Separate and Manipulate Different Kinds of Particles by Dielectrophoresis

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Abstract

This research employs dielectrophoresis (DEP) force to separate and manipulate bio-particles. Exchanging electro-field attempts to separate different kinds of bio-particles (yeast, cells, micro-polystyrene beads, or virus), and to manipulate particles to move simultaneously. The purpose of manipulation is moving bio-particles to next station on an integrated chip. In order to simplify experiment and observe the process, we design a platform using ISA (Industry Standard Architecture) bus slot to standardize the interface between the controller and connector of the experimental chip. We also used software (CFD-RC) to simulate electric field distribution of the electrode array.

Key Words: Permittivity, DEP Force, Transportation.

1. Introduction

Expectably, integrated biochip will be a very promising product. It can detect what disease patients have by only a drop of blood or urine in several hours or several minutes. Separation and manipulation are indispensable to achieve integrated biochip. When sample is introduced into the integrated biochip, separation must eliminate the wastes in the sample, and manipulation must move other available desired things to next station of integrated biochip.

When particle dimension is decreasing until it cannot be controlled by visible contact force, electrophoresis (EP) and DEP force [1-4] are two methods for control.

For controlling micro-particles, DEP force is especially more efficacious. Thus in this research, we employed DEP force to control particles.

In order to achieve the purpose of separating and manipulating particles, finding out the property of bio-particles is necessary. ROT measurement and Levitator measurement [1,2] are the main methods to measure the permittivity of the particles. Main factors of DEP force are size, permittivity of particles and frequency. Since permittivity and size are constant, frequency will be varied to determine the polarity and magnitude of the DEP force.

2. Theories

The DEP force is formulated as below.

\[ F_{DEP} = 2\pi r^3 e_m \text{Re}\{K(\omega)\} |E_{rms}|^2 \]

(1)

where \( E_{rms} \) is the root-mean-square value of electric field, \( r \) is the particle radius, \( \omega \) is the angular field frequency, and \( \text{Re}\{ \} \) indicates the real part of \( K(\omega) \). The factor \( K(\omega) \), a measurement of the effective polarization of particle, is shown as follows

\[ K(\omega) = \frac{e_p^* - e_m^*}{e_p^* + e_m^*} \]

(2)

where \( e_p^* \) and \( e_m^* \) are complex permittivity of the particle and medium, and
where $j = \sqrt{-1}$, $\varepsilon$ is permittivity, and $\sigma$ is the conductivity of the dielectric. Employing Eq. (1) and (2), one can obtain the relation of DEP force with frequency, and thus decide which frequency to be applied in the experiment.

Known by Eq. (2), $K(\omega)$ is dependent on particle and medium. At an applied particular frequency in AC, particle and medium will generate DEP force. Since the permittivity are different, the direction of DEP force is dependent on efficiency of polarization with particle and medium. Although different particles are in the same medium their efficiencies of polarization are not the same. When DEP force is different between two particles, the two particles will be separated.

The conventional traveling-wave-dielectrophoretic force acting on a polarized particle in a non-uniform electric field is proportional to the in-phase component of the induced dipole moment and field strength, and can transport particles [3].

When two or more kinds of particles mixed in the electric field, the particles which are applied by positive DEP are attached to electrode surface, and particles which are applied by negative DEP are directed along the channel.

3. Simulation

In order to increase practicability of experiments, we designed the shape of electrode by using CFD-RC simulation software to simulate electro-field distribution, and followed the result of simulation to design electrode patterns. Figure 1 shows result of simulation, left of figure is $z$ direction of electro-field, and center is $x$ direction, right is $y$ direction.

4. Manufacture

4.1 Standards

Glass is selected as the substrate in the experiment, because it is transparent and easy to observe. Electrode was constructed on glass substrate. Consider the experimental stability and accuracy, electro-field should be precisely applied through electrodes, and chip should be able to use repeatedly so we consider adopting ISA (Industry Standard Architecture) Bus slot to act as interface between controller and experimental chip. There are 29 connecters constructed on the chip. Figure 2 shows the dimension of connecter on the chip.

4.2 Fabrication

Thermal evaporator was used to construct a layer of aluminum on glass substrate, then photolithography and etching were employed to build the electrode pattern. The channel of chip is built by thick photoresist (T151N), and it then covers a cover slip or ITO glass to seal up the channel. Figure 3 shows two finished chips.

5. Experimental

5.1 Setting

Figure 4 illustrates the experimental setup. Using a function generator to connect controller input, we use LPT port to communicate with PC. The experimental chip was fixed at base of micro-
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Figure 4. Experimental setup.

Figure 5. Electrode patterns: (a) conventional, (b) proposed.

Figure 6. Phased signal of electric field.

Table 1
Experimental particles

<table>
<thead>
<tr>
<th>Particle</th>
<th>Size (µm)</th>
</tr>
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<tbody>
<tr>
<td>polystyrene beads</td>
<td>7</td>
</tr>
<tr>
<td>lymphocyte</td>
<td>10</td>
</tr>
<tr>
<td>yeast</td>
<td>1–2</td>
</tr>
<tr>
<td>L929</td>
<td>20–30</td>
</tr>
</tbody>
</table>

scope, and ISA bus slot is used to connect controller. In the experiment, we set the digital video over microscope for image recording, and use IEEE 1394 wire to communicate with PC.

The function generator can generate maximum frequency 40 MHz, and 20 volts peak to peak. The interface was built by 8255 (Programmable peripheral interface) IC. Each 8255 can provide 24 I/O controllable connecters, and supply six kinds of signals to exchange. There are four 8255 ICs and several relays used to switch signal in the interface.

Figure 7. (a) Polystyrene beads, (b) yeast and polystyrene beads.

Figure 8. Lymphocyte transported by traveling wave DEP force.
5.2 Preparation

The experiment attempts to test several kinds of particles listed in Table 1, and the conductivity of medium is 110 µs/cm after blending with 1 M KCl solutions. Add particles into medium and drop the mixture into channel of experimental chip. We implement two kinds of experiments, one is only separation without transportation, and the other is separation with transportation. In case of only separating particles we apply frequency range of 100 kHz – 10 MHz and potential of 10 volts peak to peak. In the other experiment we apply frequency in 1 MHz and potential of 7 V peak to peak, and observe variation of particles in electric field.

5.3 Experimental

We designed two electrode patterns. Figure 5(a) shows the traditional separation electrode, which is used to test the effect of separate particles without translation. Figure 5(b) shows the electrode used to separate and transport particles. The experimental voltage signal on each pin of the chip is controlled by software. We use interface circuits to set the pins as the applied voltage. The electrodes are applied signals with different phases as shown in Figure 6.

6. Results and Discussion

Yeasts in the frequency range of 10 KHz–10 MHz are always supported negative DEP, polystyrene beads are supported positive DEP. When the electric field was applied, polystyrene beads were repelled between neighbor electrodes, and yeast was attracted to electrode surface. Figure 7(a) shows that the polystyrene beads are repelled between two electrodes, and Figure 7(b) is the result of separation with yeast and polystyrene beads at frequency of 1 MHz and potential of 10 V peak to peak.

Figure 8 shows that lymphocytes and yeasts were separated and transported by traveling wave DEP force. In the beginning, electrodes were not applied with electro-field (Figure 1). After the electro-field is applied, yeasts were attracted to electrode (Figure 3). Meanwhile, lymphocytes were repelled to center of channel (Figure 2) and directed along the channel (Figure 4).

7. Conclusions

This study succeeded to employ DEP force to separate and transport two particles simultaneously. Although in actual application, it may have more kinds of particles in the sample, we believe the proposed electrode array pattern and applied control signal types can be used to separate and transport multi-kinds of particles simultaneously.

References


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