

A Structure to Reduce Voltage in Microparticles Separation by using Dielectrophoresis Mechanism

Ali Taghadosi Aghamahli¹, Bahram Azizollah Ganji²

1- Department of Electrical & Computer Engineering, Babol noshirvani University of Technology, Babol, Iran
Email: taghadosalii@Gmail.com

2- Department of Electrical & Computer Engineering, Babol noshirvani University of Technology, Babol, Iran
Email: baganji@nit.ac.ir (Corresponding author)

Received: January 2017

Revised: January 2017

Accepted: January 2017

ABSTRACT:

This paper presents a new structure in order to reduce voltage in dielectrophoresis (DEP). DEP is one of the most popular techniques to separate microparticles which needs an electric field in microfluidic devices. In this design we bend the microchannel (L-shaped) to reduce applying voltage. Also we change the outlet channel size which effectively reduces voltage. In the old design, we needed 2.5 V to separate 3.5 μm and 4 μm in diameter particles. In the new design, we keep constant all the effective parameters and bend the middle of the measuring microchannel and change the outlet microchannel size from 40 μm to 50 μm . We need 1.45 V to separate microparticles in the new conditions.

KEYWORDS: Dielectrophoresis, Microparticle, Microfluidic

1. INTRODUCTION

Dielectrophoresis was first reported by Debye et al in 1954 [1] and further developed by Pohl in the 1970s [2]. DEP is one of the most popular methods for particle manipulation in microsystems due to (i) its label-free nature, (ii) its favorable scaling effects, (iii) the simplicity of the instrumentation and (iv) its ability to induce both negative and positive forces [3]. Generally, in an AC-DEP, an array of metal electrodes are embedded inside a microdevice to generate a spatially nonuniform electric field [4]. Lewpiriyawong et al. proposed the use of conductive PDMS as 3-D sidewall electrodes, and utilized AC-DEP for the continuous separation of 10 and 15 μm polystyrene particles. Iliescu et al. proposed to use of highly doped silicon as an electrode and fabricate a 3-D electrodes, and managed to separate viable and non-viable yeast cells [3]. The electrodes placement presents some important disadvantages such as Joule heating and electrolysis of the suspending medium which can alter the trajectory of the particles and greatly hinder the separation [5]. Furthermore, even slightly increasing the temperature ($\Delta T \approx 4^\circ\text{C}$ above physiological cell temperature) inside the channel may lead to cell death for in vivo mammalian cell experiments [3].

In this work, we propose the new design to reduce applying voltage by bending the measuring microchannel and changing one of the outlet channel

size. Reducing voltage causes to produce less Joule heating which increases the device functionality.

1.1. Dielectrophoresis Theory:

Particles suspended in a medium between two electrodes under tension are polarized by the ensuing electric field [6]. DEP refers to the motion of a polarizable particle (or a cell) in a medium under non-uniform electric field due to polarization effects [7]. Charges inside the particles accumulate near the particle-medium interfaces and attract charges inside the medium. Charges also accumulate at the interfaces on the medium side. These accumulations of electric charges form what are called electric double layers. The polarizabilities of both medium and particles determine the relative quantity of charges inside and outside the particles. As negative and positive charges attract, and effectively cancel each other, electric dipoles are created. These relative differences determine the orientation of the dipoles. A net dipole inside an electric field is subjected to forces resulting from the attraction of opposite charges and the repulsion of identical charges. In the case of a symmetrical electric field generated by electrodes of identical sizes and shapes, for example, the forces cancel each other and no resulting force occurs. If the electric field is homogeneous, when electrodes of different sizes are used for example, a resulting force is

applied on each particle. This force can be expressed by:

$$\vec{F}_{DEP} = 2\pi\epsilon_m R^3 f_{CM} \nabla |\vec{E}|^2 \quad (1)$$

Where ϵ_m is the permittivity of the medium, R is the radius of the particle, f_{CM} is the Clausius-Mossotti factor and \vec{E} is the electric field [5].

The f_{CM} , which describes the relative polarization of a particle with respect to the surrounding medium, is a geometry- and frequency-dependent variable that for spherical particles is defined as below:

$$f_{CM}(\epsilon_p^*, \epsilon_m^*) = \frac{\epsilon_p^* - \epsilon_m^*}{\epsilon_p^* + 2\epsilon_m^*} \quad (2)$$

Where $\epsilon^* = \epsilon_0 \epsilon_r - j(\frac{\sigma}{\omega})$ is the complex permittivity and subscripts ‘‘p’’ and ‘‘m’’ stand for the particle and the medium, in which σ is the electric conductivity, and ω is the angular frequency of the applied electric field [8].

This factor, which varies from -0.5 to 1 , determines if the particles are attracted or repulsed by regions of high electric field intensity [9].

The translational motion of a particle is governed by:

$$m_p \frac{d\vec{u}_p}{dt} = \vec{F}_{ext} \quad (3)$$

where m_p is the particle mass, \vec{u}_p is the particle velocity and \vec{F}_{ext} is the net external force.

$$\vec{F}_{ext} = \vec{F}_{drag} + \vec{F}_{DEP} \quad (4)$$

The drag force on a spherical particle which is proportional to the relative velocity between the particles and the fluid is given by:

$$\vec{F}_{drag} = 6\pi\eta R(\vec{u} - \vec{u}_p) \quad (5)$$

At the creeping-flow limit, which is known as Stoke’s law [10], where R is the particle radius, η is the fluid viscosity and \vec{u} is the fluid velocity.

The DEP force acting on a spherical particle is given by (1). It can be assumed that the particles move with the terminal speed at all times. Therefore, the acceleration term can be safely neglected. Substituting (1) and (5) into (4), the particle velocity can be obtained as:

$$\vec{u}_p = \vec{u} - \frac{\epsilon_m R^2 Re[f_{CM}]}{3\eta} \nabla |\vec{E}|^2 \quad (6)$$

The trajectories of the particles can easily be obtained as a streamline plot [3].

1.2. Electric field and velocity field distributions:

In order to find the electric field, Maxwell equations are solved with the following boundary conditions: insulated in the walls, applying voltage in the electrodes. In order to find velocity field, Continuity (7) and Navier-Stocks (8) equations are solved with the following boundary conditions: no-slip at the microchannel wall, specific flow rate in the microchannel inlets and zero pressure in the microchannel outlets.

$$\nabla \cdot \vec{u} = 0 \quad (7)$$

$$\rho \frac{\partial \vec{u}}{\partial t} + \rho \vec{u} \cdot \nabla \vec{u} = -\nabla P + \eta \nabla^2 \vec{u} \quad (8)$$

Where \vec{u} , ρ , η and P denote fluid velocity, density, viscosity and pressure respectively.

1.3. Particle trajectory:

The balance between fluid drag force and the DEP force is critical. Particles flow through the channel by drag force and repel by negative DEP force. So trajectory of the particles are deflected by negative DEP force. DEP force depends on particle volume so we can separate particles with different sizes with proper DEP force at the end of microchannel according to fig. 1.

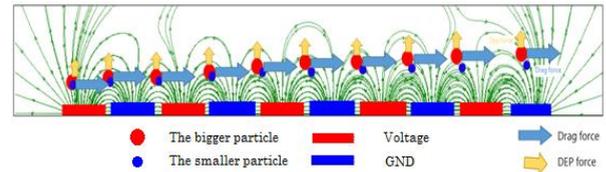


Fig. 1. Drag and DEP forces in a micro channel

2. MICRO CHANNEL GEOMETRICAL STRUCTURE

Fig. 2 shows the schematic of the microchannel geometry. The width of all microchannels is 40 μm , microelectrodes width is 40 μm and distance between them is 10 μm . The frequency of AC voltage is 100 kHz. The velocity of the inlets is 850 $\mu\text{m/s}$ and 150 $\mu\text{m/s}$. Outlets have no pressure.

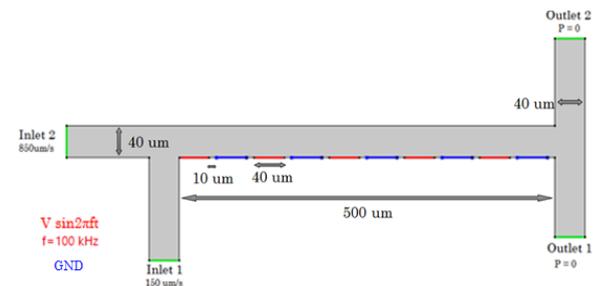


Fig. 2. Specification of the old design

Fig. 3 shows the new design. We changed the second outlet microchannel's size from 40 μm to 50 μm and bent the measuring microchannel (L-shaped).

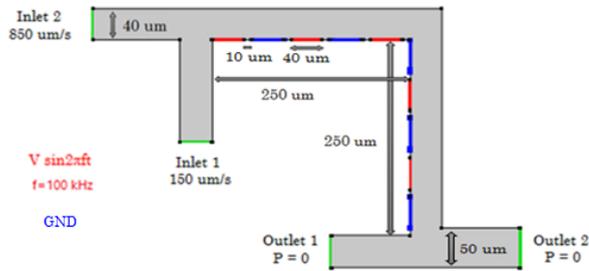


Fig. 3. Specification of the new design

3. RESULTS AND DISCUSSION

The simulations of these two designs were carried out by using COMSOL multiphysics software. Velocity field is shown in fig. 4 by solving (7) and (8). Electric potential distribution is shown in fig. 5. in the old design. The magnitude of outlets' velocity are the same and symmetric.

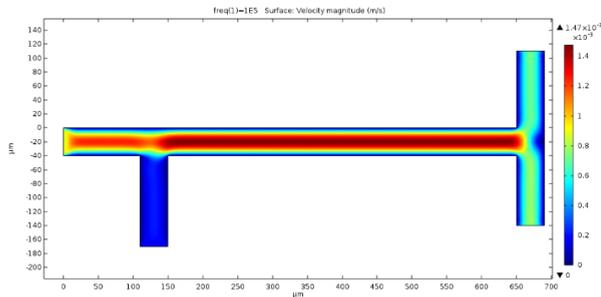


Fig. 4. Velocity field distribution in the old design

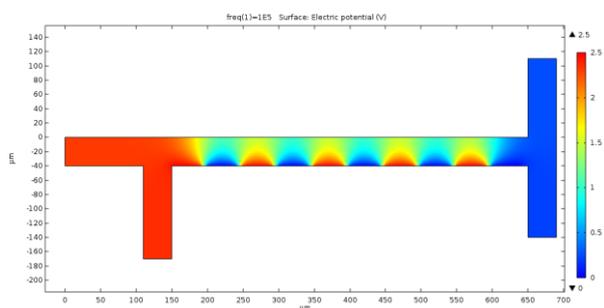


Fig. 5. Spatial variation of the electric potential in the microfluidic channel in the old design

Simulator (COMSOL) uses velocity and electric potential distribution to determine the trajectory of the particles. Fig. 6 shows the particle trajectories in the absence of the dielectrophoretic force (without applying voltage). All of the particles follow the same path and exit through the first outlet. Fig. 7 shows the particle trajectories when the particles are subjected to the dielectrophoretic force (applying voltage). Due to

differences in the particle volumes, they exit through different outlets.

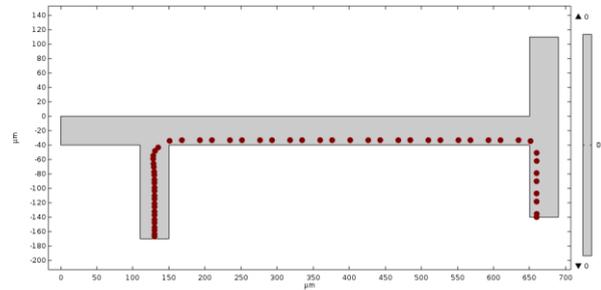


Fig. 6. Particle trajectories without applying voltage in the old design

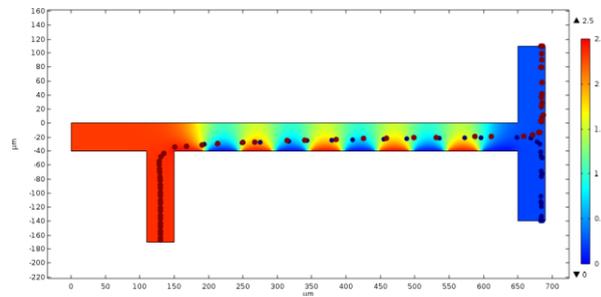


Fig. 7. Particle trajectories with applying voltage in the old design

Fig. 8 shows velocity field in the new design. The magnitude of velocity in outlet 2 is more than outlet 1 because of bending the microchannel and changing the second outlet size.

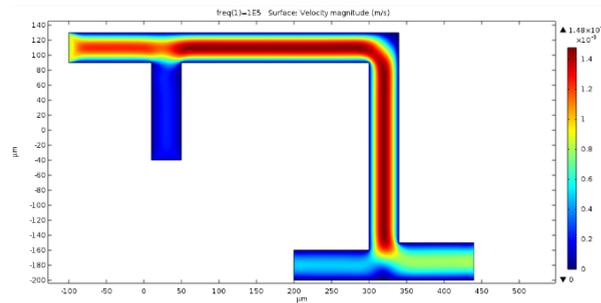


Fig. 8. Velocity field distribution in the new design

Fig. 9 shows particle trajectories in the absence of the dielectrophoretic force (without applying voltage). All of the particles follow the same path and exit through outlet 1.

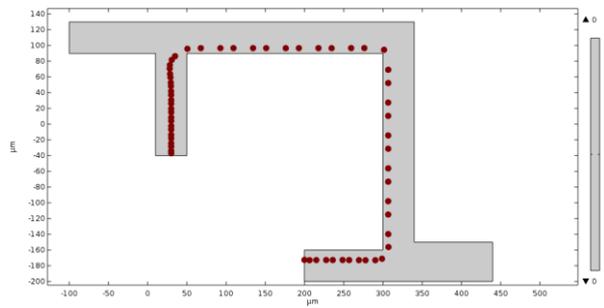


Fig. 9. Particle trajectories without applying voltage in the new design

Fig. 10 shows the particle trajectories when the particles are subjected to the dielectrophoretic force (applying voltage). Due to differences in particle volumes, they exit through different outlets.

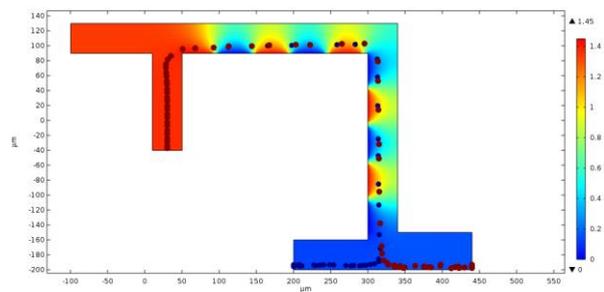


Fig. 10. Particle trajectories with applying voltage in the new design

Velocity field in the outlets is symmetric in the old design so particles go to the middle of microchannel by drag and DEP forces. Particles are separated in this condition. But velocity field in the outlets is asymmetric so particles need smaller DEP force to be separated in the new design. The magnitude of resultant force acting on particles into outlet 2 is more than outlet 1 in the new design according to fig. 11. So particles need lower voltage in the new design than in the old one to separate particles.

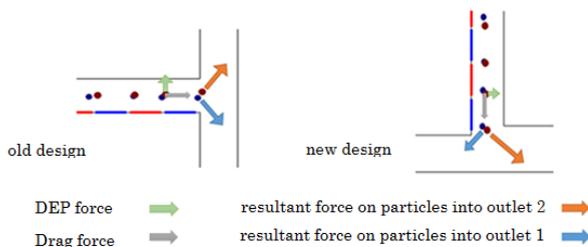


Fig. 11. Comparison of two designs

4. CONCLUSION

In this paper, the new structure is proposed to reduce applying voltage to separate different size of particles in dielectrophoresis mechanism. Using drag force can be an effective way to reduce voltage. The old design needed 2.5 V to separate 3.5 μm and 4 μm in diameter particles but the new one needs 1.45 V to separate these particles. So we can reduce 42 percent of needed voltage. It causes to produce less Joule heating. Joule heating may cause negative effects like electrothermal force, bubble generation and bioparticles damage, which lowers device functionality and performance.

REFERENCES

- [1] P. Debye, E.B.H., W.A. Barber, G.J. Arquette, "Experiments on polymer solution in inhomogeneous electrical fields," J. Chem. Phys., 22, 1954, pp. 152-153.
- [2] C. Iliescu, G. Tresset, L. Yu, G. Xu, "3D Dielectrophoretic Chips: Trapping and Separation of Cell Populations," Romanian journal of information science and technology. Vol. 13, No. 1, pp. 49-64, 2010.
- [3] B. Cetin, D. Li, "Dielectrophoresis in microfluidics technology," Electrophoresis, Vol. 32, pp. 2410-2427, 2011.
- [4] T. Z. Jubery, S. K. Srivastava, P. Dutta, "Dielectrophoretic separation of bioparticles in microdevices: A review," Electrophoresis, Vol. 30, pp. 691-713, 2014.
- [5] N. Guerin, M. Levesque, D. Therriault, "Helical dielectrophoresis particle separator fabricated by conformal spindle printing," Biomedical Science and Engineering, pp. 641-650, 2014.
- [6] Kang, Y., Li, D., Kalams, S.A. and Eid, J.E., "DC-Dielectrophoretic Separation of Biological Cells by Size," Biomedical Microdevices, Vol. 10, pp. 243-249, 2008.
- [7] H.A. Pohl, "Dielectrophoresis: The Behavior of Neutral Matter in Nonuniform Electric Fields," Cambridge University Press, Cambridge. 1978.
- [8] K. Khoshmanesh, S. Nahavandi, S. Baratchi, A. Mitchell, K. Kalantarzadeh, "Dielectrophoretic platforms for bio-microfluidic systems," Biosens. Bioelectron, Vol. 26, pp. 1800-1814, 2011.
- [9] T.B. Jones, "Electromechanics of Particles," Cambridge University Press, 2005, England.
- [10] L.G. Leal, "Advanced Transport Phenomena: Fluid Mechanics and Convective Transport Processes," Artech House, New York, USA 2006, pp. 164-168.