Toward 100% Yield of One-to-One Particle Encapsulation Using Dielectrophoretic Particle Alignment Technique

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Abstract Particle encapsulation using microfluidics technology is effective for application of synthesis, single cell analysis, and drug discovery. However, if the particles are supplied randomly to the region in which droplet is generated, the number of particles in the droplet follows the Poisson distribution. This decreases the success-rate of the encapsulation when a one-droplet-one-particle is required. We developed a technique using the boxcar-type electrodes that can control the streamwise interval and timing of the particles flowing in microchannel by dielectrophoretic (DEP) forces, and applied it to the upstream region of the droplet-generation section. The interval of the particles was adjusted to that of the droplet generation, and alignment performance before they enter the droplet-generation region and the frequent distribution of the number of particles in the droplet were measured. We achieved 100% success-rate of one-to-one particle encapsulation in the case of average number of particles (number density) in a droplet equal to 0.40.

Keywords: Microfluidics, Dielectrophoretic Force, Alignment, Timing Control, Encapsulation, Droplets

1. Introduction

Controlling the position of the particles, the interval (space) between the particles, and the timing when they pass the specific location in the microchannel is an important technique to perform the sensing, sorting, and encapsulation accurately in microfluidic devices.

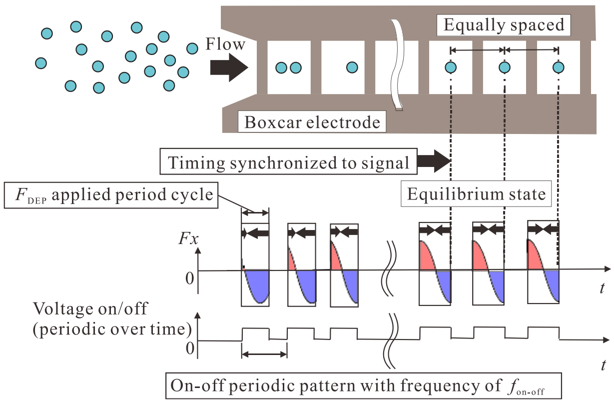
We developed a technique that can control the timing, interval (spacing), and velocity of the particles in the microchannel by exerting forces on the particles periodically over space and time (see Fig. 1 (a)) [1-3]. Regions of dielectrophoretic force accelerating and decelerating the particles are formed periodically in the streamwise direction by using boxcar-type electrodes, and the force is activated periodically over time. We showed that the combination of these two schemes could align the particles and Jurket cells with equal spacing and intervals [2,3]. In this presentation, we will apply this technique to the particle encapsulation system and evaluated the alignment of the particles, timing matching with the droplet generation, and the success rate of one-droplet-one-particle encapsulation.

2. Methods

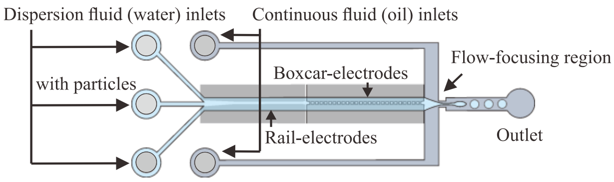
Figs. 1 (b)-(d) show the schematic and dimensions of the microchannel and electrodes. The boxcar-electrodes were patterned on the bottom wall, and the ground electrode covered the top wall of the main channel. We used the flow-focusing type channel to generate droplets, which was installed to the location downstream of the boxcar-electrode region (see Fig. 1 (d)).

Polystyrene microparticles with diameters of 12 μm (Thermoscientific, 4212A) were used in the measurements. The particles were mixed in Milli-Q water at concentration of 0.2 %, and was supplied to the main channel. Silicone oil (Shin-Etsu Chemical: KF-96-50CS) with 0.5wt% hydrophobic surfactant (Tokyo Ohka Kagaku: Span80) was supplied to the side flows of the flow-focusing type channel.

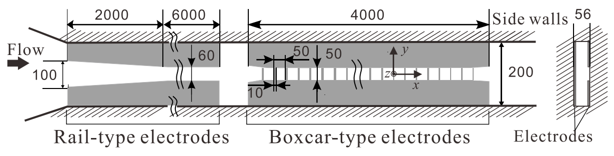
The flow rate of the center flow and side flows were 0.5 and 1.85 μL/min, respectively. We applied an alternating current voltage to the electrodes with voltage of $V_{\text{p-p}}$=8.5V, and frequency of f_{V}=10MHz. This voltage was turned on and off periodically with a frequency of $f_{\text{on-off}}$=14 Hz, and with duty rate of 50%.



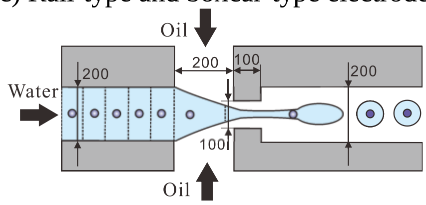
(a) Particle alignment and timing control



(b) Microchannel



(c) Rail-type and boxcar-type electrodes



(d) Flow-focusing section

Fig. 1: Schematic images of (a) particle alignment by applying periodic force over space and time using dielectrophoretic force, (b) microchannel with particle alignment and droplet generating regions, (c) rail-type and boxcar-type electrodes attached to the bottom wall, and (d) water in oil droplet generation using flow-focusing channel (unit in μm).

3. Results and Discussion

Fig. 2 shows the photograph of the aligned particles, droplet generation, and particle encapsulation at the flow-focusing section. Fig. 3 shows the probability density function (PDF) of the interval between the droplets, and the accuracy of the interval between the particles at the boxcar-electrode region. δt is the deviation of the particle time interval from the on-off period $t_{\text{on-off}}$ of the applied voltage. The droplets are generated periodically at the flow-focusing region, and the PDF gives a peak at 66ms with standard deviation of 1.4ms. The PDF of δt_p gives a peak at zero with reasonably small variation showing accurate particle alignment.

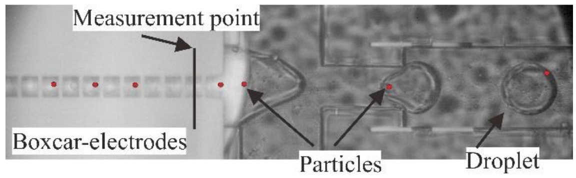
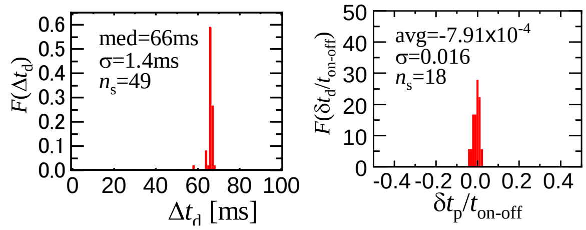


Fig. 2: Snapshot of the flow-focusing region.



(a) Droplet generation (b) Particle supply

Fig. 3: Probability density function of time-interval of the droplets and the particles.

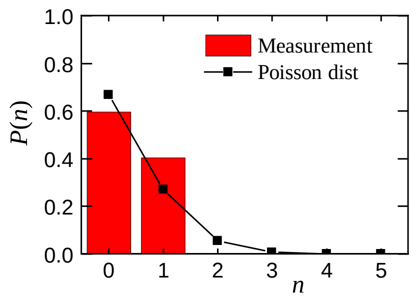


Fig. 4: Frequency distribution of the number of particles in droplet (λ=0.4).

Fig. 4 shows the frequency distribution of the number of particles encapsulated in the generated droplets. The average number of particles in droplet is λ=0.4. By controlling the interval of the particles using the present method, all droplets which encapsulate the particles have only one particle (n=1), and droplets with more than one particle was not found, representing 100% yield of one-to-one particle encapsulation. If we compare it with the case of particles flowing with random interval (Poisson distribution), the rate of n=1 increases by 50%. This improvement of the encapsulation performance becomes more significant as λ increases, and leads to higher throughput.

References

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