A SINGLE PARTICLE ENCAPSULATION WITHIN DROPLET IN ARRAY-BASED MICROFLUIDIC PLATFORM

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ABSTRACT

In this paper, we describe a passive single particle encapsulation within a droplet using array-based microfluidic platform. In order to trap a single particle into an array of well where a droplet is created, the hydrodynamic resistances of by-passing channel and trapping channel are calculated. By the hydrodynamic resistance, the particles are successfully trapped into the array of the wells. Subsequently, air and immiscible oil were induced to create droplets encapsulating the particles. By applying backward flow, the droplets were released for a post processing. We expect that the proposed method can be applicable in studying a single cell analysis.

KEYWORDS

Droplet, Single Particle Encapsulation

INTRODUCTION

There has been a droplet microfluidic platform for high-throughput applications in developing biological and chemical researches as a promising platform. Since the droplets are surrounded by immiscible carrier oil, they are not only considered as a single micro-reactor but also prevented from a cross-contamination between droplets. In addition, the droplet-based platform allows all molecular reactions to be confined to the small volume of droplet resulting in fast molecular reactions of interest and significant reduction in reagent volume [1-2]. One of the emerging studies in the droplet-based microfluidic platform is to encapsulate a single particle or cell within droplet for single cell level studies [3]. However, despite the progress in a particle at the single-particle level and droplet handling techniques, there is a need for low-cost and simple approaches without external forces (e.g., dielectrophoresis) [4]. To overcome this technical challenge, a simple particle encapsulation method is achieved by hydrodynamic forces to trap the particles and release the droplets in a passive manner. We believe that it has a potential to diverse lab-on-a-chip applications in studying a single cell.

PRINCIPLE

This device consists of three major functions: particle trapping, encapsulation within a droplet and droplet releasing (Fig. 1). The microfluidic channel is designed based on fluidic resistance [5-6]: when the particle trapping site is unoccupied, the particle in flow is carried into the trap site along the trapping stream since the trapping channel has a lower flow resistance than that of by-passing channel. But, once the particle is trapped, which can increase the fluidic

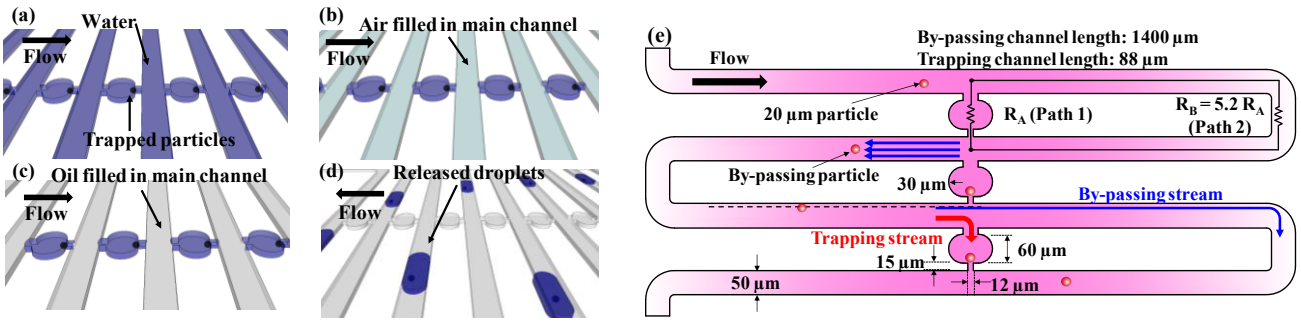

Figure 1: Working principle for a single particle encapsulation within droplet in the array-based device. (a) Particle trapping. (b) Air flow filled into the microfluidic channel. (c) Oil carrier flow surrounding the water droplets. (d) Droplet releasing. (e) Trapping mechanism by the trapping stream and by-passing stream.

resistance, the main flow traverses the by-passing channel to trap next particle (Fig. 1(e)). After the particle trapping, the air flow is applied to the microchannel to form a water droplet surrounded by air. Subsequently, the oil carrier flow is applied for water-in-oil droplet. To release the formed droplet from the microarray, backward oil flow is injected. Since the main oil flow traverse the narrow channel in trapping site, the droplets are easily released, and then they can be collected.

FABRICATION/EXPERIMENT

The microfluidic channels were formed on 3 inch silicon wafer (University wafers, South Boston, MA, USA) by using conventional soft-lithography techniques. In order to remove a thin oxide layer that makes adhesion poor between

SU-8 and a wafer on the wafer, it was submerged into BHF (buffered hydrofluoric acid) at room temperature for 5 min. Afterwards, it was rinsed with acetone, methanol and distilled water. For a soft mold, the SU-8 (SU-8 2015, Micro-Chem Corp, Newton, MA, USA) was then spin coated with target thickness (e.g., 25 µm) on the cleaned wafer using a spin processer (WS-650Mz NPP from Laurell Technologies, North Wales, PA, USA). After spin coating process, a conventional UV photolithography method was used. A prepolymer of PDMS (Sylgard 184, Dow Corning) and curing agent was thoroughly mixed at a ratio of 10 : 1 (wt/wt) and the PDMS was carefully poured onto the SU-8 master mold. After curing, the PDMS was peeled off and bonded irreversibly on a glass substrate by exposing O_2 plasma on the surface of PDMS and glass. As model particle, 20 µm single polystyrene microbeads (4220A, Duke Scientific Corp., Palo Alto, CA) were used and mixed into DI water. HFE-7500 oil (3M) was used and the ammonium carboxylate of Krytox 157 FSL (Dupont) was added to the oil at 2% by weight as a surfactant. All experimental results were captured by a CCD camera mounted on a Nikon stereo-type microscope.

RESULT/DISCUSSION

For the stable particle trapping, the volumetric flow ratio (Q_t/Q_b) along the two paths, trapping stream and by-passing

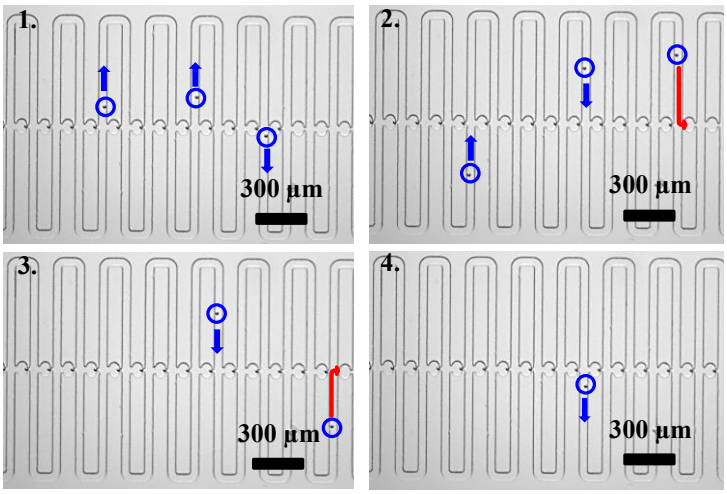

Figure 2: Sequential photographs of the particle manipulation showing the by-passing and trapping particles.

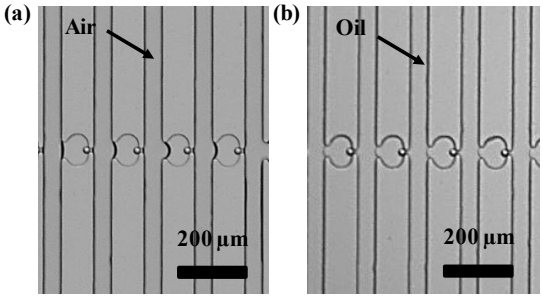

Figure 3: Droplet formation from the trapping site. (a) Water-in-air droplets. After the particle trapping, the air flow was injected into main channel. Because of high surface tension at the interface between the air and water, the droplets were easily formed. (b) Water-in-oil droplets. The air flow was replaced with the oil carrier flow.

stream, was defined to 5.2 by the fluidic resistance since the center of mass for the particles must be positioned in the trapping stream (Fig. 2). Based on the calculation, the ratio (Q_t/Q_b) must be larger than 4, by assuming that the particles move 40 µm away from the center of particle to the trapping site as a worst case. The microparticle suspension flow rate was set at 50 µl/hr. For the droplet formation, the air flow was applied with 100 µl/hr as a pre-process to easily form the water droplet: (1) low pressure drop through path 1 and (2) high resistance by a surface tension at air-water interface. The

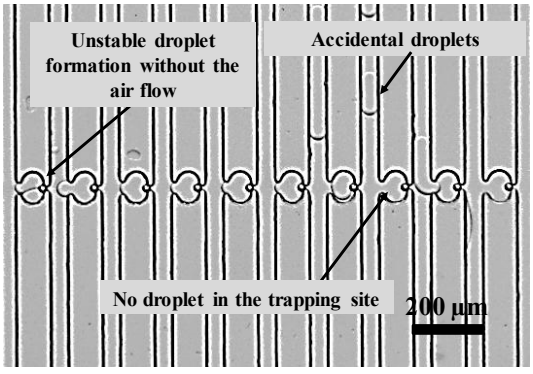

Figure 4: Photograph of unstable droplet formation in the microfluidic channel due to low surface tension between the water and oil. Despite the particles located in the narrow channel, it is not fully blocked by the particles, thus the oil flow can pass through the channel.

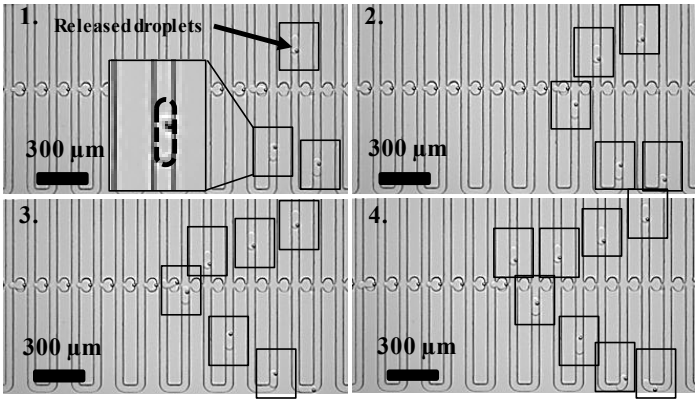

Figure 5: Sequential photographs of droplet releasing into main channel by applied the oil flow in a backward direction. The released droplet can be collected for a post process. The black rectangles show the released droplet.

surface tension of water-air (72 mN/m) is greater than that of water-oil interface (HFE-7500, 1-5 mN/m), meaning that the water can easily resist the pressure caused by air flow compared to the oil flow (Fig. 3). When the oil carrier flow was applied without the air flow, the droplets could not be formed as shown in Fig. 4. Subsequently, the oil fluid was applied forward with 100 μl/hr for the droplets. To release the droplets from the array, 500 μl/hr oil flow was applied in a backward direction (Fig. 5).

CONCLUSION

We have demonstrated the simple and passive method for the single particle encapsulation in array-based microfluidic platform where the particle trapping, droplet formation, and droplet releasing were accomplished.

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