DIELECTROPHORETIC ALIGNMENT AND SORTING OF MICROPARTICLES IN MICROCHANNEL FLOWS USING LADDER-TYPES ELECTRODES

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ABSTRACT

The present study describes a new micro-device which can accurately align and sort particles in a very high rate using the dielectrophoretic (DEP) force. The rail- and ladder-type electrodes can precisely locate the particles in certain spanwise and height positions, and moreover, control the distance between particles and align them. In combination with the flip-type electrode, the particle could be sorted accurately.

KEYWORDS: Dielectrophoresis, Particle alignment and sorting, Ladder-type electrodes, Microchannel

INTRODUCTION

Although various means of manipulating and sorting particles have been presented in the past [1], the accuracy and rate have not fully reached the level to satisfy the demands of the applications (e.g. >1,000 particles/s). To increase the sorting rate, it is necessary to control the streamwise positions of these particles before guiding them to the on/off gate electrodes for manipulation. To tackle this problem, we have developed a DEP force based device that can align the particles in the channel flow equally spaced in the streamwise direction using the “rail-type” [2] and “ladder-type” electrodes.

THEORY

Figure 1(a) shows the microchannel and the thee electrodes together with the principle how the particle can be aligned and sorted. With the negative DEP force working on the particles, the three types of electrodes can control the particle spanwise and height positions, streamwise distance between particles, and sort the particles.

The particle alignment function of the ladder-type electrodes appears only when the voltage is fluctuated in a frequency synchronized with the particle streamwise velocity and the electrodes pitch. Figure 2(b) shows the on/off characteristic of the voltage which is periodically changed in a square wave form. High frequency fluctuation of 10MHz is applied when the voltage is on to generating DEP force. As shown in Fig. 1 (b) and (c), when the phases of the voltage applied and the particle relative position to the ladder-type electrode do not match, then $F_{\mathrm{DEP},x}$ and $F_{\mathrm{DEP},z}$ work to correct the position of the particle to move toward the appropriate one.

By these effects, since the period when the particle is supplied from the ladder-type electrode is synchronized with the phase of the voltage on/off cycle, it is easy to adjust the timing for the on/off of the flip-type electrode used to sort the particles.

NUMERICAL

The particle motion was calculated by solving the translational and rotational equations of motion. The hydrodynamic force working on particles was estimated employing the modified stokes law of force on a particle considered the wall effect [3]. F_{DEP} was obtained based on the Clausius-Mossotti function[4] using the electric field calculated by COMSOL Multiphysics Ver. 4.3a.

The A-C voltage applied to the electrodes was $20\mathrm{V}_{\mathrm{p\text{-}p}}$ with frequency of 10MHz. The on/off frequency was f_{ladder}=125Hz. The channel mean velocity was u_{m}=12.5mm/s. The initial values of the relative positions of the particles at t=0s were $x_{\mathrm{p},0}$=0 and 20μm, respectively.

EXPERIMENTAL

The microchannel is made of two glass substrates, which Pt electrodes are sputtered, with SU-8 (Microchem) patterned with the microchannel. Flow rate and the u_{m} were 6.4μL/min and 11.6mm/s,

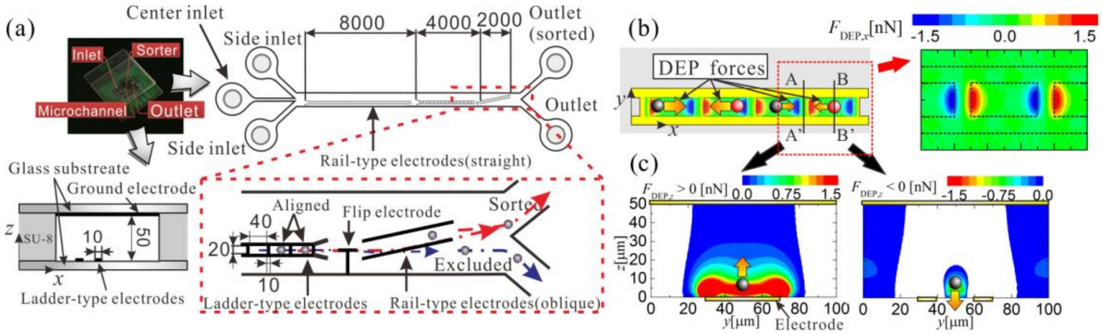

Figure 1: Schematics of (a) the microchannel, (b) $F_{\mathrm{DEP},\,x}$ on the x-y plane at z=6µm and (c) $F_{\mathrm{DEP},\,z}$>0 on the y-z plane (A-A' plane of (b)) and $F_{\mathrm{DEP},\,z}$<0 on the y-z plane (B-B' plane of (b)).

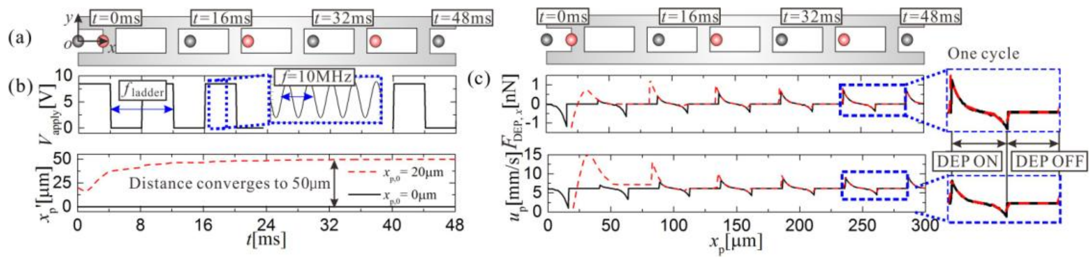

Figure 2: (a) The schematic of time series variation of particles' positions, (b) the relative positions of the particles initially located at $x_{p,0}$=0 and 20µm at t=0s and the applied low frequency oscillation, and (c) the F_{DEP} applied to the particles in these two cases and their streamwise velocities.

respectively. The 12µm polystyrene particles (Thermo fisher scientific, 4212A) suspended in PBS (phosphate buffered saline) solution was supplied by the center flow of the sheath flow.

High-speed camera was used to record the image and measure the particle motions. The particle velocities and positions were analyzed using the motion analysis software (Library, Move-tr/2D ver7.90).

RESULTS AND DISCUSSION

Figure 2(b) shows the time series variation of the relative positions of particles, $x'_{\mathrm{p}}(t)= x_{\mathrm{p}}(t) - x_{\mathrm{p,r}}(t)$, where $x_{\mathrm{p,r}}(t)$ is of the particle whose initial position is $x_{\mathrm{p}}(t)$=0µm. $x_{\mathrm{p}}(t)$=0µm is the center of the pitch of the ladder-type electrodes (see Fig 2(a)). $x_{\mathrm{p,r}}(t)$ also presents the periodical trajectory of the particle after converging to a certain value by the F_{DEP}. Figure 2(c) shows the $F_{\mathrm{DEP},x}$ and the particle streamwise velocities u_{p}. The F_{DEP} moves the particle to the relative positon where the positive and negative F_{DEP} balances during one periodical period.

Figure 3 shows the snapshots of the particles flowing in the microchannel. The particles are located at the same position relative to the ladder. They are spaced at multiples of t_{s}, which is the distance of the particle converted to time. The distance between particles will converge to the ladder pitch 50µm. And the t_{s} becomes 8ms=1/f_{ladder}.

Figure 4 shows the probability density distribution (PDD) of δ in the cases of the inlet and outlet of the ladder-type electrodes. δ is the deviation from the synchronized timing. At the inlet, the distribution is dispersed showing that the particle enters the region with random positions. At the outlet, however, a peak is observed around δ=0 with the deviation less than ±5% indicating that the particles are aligned in the position synchronized with f_{ladder}.

Figure 5 shows the PDD of the particle spanwise positions, y_{p}, measured at the outlets of the ladder-type electrodes and the sorting region. The flip (gate) electrode is turned on and off at the same timing with the ladder-type electrodes. In Fig. (a), y_{p} measured at the outlet of the sorting region varies since the period when the flip electrode is turned on does not match with the one when the particles passes the flip electrode.

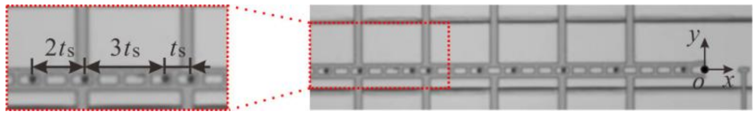

Figure 3: Snapshots of the particles aligned equally spaced as they flow along the ladder-type electrodes.

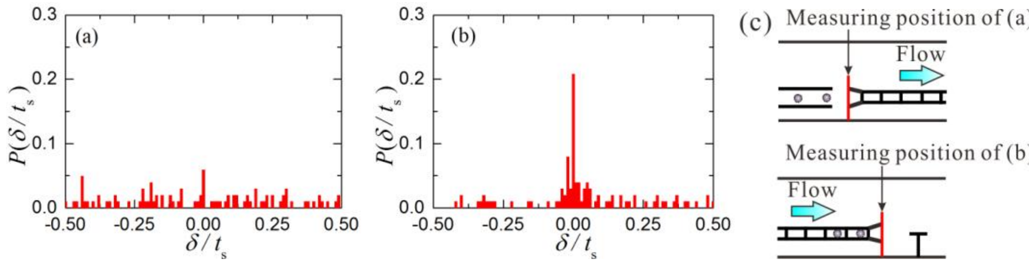

Figure 4: Probability density distributions of the deviation of the particles δ from the synchronized time at the (a) inlet and (b) outlet, and (c) schematics of the measuring positions.

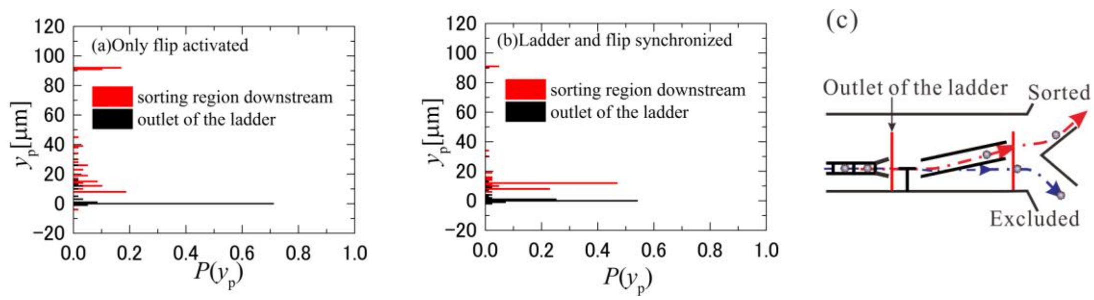

Figure 5: Probability density distributions of the particles spanwise positions y_p at the outlets of the ladder-type electrodes and the sorting region in the cases of (a) non-activated (only flip activated) and (b) activated (ladder and flip synchronized). (c) shows the measuring points of these two locations.

On the other hand, in the activated case, the flip-type electrode is activated at an appropriate timing and the particle is successfully moved upward not to be trapped by the oblique-rail-type electrodes. The y_p at the outlets of the sorting region shows a peak in this case, and particle sorting of 125Hz is achieved.

CONCLUSION

It has been confirmed numerically and experimentally that the positions and interval of particles can be controlled by using the ladder-type electrode. In combination with the flip-type electrode, the possibility of reaching the sorting rate higher than 125Hz was shown.

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REFERENCES

[1] Z. R. Gagnon, "Cellular Dielectrophoresis: Applications to the Characterization, Manipulation, Separation and Patterning of Cells," Electrophoresis, 32, 2466-2487, 2011.

[2] K.Tatsumi, H. Shintani, Y. Katsumoto, and K. Nakabe, "Dielectrophoretic Sorting of Microparticles and Lymphocytes Using Rail-Type Electrodes," micro-TAS2013, 2013.

[3] A. J. Goldman, R. G. Cox, and H. Brenner, "Slow viscous motion of a sphere parallel to a plane wall," Chemical Engineering Science, 22, 637-660, 1967

[4] T. B. Jones, "Electromechanics of particles," Cambridge University Press, 1995.

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