Trap geometry characterization of flow through dielectrophoretic-microfluidic device for particle trapping

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Motivation

- Disease diagnosis, gene analysis, drug screening, tissue engineering – all these important biomedical applications require separation, manipulation, concentration and immobilization of specific bioparticles and cells. For successful application, these micro- and nano-sized particles need to be isolated from their original mixture (e.g. saliva, blood and other body fluids).

- Most of the traditional techniques (e.g. filtration, centrifugation, electromagnetic separation) for concentration and immobilization of bioparticles are time-consuming.

- Dielectrophoresis (DEP), one of the electro-kinetic methods, can be effectively used to separate and isolate particles based on their size, structural properties and behavior under induced electrical field.

Method

A neutral, but dielectric particle suspended in a medium becomes electrically polarized when subjected to a non-uniform electric field. This is due to partial charge separation which leads to an induced dipole within the particle. Based on the electric field and the medium, the particle experiences attraction or repulsion motion towards a specific pole of the electric field. For a homogeneous solid spherical particle of radius r, the DEP force is described by:

$$F_{DEP} = 2\pi r^3 \varepsilon_0 \varepsilon_m Re[f_{CM}]\nabla E^2$$

ε_m	=	permittivity of the surrounding medium	∇E^2 =	electric field gradient
ε_0	=	permittivity of the free space	f_{CM} =	Clausius-Mossotti (CM) factor

- The CM factor (f_{CM}) is a function of the medium and the particle complex permittivities; and they are dependent on the frequency of the electrical field.

- Sign of the CM factor dictates the direction of DEP force: attractive/positive (pDEP) and repulsive/negative (nDEP), moving particles toward the high and low intensity electric fields.

- The spatial gradient of the electric field varies depending on trap geometry.

A microfluidic device has been designed and fabricated (Figure 1) with arrays of differently shaped (triangular, square and circular) μ-traps using photolithography and metal deposition techniques. For this study, the nDEP force was analyzed numerically using the finite element analysis (FEA) with COMSOL Multiphysics.
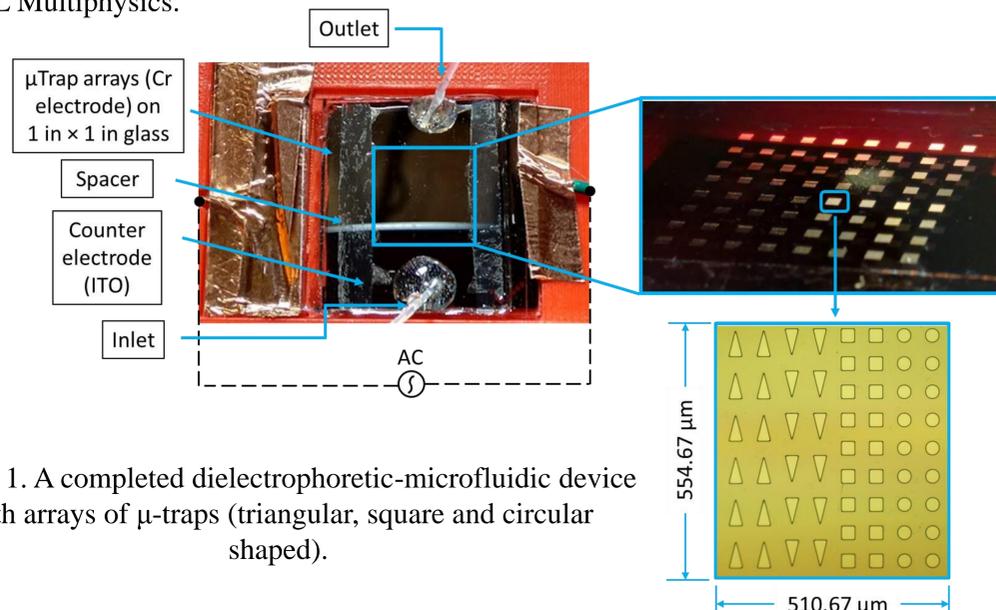

Figure 1. A completed dielectrophoretic-microfluidic device with arrays of μ-traps (triangular, square and circular shaped).
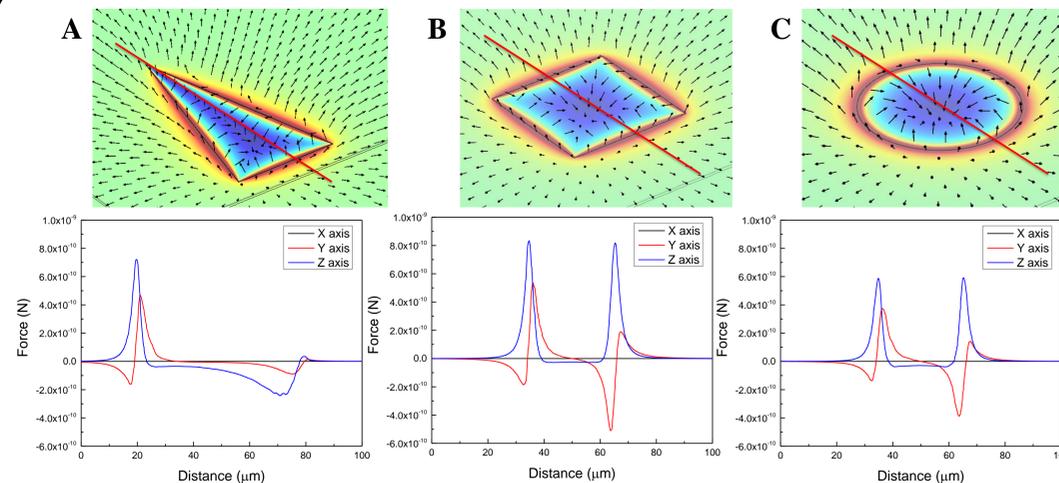
Results

Figure 2. Comsol Multiphysics simulation indicating direction and magnitude of the nDEP force along trap cross section for (A) Triangular shape, (B) Square shape and (C) Circular shape μ-trap.

The FEA simulation results (Figure 2) illustrate that –

- Inside the μ-trap, direction of DEP force is directed toward the inside area of the trap

- At the boundary, DEP force is directed outwards

- DEP force (z-axis) along the rim is upward and inside the trap is downward

- Need downward force (z-axis) for successful trapping inside the μ-trap

- Circular trap shows overall stronger (up to 30%) uniform downward force (z-axis). However, triangular shape shows strongest downward force (z-axis) near the vertex.

DEP based μ-trap arrays containing all three shapes were tested to immobilize 4 μm (radius) polystyrene beads. As shown in Figure 3, μ-traps of all three shapes were able to trap particles inside the μ-trap based on nDEP.
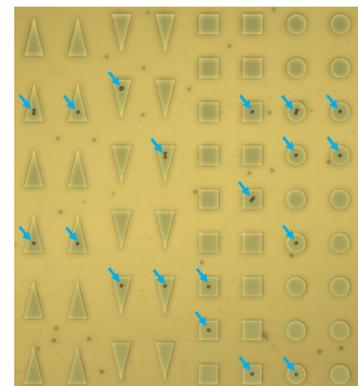

Figure 3. Trapped 4 μm (radius) polystyrene beads (marked) in μ-trap arrays.

Discussion and Future Work

The developed nDEP based-microfluidic device is successfully used to immobilize micro-particles. The simulation results indicate variation on generated DEP-force inside and around the μ-traps with changes in geometry of the μ-traps. Initial experimental data reveals that the behavior of trapped particles is different for different shapes of the μ-traps. Further analysis of the behavior of trapped particles from experimental data will provide more insights of the trapping force dynamics for each of the three different shapes. This will allow to optimize the geometry of the μ-trap for higher trap stiffness and enhanced trapping efficiency.

References

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