ROBUST ON-DEMAND ELECTROSTATIC DROPLET CHARGING AND SORTING IN A DROPLET-BASED MICROFLUIDIC DEVICE

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ABSTRACT

This paper reports droplet-based microfluidic devices for on-demand electrostatic droplet charging and sorting. This device combines two different segments; one is a hydrodynamic flow focusing structure to generate two phase droplet formation and the other is two paired-electrodes for charging and sorting with electrostatic actuation using DC voltage. Different electrostatic actuation polarity could result in on-demand droplet charging and sorting with droplet generation. Therefore, we can control single droplet using the proposed electrostatic droplet charging and sorting microfluidic device.

KEYWORDS: droplet, sorting, electrostatic charging, droplet-based microfluidics

INTRODUCTION

The droplet-based microfluidics involves the generation and manipulation of discrete droplets inside microfluidic devices [1]. It has been possible to sort droplets by pre-charging and steering them with electric fields [2]. Our group has demonstrated concurrent droplet pre-charging and sorting of up to 600 droplets/sec by synchronized electrostatic actuation [3]. However, such methods are not compliant with manipulation of preformed neutral droplets. And their polarity could not be changed once charged. In this research, we present a method for robust on-demand electrostatic droplet charging and sorting. The proposed method can provide the ability to digitally manipulate droplets at a very high-throughput.

THEORY

Our device consists of: hydrodynamic flow focusing structure to generate water-in-oil droplets and two paired-electrodes system. One set of electrode (charging electrode, CE) is for electrostatic droplet charging, and the other (sorting electrode, SE) is for droplet sorting (Fig. 1). Once positive voltage is applied at CE, the negative charge is induced over water droplet, and vice-versa. According to its surface charge polarity, negatively- or positively-charged droplet finds its outlet at the SE patterned area.

EXPERIMENTAL

Microfluidic channels (width and height of 50 µm) were fabricated with polydimethylsiloxane (PDMS) using soft lithography technique. For the soft mold, 50 µm thick negative photoresist (SU-8 2025) was coated and patterned. And, a 10 : 1 mixture of PDMS prepolymer and curing agent was stirred thoroughly and degassed in the vacuum chamber (30 min). Then, this mixture is poured on the soft mold and cured 1 hour at 70 ˚C in an oven. ITO (100 nm) was patterned for both electrodes (CE and SE) on a glass substrate using sputter machine. Uniform oxide layer (300 nm) was grown over the electrode and substrate for insulation layer. And a window (40 × 40 µm) was etched over the CE's ground electrode to realize contact between droplet and electrode. Finally, electrode patterned substrate and PDMS microfluidic channels were exposed to O_2 plasma and sealed irreversibly. DI water and mineral oil were used as aqueous and oil phase respectively.

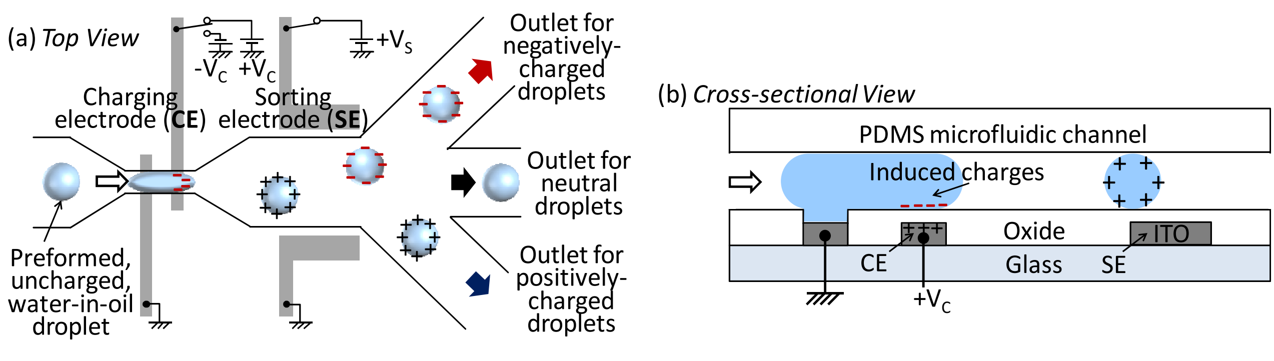

Fig. 1 *Working principle for robust on-demand electrostatic droplet charging and sorting in a droplet-based microfluidic device. Once a preformed, uncharged, water-in-oil droplet is electrostatically charged, it is sorted by its polarity.*

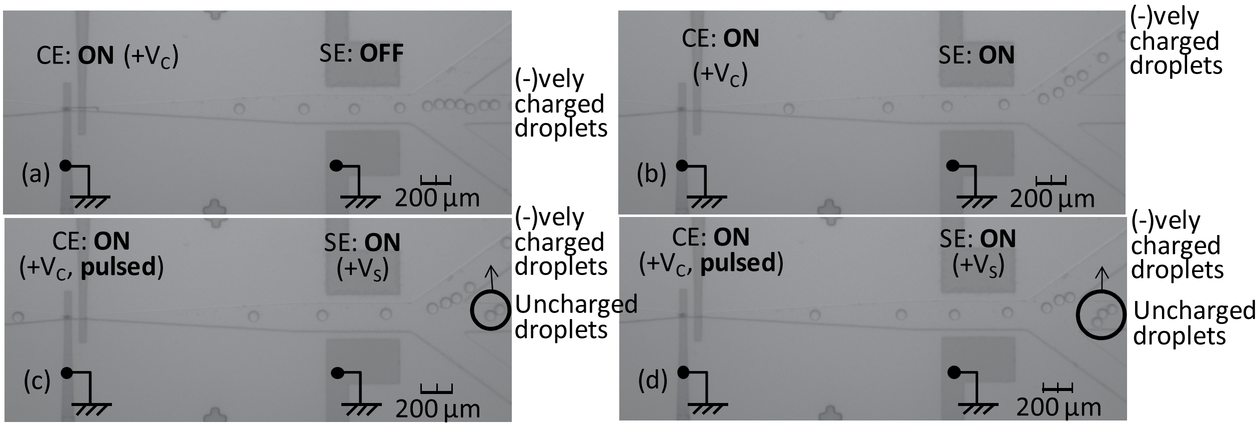

Fig. 2 *Photographs of on-demand electrostatic droplet manipulation. (a) Negatively-charged droplets flowing into the middle outlet (V_C = +80 V and V_S = 0 V). (b) Continuous droplet sorting of the negatively charged droplets (V_C = +80 V and V_S = +110 V). (c) and (d) Selectively charging and sorting with different pulse frequencies for CE (V_C = +80 V (pulsed) and V_S = +110).*

RESULTS AND DISCUSSION

Our device was tested for charging and sorting by varying the flow rates and applied voltages. Fig. 2 shows continuous droplet charging and sorting. When no potential was applied at SE, every charged droplet flowed into the middle outlet (Fig. 2a). But, when a potential (V_S = +110 V) is applied at SE, negatively-charged droplets were sorted by its polarity (Fig. 2b, 2c and 2d). Negatively- and positively-charged droplets could be obtained by applying +80 V / –80 V at CE respectively. We could control the number of droplets at any outlet through frequency and polarity control of CE voltage (Fig. 2c and 2d).

Fig. 3a and 3b show time lapse trace line for negatively- and positively-charged droplets. Water and oil flow rates were set at 15 µl/hr and 75 µl/hr respectively, and corresponding droplets size were 67 ~ 71 µm. To induce a negative charge over a droplet surface, we applied positive voltage at CE (V_C = +80 V), and sorting voltage was fixed to +110 V (V_S = +110 V) (Fig. 3a). A negatively-charged droplet followed the dotted trace line which is the trace for neutral droplet before it reaches SE area (Fig. 3a, 0 ms). As soon as it reaches SE area, negatively-charged droplet starts to change its flowing direction slightly. In this case, we applied positive potential at upper electrode (SE) so negatively-charged droplet was attracted to upper electrode. Although the displacement of negatively-charged droplet is small, it was enough to sort a droplet to the side outlet. For positively-charged droplet, we applied the same CE and SE voltage but different polarity for CE (V_C = –80 V and V_S = +110 V) (Fig. 3b). With this change, we could sort positively-charged droplet, the trace is marked by a solid line.

Fig. 4 shows a summary of working conditions of our device. Droplets could not be sorted when flow rate ratio (Q_{Ratio} = Q_{Oil} / Q_{Water}) is low (big droplet) or high (small droplet) (Fig. 4a). Our optimized experiment condition of flow rates was when Q_{Ratio} was 5 and 6 (Fig. 4b). When Q_{Ratio} is low, droplet charging was successful. However, a high sorting voltage (V_S) is needed to sort charged droplets, which can lead to fusion between droplets (Fig. 4c). And, when Q_{Ratio} is high, generated droplet could not cover both pads of CE, which leads to unsuccessful charging (Fig. 4d).

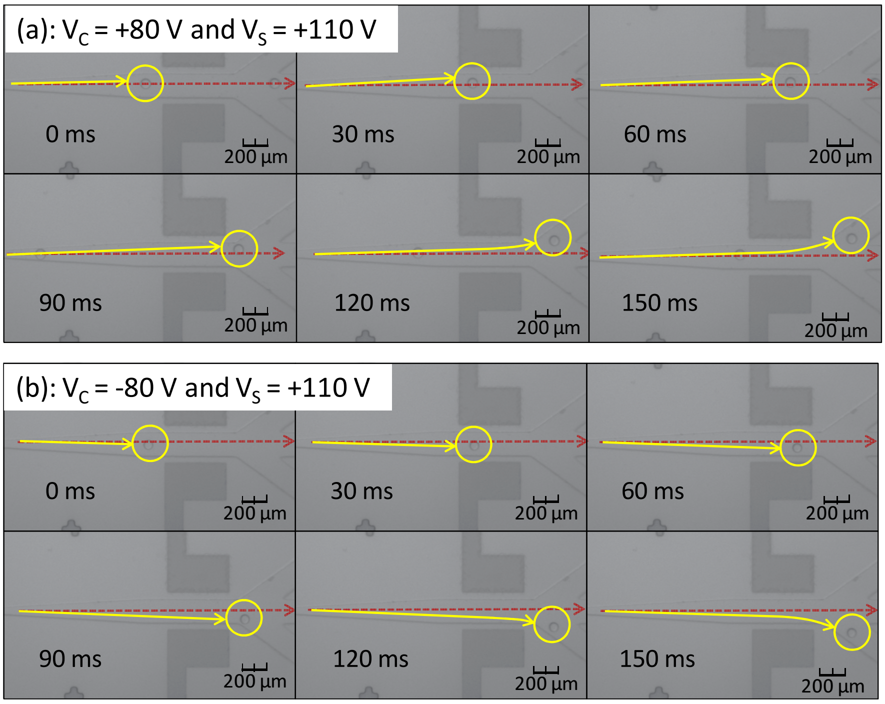

Fig. 3 *Photographs of single surface-charged droplet with different polarity with trace lines. (a) A negatively-charged droplet flowing into the upper outlet (V_C = +80 V and V_S = +110 V). (b) A positively-charged droplet flowing into the lower outlet (V_C = -80 V and V_S = +110 V).*

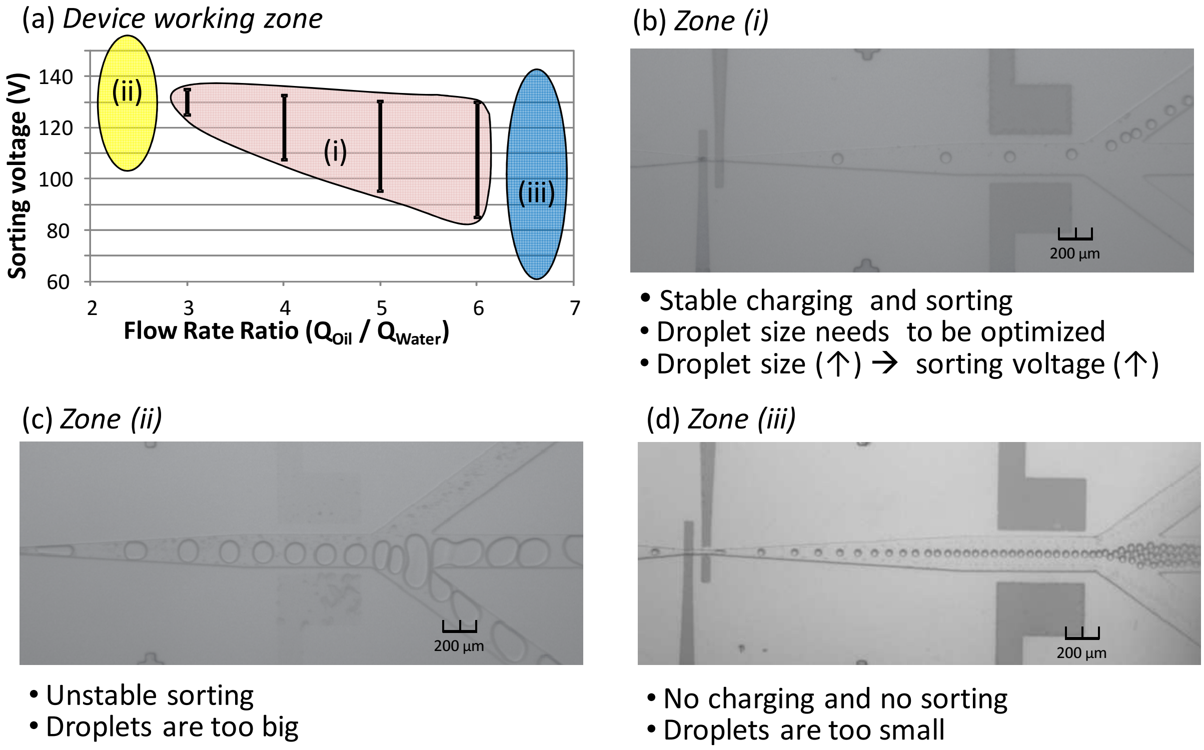

Fig. 4 *Device working zone and photographs for each zone. Flow rate ratio needs to be optimized for stable charging and sorting. (a) working zone summary chart. (b) zone (i) is optimized area for droplet charging and sorting. (c) zone (ii) is good for charging but too big droplet size caused to sorting failure. (d) zone (iii) is not good area for charging due to small size of droplet.*

CONCLUSIONS

We have demonstrated an electrostatic droplet manipulation device that can selectively charge preformed neutral droplets on-demand. Many different types of on-chip operations (e.g., sorting, bifurcation and electrofusion) could be performed downstream. Addition of charge or change of polarity could be done by additional set of CE. Thus, we can digitally manipulate individual droplets using the proposed electrostatic droplet charging and sorting method.

ACKNOWLEDGEMENTS

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