Spring 2013

Reservoir-Based Dielectrophoresis (rDEP) for concentration and separation of cells/particles.

Saurin H. Patel

Reservoir-Based Dielectrophoresis (rDEP) for concentration and separation of cells/particles

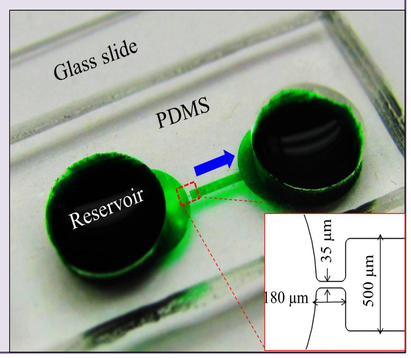
Saurin Patel, Dr. Xiangchun Xuan
Department of Mechanical Engineering, Clemson University, Clemson, South Carolina

1. Motivation

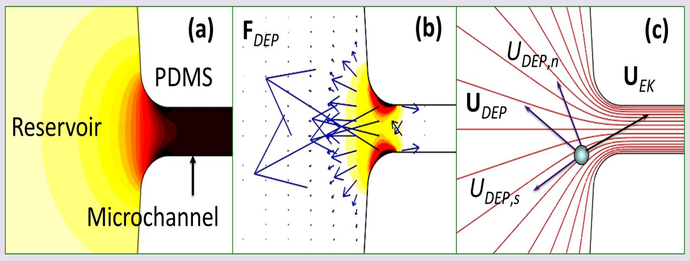
- The fundamental understanding of cell and particle electrokinetics in microchannel is critical to the design and electrical control of microfluidic devices.
- The approach exploits the cell and particle dielectrophoresis that is induced by the electric field gradient inherent at the reservoir-microchannel junction to selectively trap cells/particels and continuously separate them inside the reservoir. This approach is therefore termed reservoir-based dielectrophoresis (rDEP).
- rDEP has unique advantages over existing dielectrophoretic approaches such as the occupation of zero channel space and the elimination of any mechanical or electrical parts inside microchannels. Such an rDEP cell sorter can be readily integrated with other components into lab-on-a-chip devices for applications to biomedical diagnostics and therapeutics

2. Microfluidic Device

The PDMS-glass microfluidic device used in the experiment is illustrated in the image. The microchannel was fabricated using the standard soft lithography technique. The inset displays the dimensions of the reservoir-microchannel junction. The block arrow indicates the direction of cellular motion in the experiment.



3. Cell/Particle Velocity



(a) Contours (the darker the larger) of electric field magnitude.
(b) Contours and directions of the induced dielectrophoretic force, $\mathbf{F}_{DEP}$
(c) Cell/particle velocity analysis.

$$\mathbf{U}_{\cdot} = \mathbf{U}_{EK} + \mathbf{U}_{DEP} = \mu_{EK}\mathbf{E}_{DC} + \mu_{DEP}(1+\alpha^2)(\mathbf{E}\bullet\nabla\mathbf{E})$$

Charge: $\mu_{EK} = f_g\varepsilon_f(\zeta_p - \zeta_w)/\mu_f$

Size: $\mu_{DEP} = \varepsilon_f a^2 f_{CM}/6\mu_f$

$\alpha = E_{AC}/E_{DC}$

Viability: $f_{CM} = \dfrac{\varepsilon_c^* - \varepsilon_f^*}{\varepsilon_c^* + 2\varepsilon_f^*}$

In the above equations , μ_{EK} and μ_{DEP} are the electrokinetic and dieletrophoretic mobility, E is the RMS value of electric field, a is the cell/particle radius, ε_f^* and ε_c^* are the complex permittivity of the suspending fluid and cell respectively and η_f is the fluid dynamic viscosity.

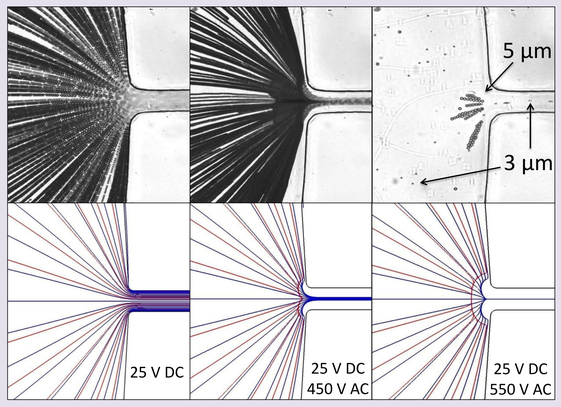
4. Numerical Modeling

The numerical modeling of electrokinetic cell motion was performed using the Lagrangian tracking method in COMSOL 3.5a using a 2D model. The model neglects the perturbations on the fluid flow field and electric field caused by the presence of the cells. A correction factor , λ_c,is used to account for the effect of cell size on the dielectrophoretic cell velocity.

$$U_c = \mu_{EK}E_{DC} + \lambda_c\mu_{DEP\_DC}\left(1 + \frac{\mu_{DEP\_AC}}{\mu_{DEP\_DC}}\alpha^2\right)\nabla E_{DC}^2$$

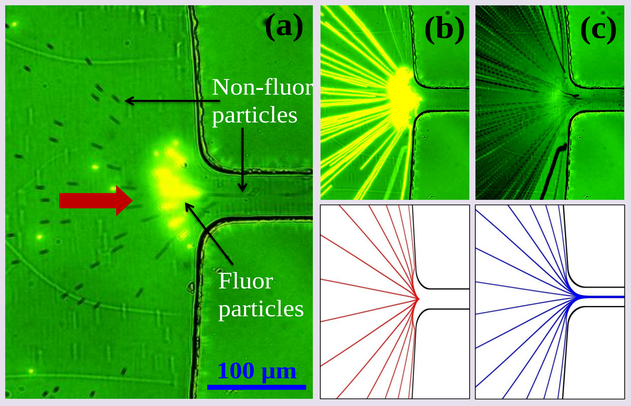
The DC electric field distribution, $E_{DC} = -\nabla\phi_{DC}$, was obtained by solving the Laplace equation $\nabla^2\phi_{DC} = 0$, where the DC electric potential difference, $\Delta\phi_{DC}$ was experimentally applied.

5. Size Based Separation



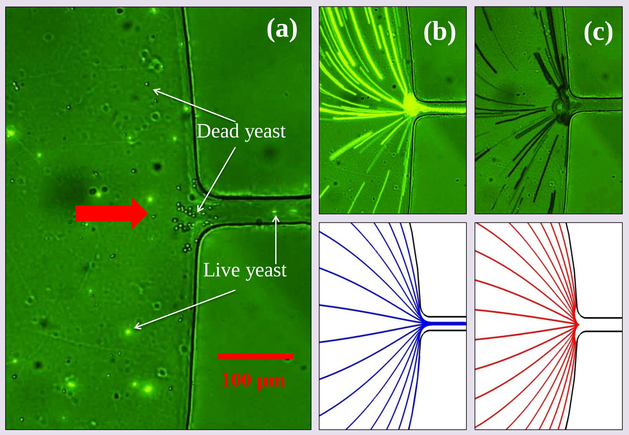
Comparison of experimentally obtained images(top row) and numerically predicted trajectories (bottom row) of 5 and 3 µm particles at the reservoir microchannel junction under various DC-biased AC electric field.

6. Charge Based Separation



Demonstration of surface charge based separation of 3 µm fluorescent and 3 µm non-fluorescent particles at the reservoir-microchannel junction by rDEP. (a) is the snapshot image of particle behavior at 50 V DC-biased 800 V ac voltage. The images (b) and (c) are comparison of experimentally obtained images (top row) and numerically predicted trajectories (bottom row).

7. Viability Based Separation



Demonstration of selective concentration and continuous separation of live and dead yeast cells at the reservoir-microchannel junction by rDEP. (a) is the snapshot image, (b) and (c) compare the experimentally obtained superimposed images (top row) of live (b) and dead (c) yeast cells with the numerically predicted trajectories (bottom row). The cell separation was driven by a 4 V dc-biased 47.5 V ac electric field at 1 kHz. The block arrow in (a) indicates the cell moving direction.

8. Conclusion

- We have developed a new method for continuous microfluidic separation of cells and particles using reservoir-based dielectrophoresis (rDEP) that exploits negative dielectrophoresis induced at the reservoir-microchannel junction.
- As seen from section 3, the streaming or trapping of a particle is determined by its electrokinetic to dielectrophoretic mobility ratio, which is a function of intrinsic cell/particle properties.
- The dependence has been utilized to implement the selective concentration and continuous sorting of 5 µm and 3 µm polystyrene particles by size [section 5], 3 µm fluorescent and 3 µm non-fluorescent polystyrene particles by surface charge [section 6] and live and dead yeast cells by viability [section 7].
- Since the demonstrated cell and particle separation takes place inside the reservoir, the entire microchannel can be spared for post-analysis, which makes the developed rDEP cell sorter perfectly positioned for lab-on-a-chip devices towards numerous biomedical applications.

9. Future work

The accumulation of cells and particles at the reservoir-microchannel junction affects the streaming species as well. The trapped cells and particles starts interacting and thus reducing the separation efficiency. The inter cellular and particle interaction needs to be studies in further details to increase the efficiency of separation. The effects of Joule heating at the reservoir microchannel junction on cell/particle focusing and trapping also needs to be studies

10. Acknowledgement

This work is supported, in part, by NSF (Xuan), Clemson University Research Grant (Xuan and Tzeng), Department of Mechanical engineering, Clemson University, and by the World Class Univesity Grant of the Ministry of Education, Science and Technology of Korea (Qian).

REFERENCES

(1) N. Pamme, Lab Chip 7, 1644-1659 (2007), (2) M. Urdaneta and E. Smela, Electrophoresis 28, 3145-3155 (2007), (3) Y. Huang, R. Holzel, R. Pethig, and X. Wang, Phys. Med,. Biol. 37, 1499-1517 (1992), (4) J. Zhu, G. Hu, and X. Xuan, Electrophoresis 33, 916-922 (2012) and (5) J.Zhu and X.Xuan, Electrophoresis 30, 2668-2675 (2009).