INDUCED LATERAL ELECTRIC FIELD (ILEF) DC DIGITAL MICROFLUIDICS

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ABSTRACT

This paper reports a low voltage DC digital microfluidics device working in air filler by inducing lateral electric field (ILEF), which enables manipulation of various positively charged and negatively charged polar solutions for biomedical applications in an oil-free digital microfluidic platform while using cheap DC electric power source. Sensitivity of threshold voltage (minimum required voltage for droplet motion) to the polarity of actuation potential and the polarity of droplet solution is also reported for the first time in this paper, by actuating droplets of positive and negative polarity with initial contact angle 85°< θ_o < 110°.

INTRODUCTION

Digital microfluidics (DMF) is used in numerous lab-on-a-chip (LOC) applications including proteomic sample preparation, enzyme assays, polymerase chain reaction, immunoassays, clinical sample processing and applications involving cell [1-6]. A combination of electrowetting and electromechanical force applied by DC or AC electric field enables manipulation of droplet surrounded by oil or air, respectively[7-11]. While DC based DMF can be a cheap and portable LOC device, AC based DMF contradicts portability since AC amplifiers are more expensive and larger in size compare to DC. However, breakdown of the dielectric layers at micro-nano scale is unpredictable for DC voltage in air medium and DC-based DMF devices working in air medium suffers from electrolysis and charge accumulation. Silicone oil is commonly used as surrounding fluid to solve this problem by reducing droplet surface tension, which limits the applicability of the DMF device in biological processes. Once silicone oil is applied to the device surface, it's also nontrivial to clean device surface. In this study, a robust oil-free DC digital microfluidics device is developed, which can be long term operational without electrolysis by increasing electrostatic force by electric field modulation.

The presented method called ILEF utilizes a negative bias to droplet containing electrode as compared to state of the art DC or AC based methods, where high electric voltage is used to the adjacent electrode which requires oil filler in DC digital microfluidics to prevent dielectric breakdown and expensive amplifier in case of AC [3]. With this iLEF platform, we evaluate correlation between voltage polarity and solution polarity by determining threshold voltage of droplet translation depending on concentrations of anionic (Sodium dodecyl sulfate) and cationic (Hexadecyltrimethylammonium Bromide) surfactants. In this newly developed electrowetting actuation scheme, horizontal actuating force is enhanced by applying a negative bias to the droplet containing electrode as compared to the conventional float mode as illustrated in Figure 1.

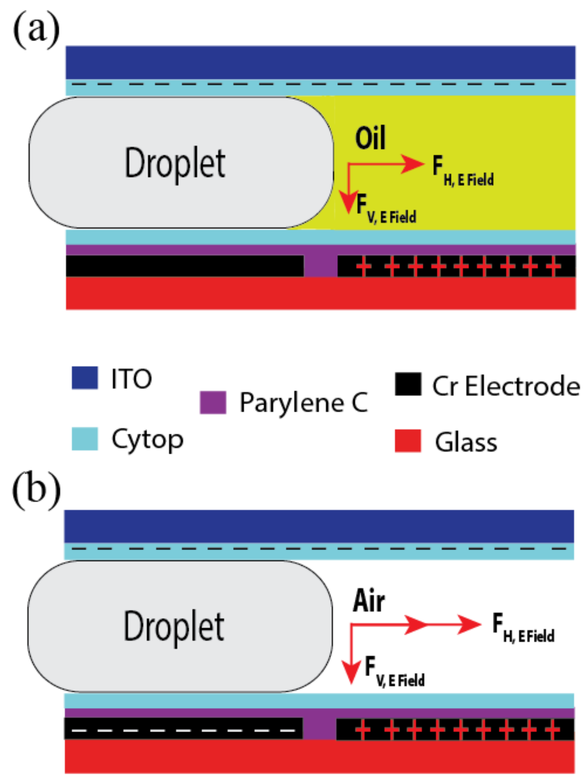

Figure 1: Comparison of actuating force on conventional DC DMF and ILEF DC DMF. (a) Actuating force on a droplet in oil filler based conventional DC DMF. (b) Actuating force on ILEF based DC DMF in air filler with horizontal dominant force component facilitating droplet motion with less threshold voltage.

EXPERIMENTAL METHODS

Materials

Chromium (Cr) coated glass substrate (25 mm x 75 mm) of 100 nm thickness from DRL, Inc. and ITO coated glass (50 mm x 50 mm) from Adafruit were purchased for bottom and top substrate of the device. Microposit S1818 positive photoresist, cytop for hydrophobic coating and fluorinert FC–40 were purchased from Rohm and Hass Electronic Materials LLC, Bellex Int. Corp., and Sigma-Aldrich, respectively. High voltage DC amplifier Q03-24

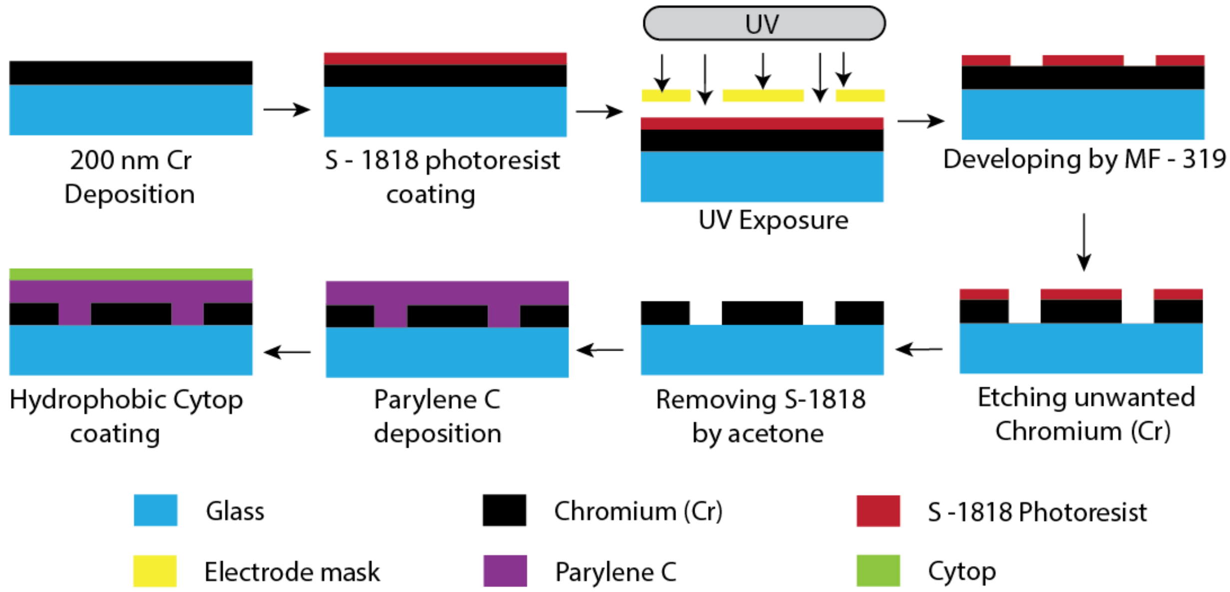

Figure 2: DMF chip fabrication procedure. 1.5 mm x 1.5 mm electrode pattern was fabricated on a Chromium (Cr) coated glass slide using standard photolithography. 2.7µm Parylene C and 60 nm Cytop was coated afterwards as dielectric and hydrophobic, respectively.

was purchased from XP EMCO. Sodium dodecyl sulfate (SDS) and Hexadecyltrimethylammonium bromide (HMAB) as anionic and cationic surfactant were purchased from Sigma-Aldrich. 3M double sided tape for spacing of top and bottom electrode was purchased from Grainger. Spring loaded pogo pin connector for device interfacing was purchased from Mill-Max.

Fabrication Procedure

Bottom actuating electrode of the DMF chip is fabricated by spin coating positive photoresist S1818 on 200 nm Cr coated glass substrate. After exposing the photoresist coated bottom substrate in a UV KUB 2 KLOE with a predesigned electrode patterned mask and subsequently developing by MF-319, unwanted Chromium (Cr) was etched out with Cr etchant. After stripping off the photoresist from the bottom electrode, it was then subsequently coated with dielectric parylene C (2.7 µm) using SCS parylene lab coater and 60 nm hydrophobic Cytop (0.1% w/v, 1000 rpm). To form top electrode, ITO coated glass slide is used and coated with only 60 nm Cytop. Hydrophobic Cytop coated top and bottom electrode was thermally heated in a conventional oven at 100º C for one hour and at 200º C for one hour.

Device Operation

DMF chip is assembled by placing top ITO electrode on top of bottom actuating electrode pattern by placing 3M double sided tape of 100 µm thickness in between. Electrical connection of the electrodes are established by spring loaded pogo pin connector to the contact pads of the DMF chip in a custom built device platform as shown in Figure 3. Droplets of DI (deionized) water were dispensed and manipulated by applying + 120_{dc} to electrode adjacent to droplet and negative ground to droplet containing electrode along with top ground electrode to induce lateral

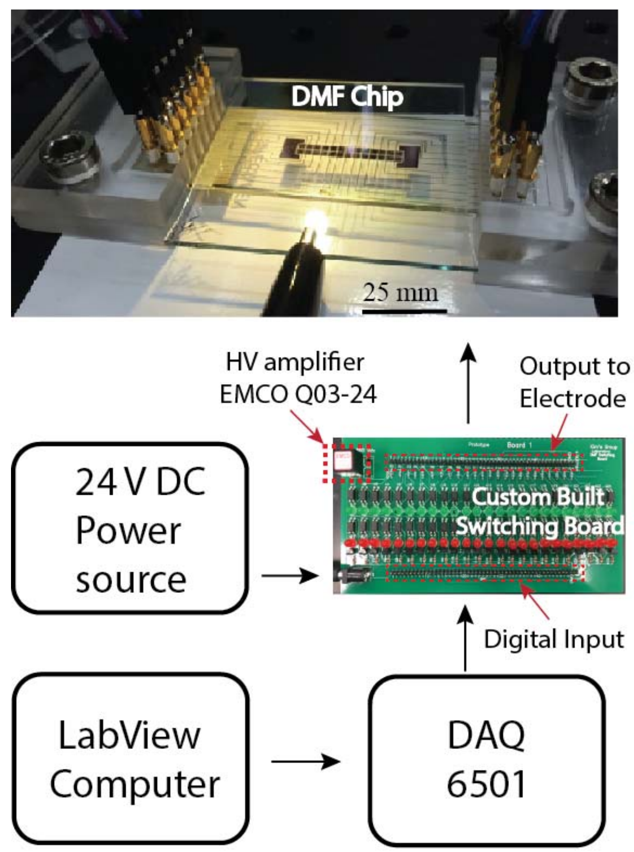

Figure 3: ILEF DMF chip in a spring loaded pogo pin connector platform, where droplets are controlled by by LabVIEW program from a computer through DAQ 6501 and custom built switching board.

electric field (LEF), thus increasing electromechanical force in the direction of droplet translation. Voltage was amplified using EMCO Q03-24 and controlled by a custom built switching board, which can simultaneously apply positive and negative voltage. Repetitive droplet dispensing, transport, split and merging were performed without any electrolysis in air medium as shown in Figure 3.

RESULTS AND DISCUSSION

By applying ILEF, threshold voltage was reduced down to ~80 V_{dc} while it was ~600 V_{dc} without ILEF for 2.7 μm parylene coated electrode in air medium for DI water droplet as shown in Table 1. The threshold voltage was also investigated for oil filler method, which clearly shows that the threshold voltage of ILEF can achieve droplet translation at even lower voltage in air filler as compared to oil filler without ILEF. Dispensing, translation and merging, as shown in Figure 4, were performed for more than 100 times without any failure with at least three droplets generated from a reservoir volume of 3 μL.

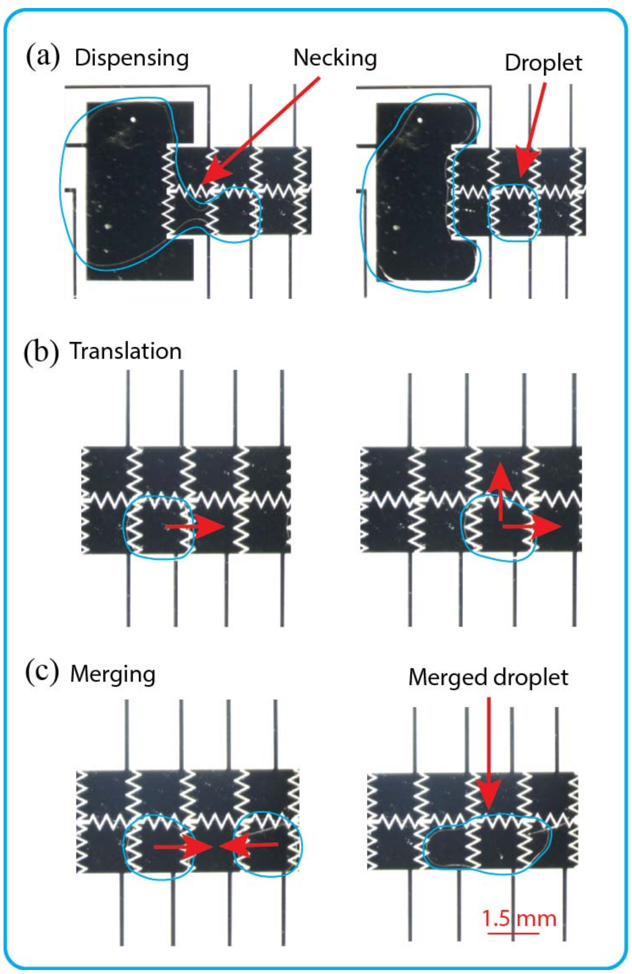

Figure 4: ILEF DMF in operation. (a) Repetitive droplet dispensing, (b) translation and (c) merging in air filler without any electrolysis by application of DC voltage.

Average volume of droplets was found to be 230 nL with only 3.9 % deviation for reservoir to control electrode surface area ratio of ~10.

Furthermore, force enhancement in ILEF was investigated by the polarity study in Figure 5, significant change in the threshold voltage is noticeable in both anionic and cationic surfactant case for positive and negative actuation potential with clear indication of the presence of attractive and repulsive forces during droplet translation. The threshold voltage was expected to decrease with increase in concentration of the surfactant for the attractive cases; however, increased concentration of surfactant also decreases the initial contact angle of the droplet, which requires more energy for droplet translation, causing increased threshold voltage. Further noticeable fact is that, ILEF enables translation of droplets with initial contact angle < 90°, which is otherwise considered to be not achievable with a conventional digital microfluidic platform. Translating droplets with < 90° initial contact angle is very useful for bioassay since there is almost no limit to select buffers and samples.

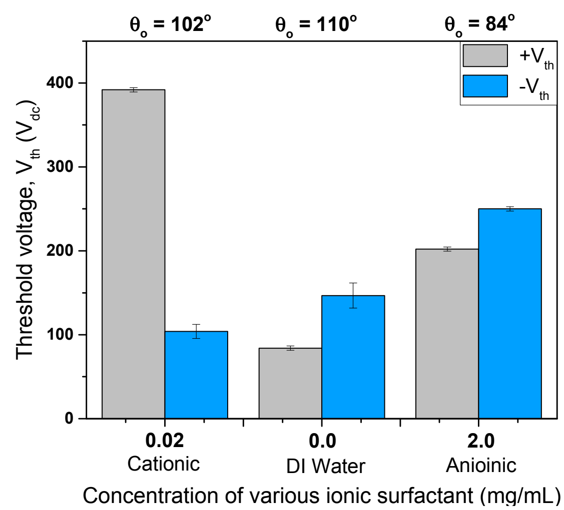

Figure 5: Effect of the polarity of d.c. actuating potential on anionic surfactant (Sodium dodecyl sulfate) solution, cationic surfactant (Hexadecyltrimethylammonium Bromide) solution and the droplet initial contact angle as change in threshold voltage (V_{th}).

Table 1: Threshold voltage comparison of DI water for with/without ILEF at air/oil filler

	Without ILEF	With ILEF
Air	600	110
Oil	80	60

CONCLUSION

ILEF DMF enables manipulation of droplet at a much lower voltage compare to the conventional system in air filler. Low voltage application in air filler and lower initial contact angle droplet manipulation of ILEF DMF promises to be great advantage in LOC applications. Desirability to have a portable device for LOC applications can also be achieved by this ILEF DMF due to its cheaper DC based voltage application. Furthermore, this ILEF DMF can also be extended to USB powered DMF due to its significant reduction of threshold voltage and facile manipulation of droplets.

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