Introduction

Dielectrophoretic traps have been broadly studied in light of their many advantages of high controllability, ease of operation, and high efficiency. However, most studies are confined to the trapping of a large number of particles and analyzing general traits of particles such as simple movements using an optical measurement [1][2]. In the previous studies, it was challenging to count how many particles were captured and how much force was needed to capture particles. Trapping a single particle and numerical analysis are required to compensate theses drawbacks. In this study, the optimized shape of trap was suggested to capture and analyze single particle. In addition, the effect of trap size on single particle trapping was investigated by numerical simulations to optimize trap size and operation conditions depending on the particle size.

Methods

In this research, each operation condition was generated by finite element method (FEM) using computer software (COMSOL Multiphysics V5.2). A particle in a nonuniform electrical field experiences a DEP force, which is given by the following equation [3],

\[ F_{\text{DEP}} = 2\pi \varepsilon_0 r^3 \text{Re}(f_{\text{cm}}) |V| E^2 \]

where \( r \), \( \varepsilon_0 \), and \( E \) are the radius of the particle, the real permittivity of the medium, and the electric field, respectively. Governing equations were analyzed and interconverted to conduct desired simulations in COMSOL. Physical and boundary conditions were also considered and tested to match the results of simulation to general traits of DEP trap.

Circular traps were analyzed to find the optimal condition for single particle trapping due to their omnidirectional and symmetrical property, which facilitates analyzing the particles regardless of their approaching direction. The obtained operation condition enables acquiring and quantifying the data related to particle’s physical properties such as speed and force that is required to capture the particle. Simulations were conducted to optimize the trap size for capturing 4 \( \mu \)m polystyrene particles. DEP force was measured at 2 \( \mu \)m height from the bottom electrodes considering the radius of the particles.

Results

The DEP force field in this simulation represents both the directivity and relative magnitude of DEP force. Based on the graphical simulation as shown in Figure 1, there are two significant characteristics of the suggested circular DEP traps. First of all, it is observed that the DEP forces inside the trap exert toward the center of trap. Secondly, the strongest forces are generated at the rim of trap and the repulsive forces are observed outside the rim.

![Graphical simulation of circular DEP traps and line graph of DEP force field.](image)

Figure 1. Graphical simulation of circular DEP traps and line graph of DEP force field. In Figure 1, negative X-axis values represent the X-axis force that exerts towards left direction, while positive values represent the X-axis force that exerts towards right direction. In case of Z-axis force, negative values represent the Z-axis force that exerts downward, while positive values represent the Z-axis force that exerts upward. In particular, Y-axis force is measured almost zero along the center line and this Y-axis value is negligible since most particles are expected to be captured along the center line.

![Differences of DEP force field depending on a trap size when the spacing between adjacent two traps are kept constant, 20 \( \mu \)m: (A) 10 \( \mu \)m; (B) 20 \( \mu \)m; (C) 30 \( \mu \)m; (D) 40 \( \mu \)m.](image)

Figure 2. Differences of DEP force field depending on a trap size when the spacing between adjacent two traps are kept constant, 20 \( \mu \)m : (A) 10 \( \mu \)m; (B) 20 \( \mu \)m; (C) 30 \( \mu \)m; (D) 40 \( \mu \)m.

Based on Figure 2 and 3, the 20 \( \mu \)m and 30 \( \mu \)m trap were considered the best suitable traps for capturing a 4 \( \mu \)m polystyrene particle among the 10 - 40 \( \mu \)m traps due to their minor effect of thrusting force at the rim and with the strong capturing force inside the trap.

![X-axis and Z-axis force depending on a trap size: (A) 10 \( \mu \)m; (B) 20 \( \mu \)m; (C) 30 \( \mu \)m; (D) 40 \( \mu \)m.](image)

Figure 3. X-axis and Z-axis force depending on a trap size: (A) 10 \( \mu \)m; (B) 20 \( \mu \)m; (C) 30 \( \mu \)m; (D) 40 \( \mu \)m.

However, in case of 10 \( \mu \)m trap, the 4 \( \mu \)m particle occupies half of diameter of the trap, which results in restriction of the area to be captured. The 10 \( \mu \)m trap was excluded for the best suitable trap due to this drawback. The 40 \( \mu \)m trap has the strongest repulsive force at the rim and the least converging force at the center. Therefore, the 40 \( \mu \)m trap was also not considered suitable for capturing a particle. In addition to demonstrating the optimized trap size, the magnitude of forces at every location on the system was also successfully simulated and quantified.

Conclusion

The single particle DEP trap with different sizes has been numerically studied to find an optimized trap size and operation condition appropriate to a specific size particle. We demonstrated that the strength and directivity of the DEP force were predictable. In addition, particle speeds and required forces to trap a particle could be quantitatively calculated in conjunction with experimental methods. The developed simulation methods will be used to determine the operation condition to trap particles using DEP.

Literature cited