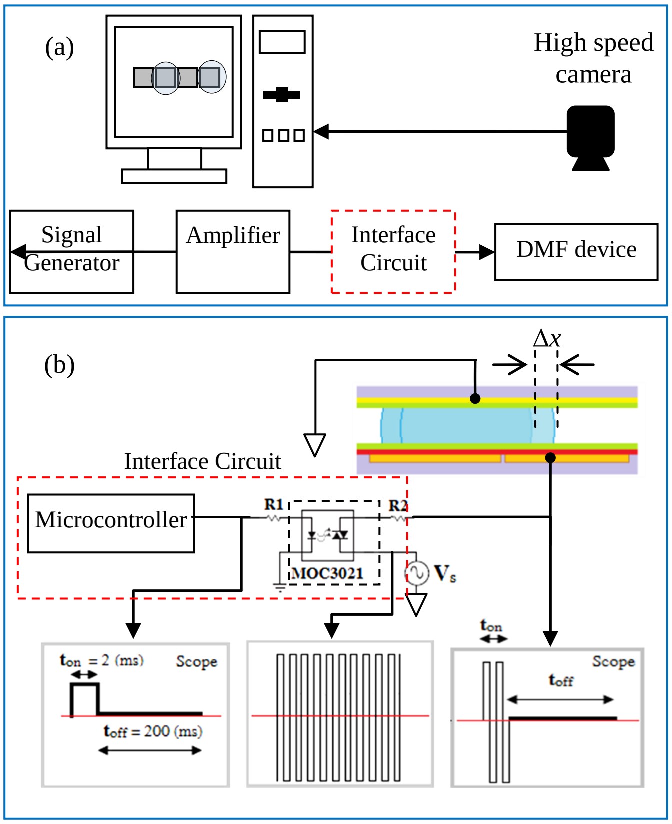

Figure 1. a) Schematic of the experimental setup, b) the interface circuit designed for modulation of the applied AC signal and integration into the DMF platform.

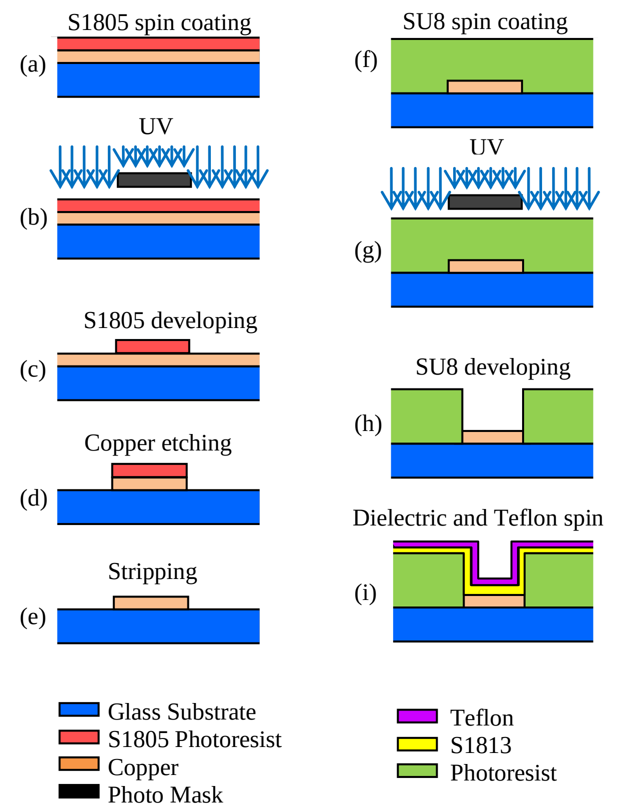

Figure 2. Fabrication process and integration of a microchannel on DMF platform.

used as the top plate. To make the device hydrophobic, both bottom and top plates were coated by a thin layer of Teflon. The top plate was utilized for sealing the channel and providing the ground electrode for the DMF electrodes.

4 EXPERIMENTAL PROCEDURE

For all the experiments, two DI water droplets with the distance of 8 mm were dispensed on the array of the electrodes on the bottom plate. The top plate was placed on the top of them over the pair of SU8 sidewalls. The volume of the piston droplet used for the experiments was 1.2 µL. The pumped liquid volume was chosen to be 4 µL. The pumped droplet was actuated with the signal coming from the designed interface circuit (Fig. 1b). The pumping technique presented was tested experimentally (see Fig. 3). It is shown that the movement of the pumped droplet in the channel can accurately be controlled by manipulating the piston droplet. The actuation signal of the piston droplet was precisely controlled to create the desired transport rate for the pumped droplet. As it is shown in Fig. 2, the signal coming from the amplifier output is an AC square wave. Using an interface circuit, this signal is frequently switched on and off for periods of t_{on} and t_{off}, respectively (see Fig 1b). The interface circuit output AC signal was applied to the electrode beneath the piston droplet. This way, the droplet was manipulated for the controlled period of time (t_{on}). The displacement of the piston droplet was found to be directly related to t_{on}. Silicon oil was used as the filler medium to reduce friction and improve sealing of the channel.

5 RESULTS AND DISCUSSION

An AC square wave signal with the frequency of $f = 1$ kHz and an amplitude in the range of 100-200 V_{p-p} was applied for manipulation of the piston droplet on the array of the copper electrodes. It is observed that the shape of the pumped droplet during pumping does not change which suggests the velocity profile of the pumped liquid is a plug flow velocity profile.

It is shown that the increase in the actuation voltage enhances the displacement of the droplet (Fig. 4). However, for voltages larger than a certain value the displacement of the pumped liquid is independent of voltage and just depends on the period of the actuation signal (t_{on}) (see Fig. 4). For instance, After 150 volts the displacement of the droplet is almost independent of the magnitude of the applied signal and only depends on the duration of t_{on} in the applied signal. Using the described signal modulation technique, t_{on} can precisely be controlled. This way, the

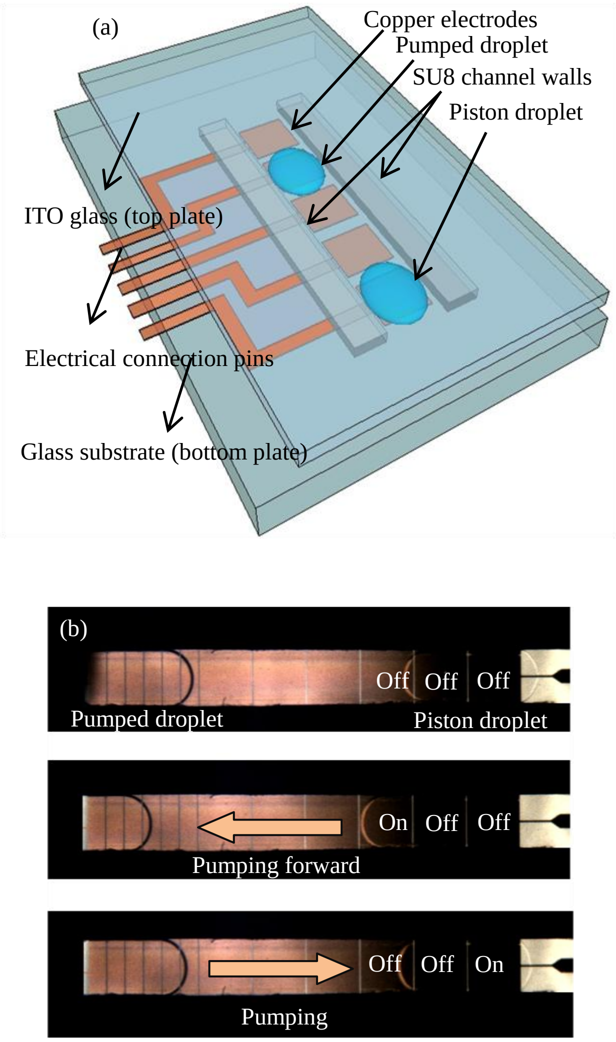

Figure 3. a) Schematic of the fabricated device, b) pumping a droplet back and forth in a microchannel integrated on a DMF platform.

power consumption of the entire system decreases dramatically since the actuation signal is only applied for a short period and it goes off (using the designed interface circuit) for a long time compared to the period t_{on}. By applying the on/off signal frequently, the piston droplet was manipulated with nearly a constant velocity in the channel. As a result, the pumped droplet was moved in the channel with the same velocity. Different flow rates of the pumped liquid were created by precisely controlling t_{on} of the applied voltage. Figure 5 shows the experimental collected data of the piston droplet position for different duration of $t_{on.}$ In addition, the average velocity of the pumped droplet is shown in Fig.5 for each case.

Due to fact that the velocity profile of the liquid (here the channel was filled with oil) after the pumped droplet is

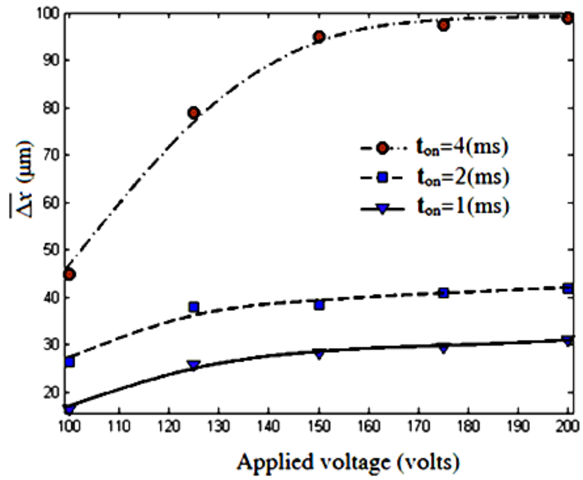

Figure 4. Droplet average displacement vs. the voltage amplitude (V_{p-p}). Three different case of t_{on} were tested.

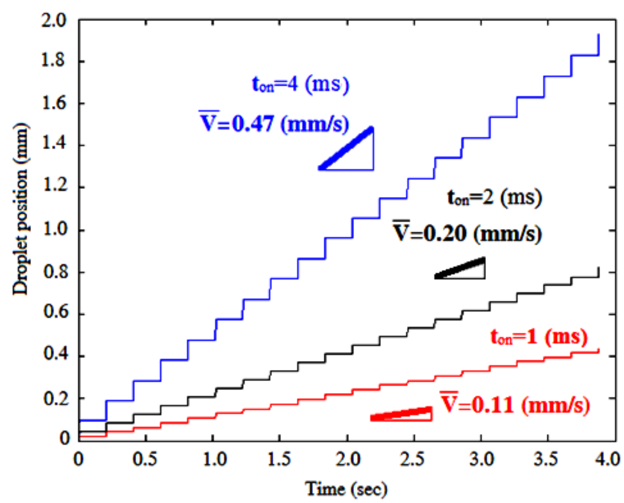

Figure 5. Tracking the pumped liquid position using the pulse modulation technique

uniform (the plug flow was observed), the flow rate of the liquid after the pumped droplet is directly proportional to the pumped droplet velocity. As a result, a controlled flow rate liquid in the channel was achieved by the presented technique.

6 CONCLUSIONS

The manipulation of a column of liquid in a SU8-based microchannel, integrated on a DMF platform, is achieved. The fabrication process of the proposed device and the experimental procedure are described. A target droplet is pumped into the microchannel using the moving force of a secondary droplet which is actuated using EWOD on an array of electrodes. It is observed that the shape of the pumped droplet during pumping does not change which suggests that the velocity profile of the pumped liquid is a plug flow velocity profile. A signal modulation technique is developed and used in order to control the flow rate of the liquid column in the microchannel and to lower the power consumption of the microfluidic system. Different flow rates of the pumped liquid were created by precisely controlling the actuation time (t_{on}) of the signal used for actuation of the piston droplet.

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