HYDRODYNAMIC DENSITY-BASED PARTICLE FOCUSING IN DIGITAL MICROFLUIDIC SYSTEMS

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ABSTRACT

A particle-separation technique for digital microfluidic system is introduced to focus and concentrate non-buoyant particles in micro-droplets. The proposed method utilizes the combined effects of the gravitational forces and the fluid flow inside the droplet. This technique does not require any additional electrical or magnetic modules. The desired hydrodynamic effect is created by spinning the droplet in a controlled fashion on a circular pattern of electrodes using electrowetting-on-dielectric technique. The fabricated device successfully focuses the non-buoyant silica beads of 5µm in a region on the central electrode; whereas the focusing behavior is not observed for the neutrally polystyrene beads.

KEYWORDS: Particle Focusing, Digital Microfluidics, Droplet, Hydrodynamics

INTRODUCTION

Despite the general success of digital microfluidic (DMF) platforms, the basic operations (merging, splitting, transport, and dispensing) do not offer the ability to control the motion of particles inside the droplets which is important for applications involving purification of biological samples [1] or binary separation of solutions [2]. The ability to isolate micron-sized colloidal particles (such as functionalized silica beads, or biological cells) on a chip can provide researchers with a powerful tool to re-design the standard laboratory procedures on DMF platforms for many point-of-care applications such as DNA and RNA purification, or enzyme-linked immunosorbent assays (ELISA). In the past decade, several techniques have been developed for particle manipulation in DMF platforms. These techniques include magnetic [3], optic [4], electrophoretic [5] and dielectrophoretic [6, 7] methods. Although all these methods have successfully incorporated particle separation into DMF systems, each method is applicable to a specific range of droplet/particle electromagnetic properties, which limits the scope of applications of these techniques. To extend the implementation of DMF technology to a wider range of applications, it is important to develop alternative particle-separation techniques which are not restricted by the droplet/particle electromagnetic properties.

EXPERIMENTAL

The experiment is performed on the array of electrodes shown in Fig. 1. The array includes a central circular electrode surrounded by six electrodes. Each of these electrodes is addressable separately. Droplets containing the particles is dispensed on the centre of the design, and then sandwiched between the top and bottom plates. The gap height is kept at 300 µm using a set of spacers. The central electrode is turned on and kept activated throughout the experiment; while the surrounding electrodes are sequentially activated for 125 ms. An AC voltage with the amplitude of 100 Vrms and frequency of 1 kHz is used for actuation. As the voltages are applied, the droplet is elongated between the central and the actuated surrounding electrodes (see Fig. 1). Under this actuation scheme, the droplet spins around the center of the central electrode after actuating each surrounding electrode.
RESULTS AND DISCUSSION

To investigate the feasibility of the proposed particle-focusing technique, suspensions of silica beads (with density of 2500 kg/m$^3$) and polystyrene beads (with density of 1060 kg/m$^3$) are tested as non-buoyant and neutrally buoyant particles, respectively. The droplet is continuously spun about the axis of rotation by constant actuation of the central electrode and sequential actuation of all surrounding electrodes. The rotation speed is 80 rpm, and the process is continued for 150 s.

Figure 2a shows a 1.5-µL droplet that contains non-buoyant silica beads. The droplet is spun around the central electrode based on the actuation scheme explained before. The droplet volume (1.5 µL) is large enough to cover the central electrode after actuation. As it is shown in Fig. 2a, the fabricated device successfully focuses the non-buoyant silica beads of 5 µm in a region of the central electrode.

To investigate the effects of the droplet size, a 1.2-µL droplet of the same suspension (of silica beads) is tested (see Fig. 2b). In this case, by actuating the electrodes, the droplet stretches over the surrounding electrode. However, the droplet volume is not large enough to cover the central region of the central electrode. As it can be seen in Fig. 2b, no focusing behavior is observed in this case, which clarify that the overlap of the droplet with the central electrode is crucial for particle focusing.

To investigate the effect of the particle density on the focusing behavior, the experiment is carried out with a 1.5-µL droplet of polystyrene beads. Interestingly, the focusing behavior is not observed for polystyrene beads (shown in Fig. 2c). Therefore, the density difference between the particles and surrounding liquid plays essential crucial role in achieving focusing regimes.

CONCLUSION

A hydrodynamic-based particle separation technique was proposed for DMF platforms which is independent of the electromagnetic properties of the particles/fluid. The proposed electrode design and actuation scheme successfully focuses the non-buoyant silica particles into specific region on the bottom plate of DMF systems.
Fig. 2: Effects of particle density and droplet size on the proposed hydrodynamic based particle-focusing method. (a) 1.5 µL droplet containing 5 µm non-buoyant particles (silica beads), (b) 1.2 µL droplet of 5 µm non-buoyant particles (silica beads), and (c) 1.5 µL droplet of 5 µm neutrally buoyant particles (polystyrene beads).

REFERENCES

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