The Experimental Studies of Bio-Particle Trapping Using Electrodeless Dielectrophoresis

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Abstract

The ability to manipulate particles, especially living cells, is fundamental needed to many biological and medical applications, including isolation and detection of sparse cancer cells, concentration of cells from dilute suspensions, separation of cells according to specific properties, and trapping and positioning of individual cells for characterization. The electrodeless dielectrophoretic (EDEP) trapping is composed of conductless tetragon structures in micro-chip. We have improved the design of EDEP geometries, correlated particle acted by DEP effects with electrical-field distributions determined through insulating microstructures produce non-uniform electric fields to drive particles in microsystems. This study is attempt to research on microfluidic trapping by using DEP force and to investigate the relation on important parameters of microchip device for our design to comprehend the factors containing the spacing between two structures, the applied voltage and flow velocity.

1. Introduction

It is important to manipulate or separate a biological small particle, such as a living cell and embryo. For the anatomical operation, it is necessary to fix the particle in solution for researching. Recently, bio-science is progressed so much with the advancement of the bio-technology. Bio-technology can be classified into gene engineering, cell engineering, and proteome engineering. In these research fields, the micro-nano manipulation, mass production, repetitive processing, high throughput, and high precision processing in the liquid are required. There are some mechanisms were used in particle manipulation, such as optical [1], magnetic [2], mechanical [3], electrical [4], etc. Dielectrophoresis (DEP) force is generated by electrode structures of appropriately designed such as the pin-plate [5], isomotive [6], polynomial [7], or castellated interdigitated forms [8]. The early studies of DEP electrode was design with thin metal wires, needles, or plates, while the modern DEP electrode employs microfabrication technology to produce microelectrode arrays capable of producing sufficiently large DEP forces to induce particle motion with small applied voltages. DEP on micro-fabricated electrodes has been proved especially suitable for its relative ease of micro-scale generation and structuring of an electric field on microchips. Moreover, integrated DEP biochips provide the advantages of flexibility, controllability, and capable of arrays pattern on a single glass slide.

Dielectrophoresis have been using as cell trapping [9], levitation [10], separation [11], and sorting [12] on an electrode array by varying electrode shape and arrangement. DEP on micro-fabricated electrodes has been proved especially suitable for its relative ease of micro-scale generation and structuring of an electric field on microchips. In this study, we use PDMS as microchannel structure for the reason of lower conductivity. The capability of trapping particles with DEP force will be studied in this article.
2. Design and theory

By properly arrange of planar electrodes design with either directly connected to a source [13] or free-floating [14] with source with AC signal. The advantages of the electrodeless DEP (EDEP) are (1) no metal deposition is needed; (2) the structure is mechanically robust and chemically inert; and (3) no gas evolution due to the electrolysis[15]. In the design shown in Fig. 1, the particles will encounter DEP force, hydrodynamic force, and gravity. The micro flow trapping design, which is showing in Fig. 2, is composed of microfluidic channel and conductless trapezoidal structure. In the model, the particles experience DEP force, hydrodynamic force, and gravity. These forces are used to determine where the particle can be trapped.

The DEP force $F_{DEP}$ acting on a spherical particle of radius $r$ suspended in a fluid of permittivity $\varepsilon_m$ is given by:

$$F_{DEP} = 2\pi \varepsilon_0 \varepsilon_m \Re[K^*(\omega)]\nabla(E^2)$$

(1)

Where $K^*(\omega) = \frac{\varepsilon_p - \varepsilon_m}{\varepsilon_p + 2\varepsilon_m}$, and $\varepsilon_p = \varepsilon - j\frac{\sigma_p}{\omega}$; $\varepsilon_m$ is the Clausius Mosotti factor. $\varepsilon_0$ is the absolutely permittivity. $\varepsilon_p$ and $\varepsilon_m$ are the relative permittivities of the particle and medium, respectively. $\sigma_p$ and $\sigma_m$ are the conductivities of the particle and medium, respectively. $\omega$ is the angular frequency of the electric field. $E$ is the magnitude of the electric field. The hydrodynamic drag force is caused by the flow of a viscous fluid around a particle, and is modeled by the Stokes’ law. The hydrodynamic lifting force [16,17] is caused by viscous flow over an object. Besides, the Navier-Stokes equations were solved herein to obtained the pressure and flow fields.

3. Chip fabrication and experiment set up

The electrodeless DEP chip is fabricated by MEMS (Micro-electromechanical Systems) technology. The chip fabrication can be divided into five procession including electrode, channel, bonding, tubing, and packing. The electrodes were deposited with chrome and aurum on the glass sequentially. Chrome was the first deposited for the purpose of enhancement. The finally deposition thickness of Chrome and Aurum are 500Å and 1000Å. SU-8 (40 um in thickness) was use as casting mold to pattern the micro-channel. The channel was structured with PDMS prepolymer. The electrode par and PDMS were bonding with oxygen plasma. The electrode pad is wiring for the purpose of electric source connection. The tubing is used as flow injection and discharging. The experiment setup consists of optical system, electrical driving single system, and fluidic system.

4. Results and discussions

The parameter studies are including the spacing between two structures, and the applied voltage. Fig. 3 shows that the spacing between two structures, and applied voltage have large affection. The spacing between two structures affect the magnitude of nonuniform electric field and the applied voltage affect the magnitude of the electric field is showing in Fig. 4. The trapping ability is defined as the minimum flow velocity which can flush away the trapped particle on the space between two structures. When the DEP force acting on particles is sufficiently strong, particles will be trapped in the spacing between the structures (Fig. 5). The dielectrophoretic trapping ability can be measured by varying parameters of the spacing between two structures and the applied voltage, as shown in Fig. 6. The experimental results show that the trapping ability is proportional to the applied voltage and inverse proportional to the spacing between two structures which agreement with the theory. By appropriate select of parameters, one can envision selectively trapping one range of particles while removing others. The potential applications of the electrodeless DEP method are selective trapping of specific ranges of bio-particles.

5. Conclusions

The electrodeless DEP trapping design is studied with simulation and experiment. The application of numerical simulation tool is helpful in terms of reducing time, cost, and risk of failure compare with error test by chip fabrication. The design principle can be obtained before one decides to invest time, efforts, and fund into to chip fabrication. The study found that the spacing between two structures, and applied voltage have large effects on the magnitude of $\nabla E^2$. The spacing between two structures can only affect the non-uniform of the electric field and applied voltage can directly affect the magnitude of the electric field and vary the magnitude of $\nabla E^2$. The dielectrophoretic trapping ability can be measured by varying parameters of the spacing between two structures and the applied voltage. The simulation
results and experiment results show that the trapping ability is proportional to the applied voltage and inverse proportional to the spacing between two structures. By appropriate select of parameters one can envision selectively trapping special range of particles while removing others.

6. References


Fig. 1 Force Analysis Diagram, including DEP force in the x direction, Hydrodynamic lift and drag force, and gravitational force.

Fig. 2 Schematic diagram of the structure design in this study.

Fig. 3 (a) The simulation result of the square of the electric field square in whole model, $E^2$, distribution with the AC signal Vpp =100 volt and frequency f=1 kHz. The distribution can be regarded as the normalized holding force (proportional to DEP force, but with opposite sign of DEP force in y direction) in current simulation conditions. (The geometric parameters of the structure are fixed: $w=40\mu m$, $t=20\mu m$, $d=500\mu m$, $\theta=45^\circ$); (b) The magnitude of the electric field square, $E^2$, along A-A' cross section.

Fig. 4 The drawing of the spacing between two structures is equal to $s=15\mu m$, $25\mu m$, $40\mu m$ and the operating condition is $V_{pp}=50$ volt with AC signal 1kHz. The magnitude of the position is equal to $1.571\times10^{11}$ V/m, $1.032 \times10^{11}$ V/m, and $6.966\times10^{10}$ V/m. (The geometric parameters of the structure are fixed: $w=40\mu m$, $t=20\mu m$, $d=500\mu m$, $\theta=45^\circ$).

Fig. 5 Experiment of electrodeless DEP for $s=15\mu m$, the diameter of particle as $4.3\mu m$ with DI water and applied voltage $V_{pp}=50$ volt with the AC signal and f=1 kHz. The minimum flow velocity $U=1.2$ cm/s. (The geometric parameters of the structure are fixed: $w=40\mu m$, $t=20\mu m$, $d=500\mu m$, $\theta=45^\circ$). (a) The particle was aced positive DEP trapped at the spacing between two structures and base of the structure by positive DEP force. (b)–(d) The trapped particle be washed away.

Fig. 6 The drawing of the minimum flow velocity for trapped particle on the space between two structures can washed away as $s=15\mu m$, $25\mu m$, $40\mu m$ at the maximum flow velocity distribution with the AC signal $V_{pp}=50$ volt, 100 volt, 150 volt and f=1 kHz.