DIELECTROPHORETIC SORTING OF MICROPARTICLES AND LYMPHOCYTES USING RAIL-TYPE ELECTRODES

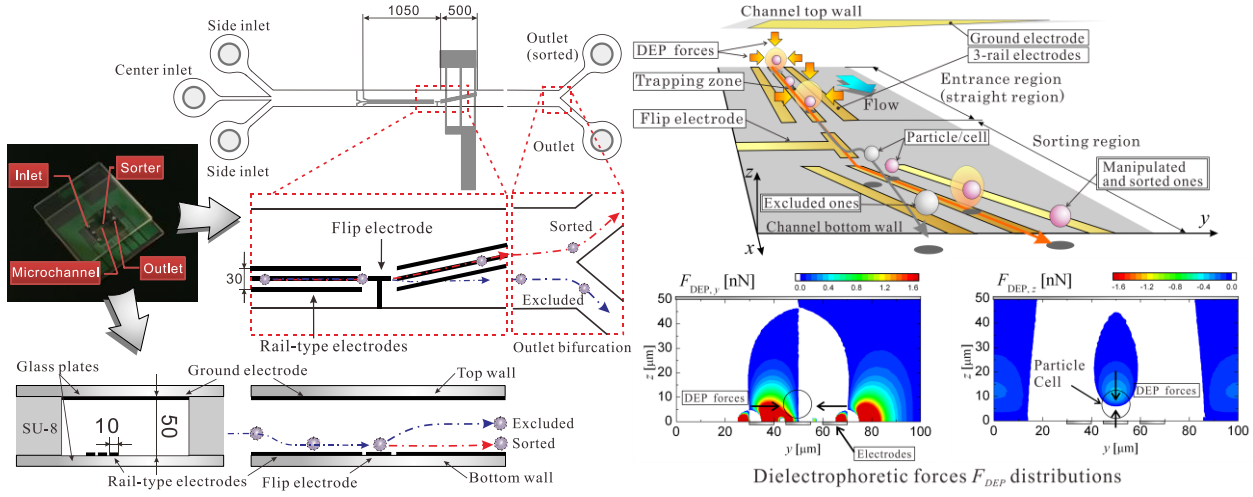
K. Tatsumi[1*], H. Shintani[1], Y. Katsumoto[2] and K. Nakabe[1]
[1] *Kyoto University, JAPAN and*
[2] *Sony Corporation, JAPAN*

ABSTRACT
A particle manipulation device using the dielectrophoretic (DEP) force is described in this study. The electrode pattern developed in this study (referred to as "rail-type electrodes") can generate a DEP force distribution that captures the particles, the DEP force of which is "negative" (repulsion force), in the specific area located at the centerline of the electrodes with some distance to the channel bottom wall. The particles can be guided accurately along the electrode, and in combination with the "flip-type electrode" the manipulation direction can be controlled, providing a possibility of particle sorting with high accuracy, reliability and response.

KEYWORDS: Microchannel, Dielectrophoretic force, Micro-particle, Manipulation, Sorting

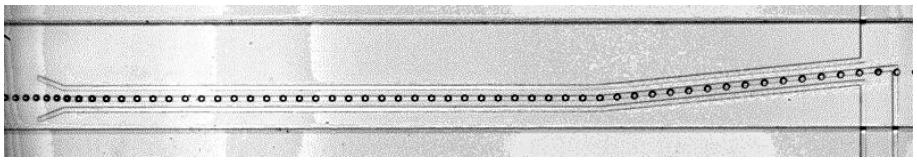
INTRODUCTION
The technologies for manipulating and sorting cells and particles in the microchannel flow by applying optical, fluid dynamic, magnetic, and electric forces have been studied intensively in the last decade [1]. In particular, the DEP force is powerful because it can produce a driving force to the particles without changing or modifying them or the fluid properties. Although many types of electrodes and channels have been proposed in other studies [2, 3], substantial issues remain to be solved for satisfying the demands of the applications, such as accuracy, response, sorting rate, and applicability under various conditions. One such problem is because the DEP force, F_{DEP}, is mainly produced by the electric field gradient, it decays markedly with the distance from the electrode. Another problem is the fact that in many cases, a negative F_{DEP}, namely a repulsion force against the electrode works on the particles and cells; therefore, it is difficult to precisely control the particle position. In order to overcome both these problems, an electrode pattern, which is not only novel and effective but also fundamental and versatile, is developed in this study; we refer to these electrodes as "rail-type electrodes." By using the rail-type electrodes, particles can be guided along the electrode in the streamwise and spanwise directions of the channel accurately. When the flip-type electrode, which is another electrode presented in this study, is combined with the rail-type electrodes, then the direction in which the particle should be guided can be selected.

THEORY
Figure 1 (a) shows the schematic of the microchannel, and the rail-type and flip-type electrodes. The top figure in Fig. 1 (b) shows the schematic of the device trapping and sorting the particles using these two electrodes. The bottom figure depicts the distributions at the streamwise cross-sectional plate (y–z plane) of the F_{DEP} working on a polystyrene particle obtained by the numerical simulation [4]. The left figure shows the y component of the F_{DEP}, and the right one shows the z component.

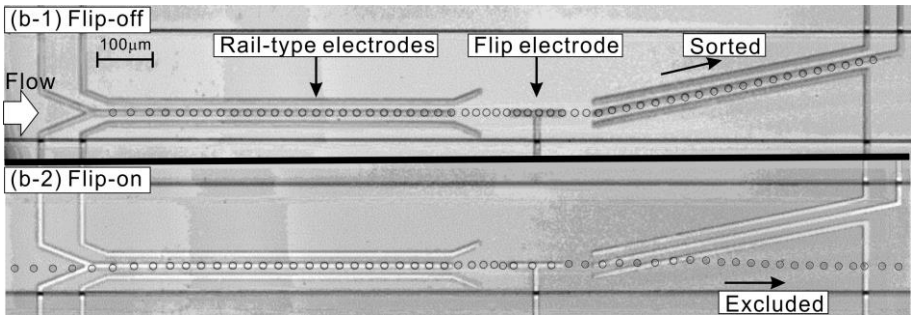


(a) Microchannel and electrodes *(b) Physics of the sorting technology*

Figure 1: (a) Schematic of the electrodes and microchannel, (b) The schematic of the physics of the sorting technology using the rail-type and flip-type electrodes, and the y and z components of dielectrophoretic forces F_{DEP} .

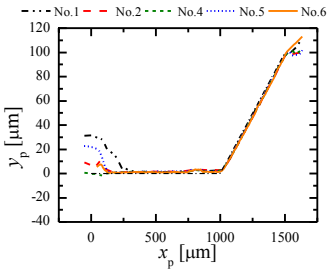


(a) Particle guided by the rail-type electrodes

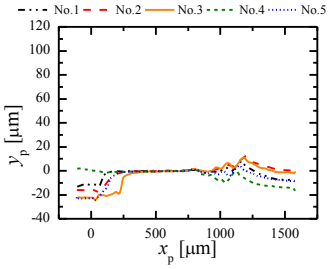


(b) Lymphocyte manipulated and sorted by the rail-type and flip-type electrodes (the cases of flip-type electrodes "off" and "on").

Figure 2. Snapshots of, (a) PS particle trapped and guided by the rail-type electrodes, (b) lymphocytes trapped, guided, and sorted by the rail-type and flip-type electrodes (turning the flip electrode "on" and "off").



(a) lymphocytes (flip-off)



(b) lymphocytes (flip-on)

Figure 3. Position distributions in the lymphocyte case.

The rail-type electrodes consist of three parallel electrodes attached to the bottom wall, and a plane electrode covering the top wall which is connected to the electric ground. As shown in the F_{DEP} distributions in Fig. 1(b), the rail-type electrodes generate negative F_{DEP} in the z direction at the centerline of the electrodes, and a positive value in adjacent to the channel bottom wall. In the y direction, a symmetric distribution is generated for F_{DEP}. These distributions produce a pocket area trapping the particles at the centerline of the electrodes and adjacent but with a certain distance to the bottom wall. The height position of the particles can be controlled by changing the voltage applied to the center electrode. Thus, the particles or cells will not contact or adhesive to the wall, which makes it easier to manipulate the particle smoothly. The particles flowing from the upstream region are trapped in this region, and then guided along the rail-type electrodes. If the electrodes are inclined to one side against the main flow (oblique region), the particles can be guided in the spanwise direction.

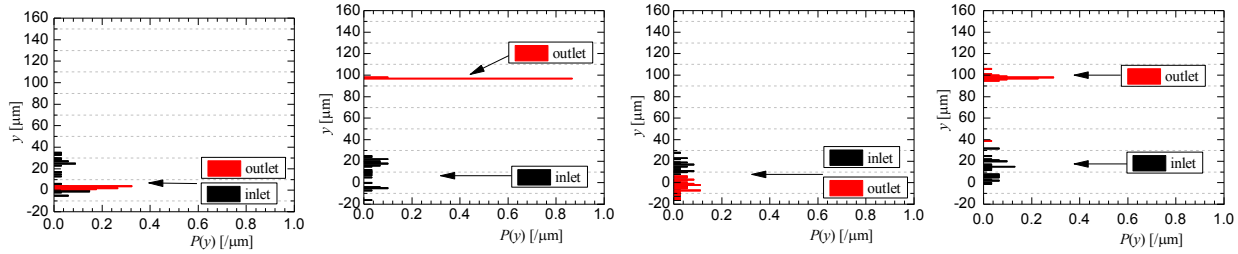
The flip-type electrode is located right upstream of the oblique electrodes. Above this electrode, a strong positive F_{DEP} in the z direction will be generated. If the voltage at the flip-type electrode is turned "off" when the particle passes the flip-type electrode, then the particles will flow along the oblique rail-type electrodes. When the flip-type electrode is turned "on", then the particles are pushed and excluded from the rail-type electrode region and flow downstream.

EXPERIMENTAL

As shown in Fig. 1(a), the device has three flow inlets by which a sheath flow is generated and the spanwise position of the particle entering the electrode area is precisely controlled. In the downstream region of the manipulation (electrode) area, the channel is bifurcated where the particles are normally guided to one side excluded from the rail-type electrodes by the flip-type electrode. The specific particles are guided along the oblique region of the rail-type electrodes by turning the DEP force at the flip-type electrodes "off", and is excluded by turning it "on". The electrodes sputtered and patterned on the bottom glass plate of the channel was made of platinum, and the top ground electrode was made of indium tin oxide (ITO). These two plates were bonded by SU-8, on which the channel was etched and patterned. The channel height and width were 50μm and 200μm, respectively. The motion of the particles was measured using a microscope and high-speed digital video camera. The particle positions and velocities were measured from the recorded images. Experiment was carried out for polystyrene microparticles (Thermofisher scientific; 4212A) with nominal diameter of 12μm, and lymphocytes (ATCC; CRL-2570) suspended in PBS solution. In the case of lymphocytes, the channel was filled and coated by the bovine serum albumin in advance of the experiment. AC voltage of $V_{p\text{-}p}$=18V and 10MHz was applied to the two side electrodes of the rail-type electrodes, and 8.0V was supplied to the center one. The total flow rates in the main channel in the cases of PS particles and lymphocytes were 2.2μL/min and 0.6 μL/min, respectively. The mean flow velocities in these cases are 3.7mm/s and 1.0mm/s.

RESULTS AND DISCUSSION

Figure 2 shows the photographs depicting the trajectories of the particles and lymphocytes. Figure 3 shows the quantitative values of the positions of several samples of lymphocytes in the cases when the flip-type electrode is turned "off" and "on".



(a)PS particle flip-on *(b) PS particle flip-off* *(c) lymphocyte flip-on* *(d) lymphocyte flip-off*

Figure 4. Probability density functions of the particle and cell positions at the inlet and outlet of the electrode region in the cases of the flip-type electrodes turned "on" and "off".

Fig. 2 (a) shows how the particles are guided along the electrode when the rail-type electrode only are used in the microchannel. One can see that the particle is trapped and guided precisely along the centerline. In Figures 2(b-1) and 3(a), which show the results when the flip-type electrode is "off", the lymphocytes are first trapped and guided along the rail-type electrode, pass the flip-type electrode, and then are guided along the oblique part. The position distributions show that the lymphocytes approaching the electrode region from various spanwise positions are all trapped and guided along the electrode at an identical position. In the case when the flip-type electrode is "on", then the lymphocytes are pushed upwards and are excluded from the rail-type electrodes as shown in Fig. 2(b-2). In Fig. 3(b), the lymphocytes are all excluded, and are not captured by the oblique rail-type electrodes and flow downstream of the straight region of the rail-type electrode. In this case, there is some dispersion in the position after the lymphocytes are excluded. This is due to the fact that the cell size and shape are not completely identical and the difference of these factors influences the amplitude and direction of the F_{DEP} working on the lymphocytes at the flip-type electrode.

Finally, Fig. 4 shows the probability density functions of the positions of the particles and lymphocytes. The black bars show the distribution at the inlet region of the straight rail-type electrodes. The red bars show the distribution at the outlet, which is the downstream of the electrode region (the region where the oblique part ends). In the figures, a dispersion is observed in the distribution for both spanwise positions of the particles and lymphocytes at the inlet. At the outlet, when the flip-type electrode is turned "on" (Figures (a) and (c)), the particles and lymphocytes are excluded from the electrodes and flow downstream indicted by the results that the spanwise positions do not differ much from the inlet. However, when the flip-type electrode is turned "off" the particle positions move in the spanwise direction by approximately 100μm at the outlet of the sorting region. Further, the dispersion is small owing to the trapping effect of the rail-type electrodes. These results confirm that, the particles and cells can be guided and sorted accurately in the spanwise direction of the channel by using the rail-type and flip-type electrodes.

CONCLUSION

Rail-type and flip-type electrodes were proposed and the performances were evaluated experimentally using polystyrene particles and lymphocytes. The results showed that the rail-type electrodes can trap the particles flowing from the upstream of the electrode region in spite of their inlet positions. They can, then, be guided along the centerline of the electrode in the streamwise and spanwise direction accurately. When the flip-type electrode was turned on, the particles were pushed away from the electrode region. The probability density function of the particle position at the outlet region of the electrodes showed that the spanwise position of the particles can be precisely controlled and selected by using these electrodes.

ACKNOWLEDGEMENTS

This work is supported by Japan Agency of Science and Technology (Development of Systems and Technology for Advanced Measurement and Analysis).

REFERENCES

[1] P. Chen, X. Feng, W. Du, and B.-F.. Liu, "Microfluidic Chips for Cell Sorting", *Frontiers in Bioscience*, Vol. 13, pp. 2464, (2008).

[2] P. R. C. Gascoyne and J. Vykoukal, "Particle Separation by Dielectrophoresis", *Electrophoresis*, Vol. 23, pp. 1973, (2002).

[3] Z. R. Gagnon, "Cellular Dielectrophoresis: Applications to the Characterization, Manipulation, Separation and Patterning of Cells", *Electrophoresis*, Vol. 32, pp. 2466, (2011).

[4] K. Tatsumi, K. Imajou, H. Shintani, Y. Katsumoto, and K. Nakabe, "Numerical Model for Microparticle and Lymphocyte Motions in Dielectrophoretic Manipulation Device", micro-TAS2011, pp. 2466, (2011).

CONTACT

*K. Tatsumi, tel: +81-75-3833606; tatsumi@me.kyoto-u.ac.jp