Analysis of Dielectrophoretic Force by Using COMSOL

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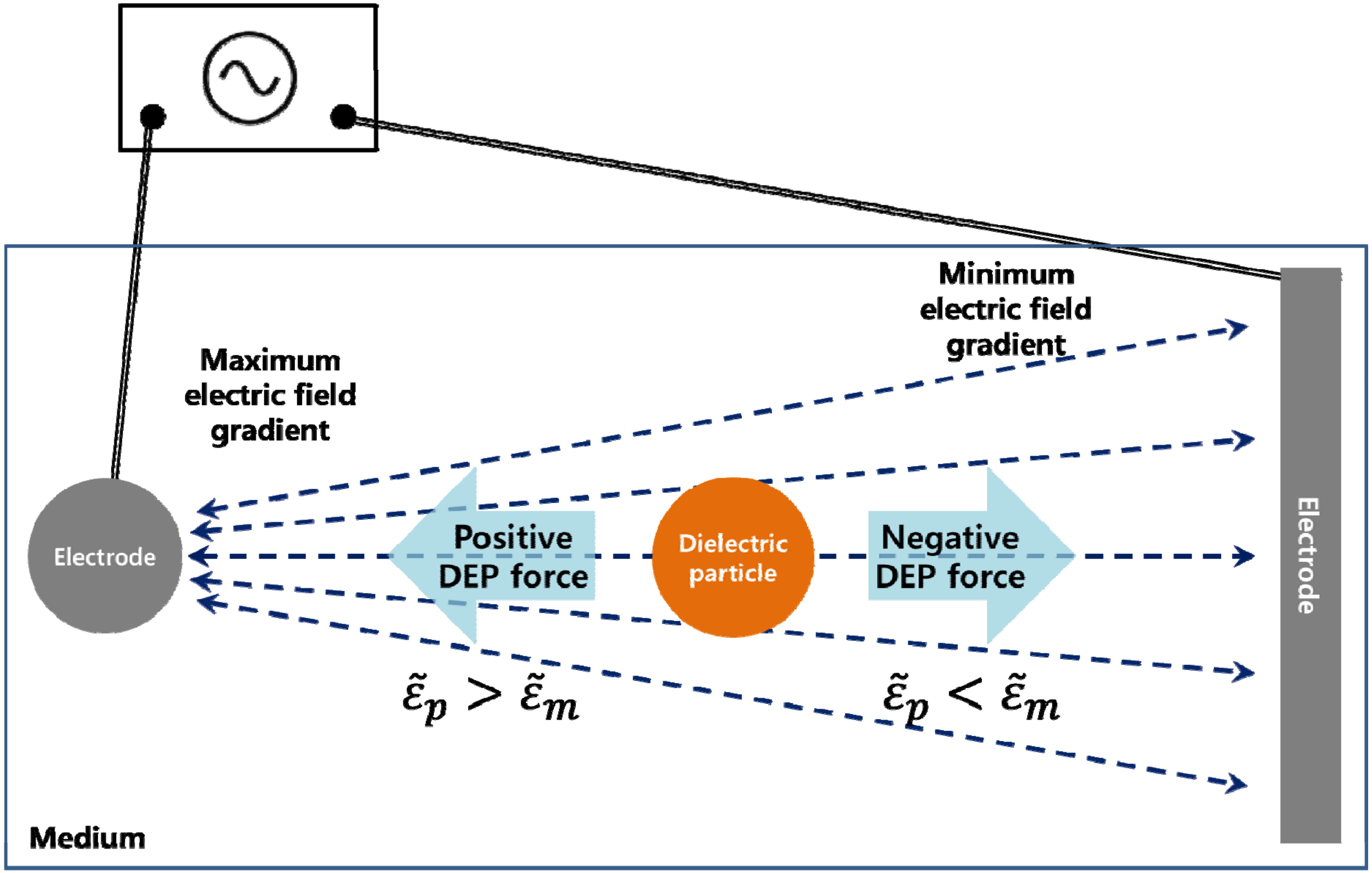
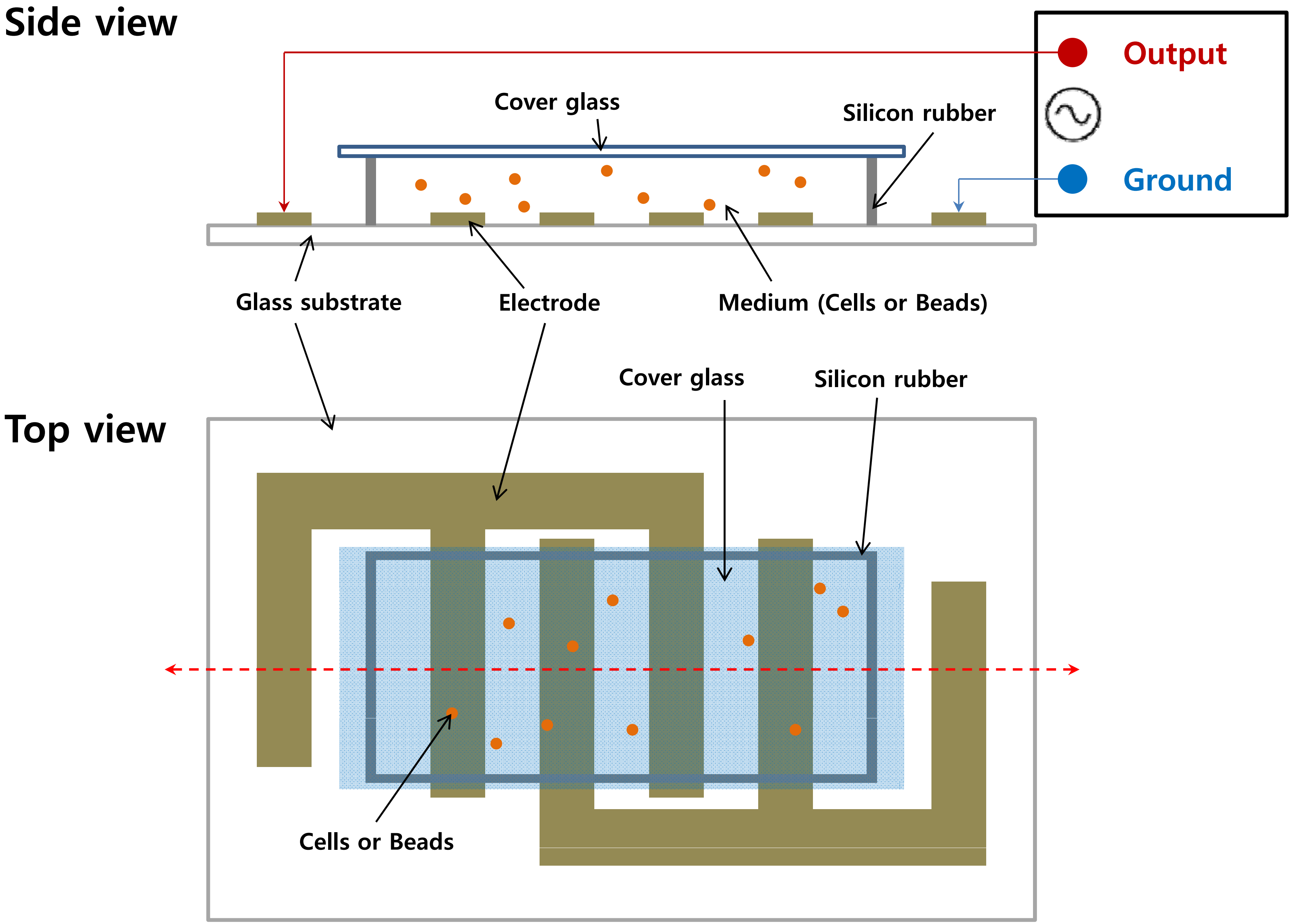
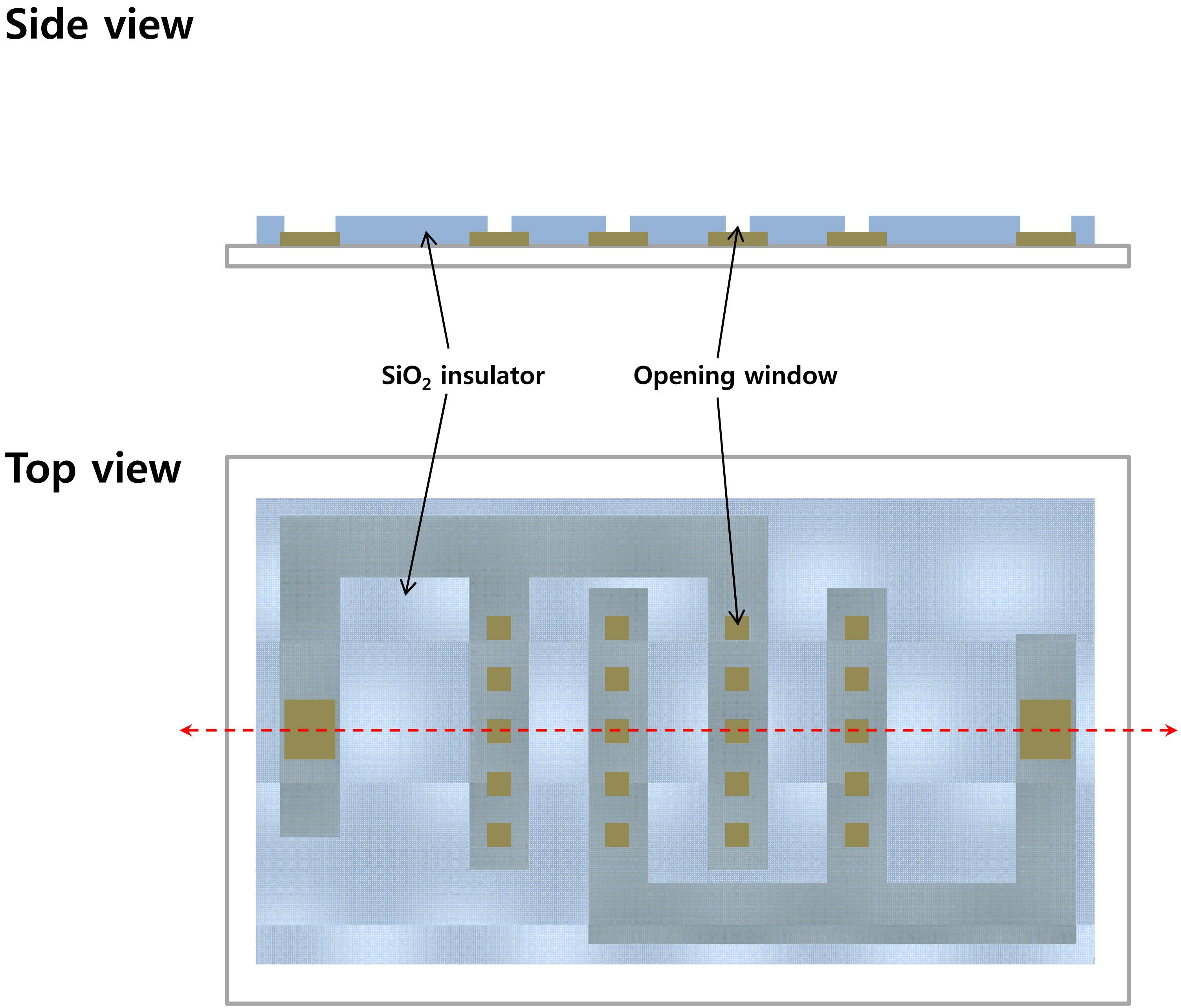
Dielectrophoresis is a phenomenon in which a force is exerted on a dielectric particle when it is subjected to a non-uniform electric field.



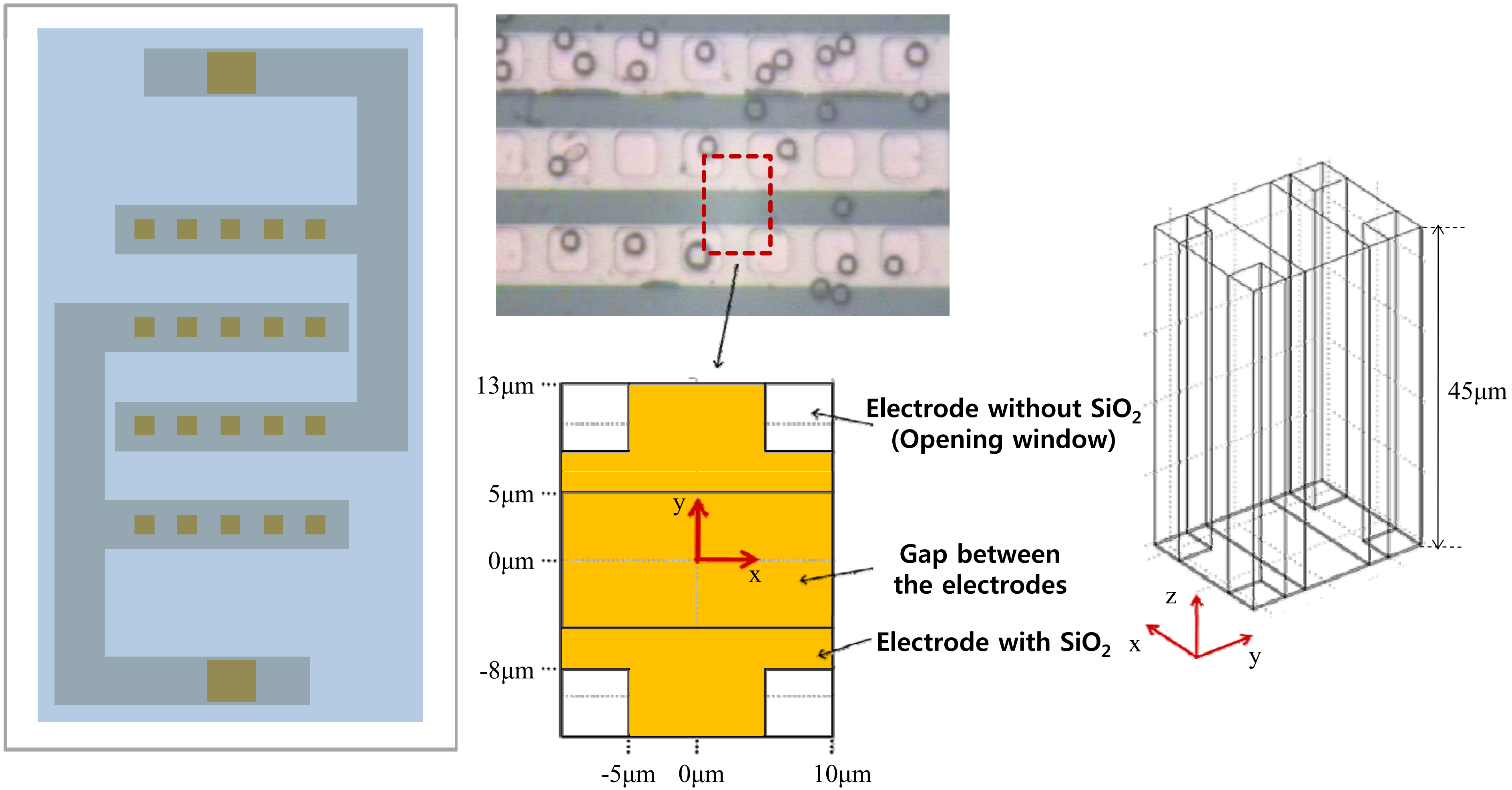
$\tilde{\varepsilon}_p$: complex permittivity



Side view
Output
Ground
Cover glass
Silicon rubber
Glass substrate
Electrode
Medium (Cells or Beads)
Top view
Cover glass
Silicon rubber
Cells or Beads


Side view
SiO_2 insulator
Opening window
Top view

Unit model for simulation



Governing equations

- Dielectrophoretic (DEP) force

$$F_{\mathrm{DEP}} = 2\pi\varepsilon_m a^3 \mathrm{Re}(f_{cm})\nabla E^2$$

- Elecrohydrodynamic force

$$F_{\mathrm{EHD}} = 6\pi\eta a v$$

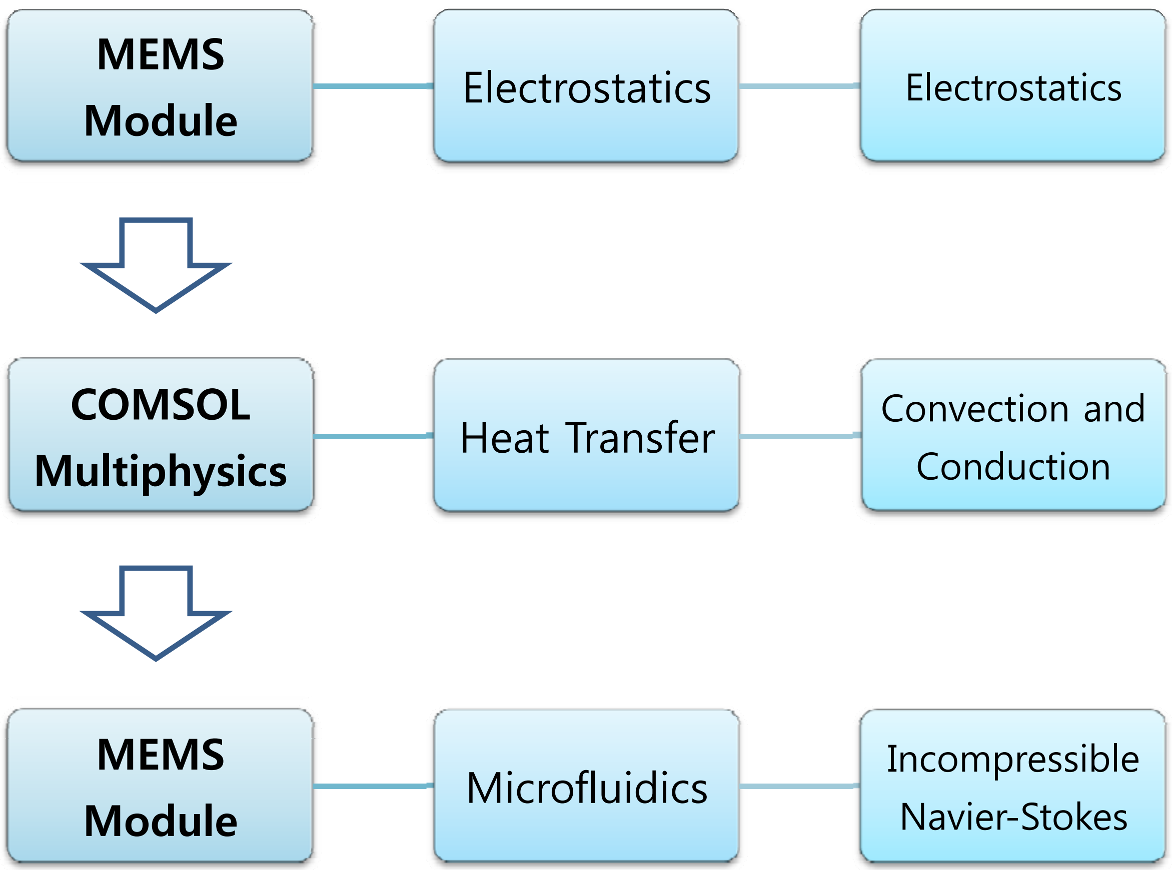
  - Electrothermal force

$$\langle f_e \rangle = \frac{1}{2}\mathrm{Re}\left[\left(\frac{(\sigma\nabla\varepsilon - \varepsilon\nabla\sigma)\cdot E}{\sigma + i\omega\varepsilon}\right)E^* - \frac{1}{2}|E|^2\nabla\varepsilon\right]$$

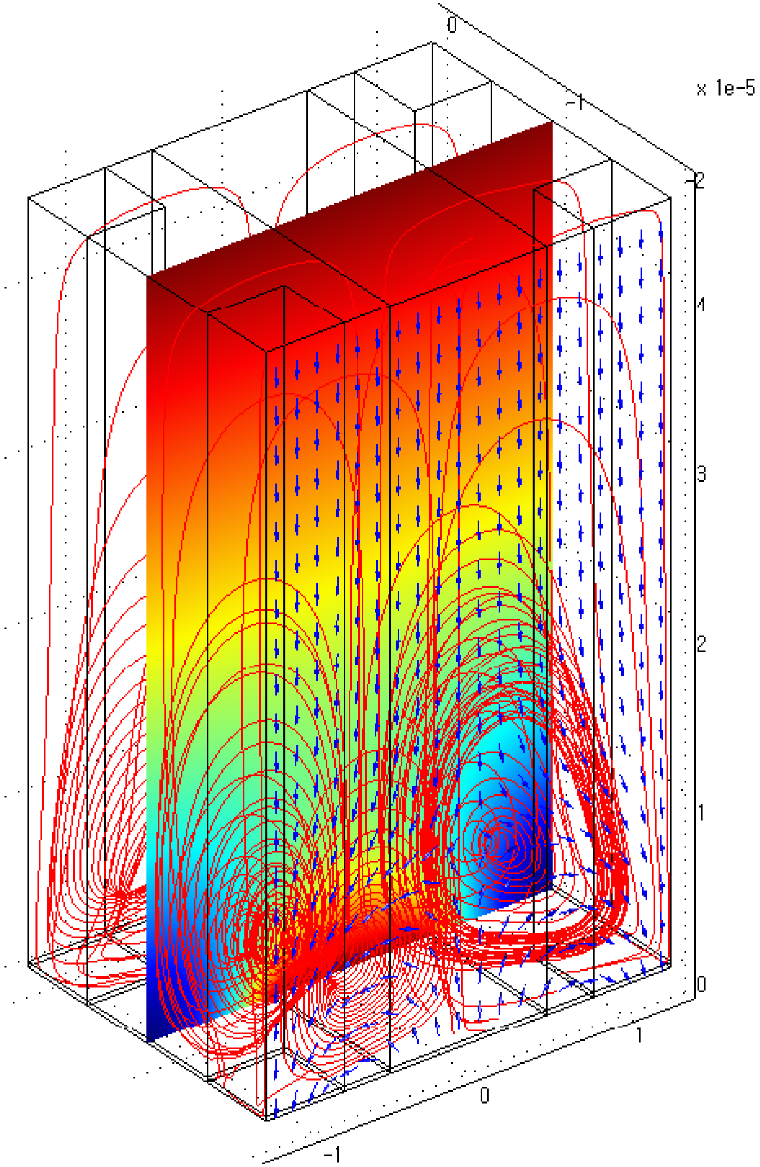
- Gravitational & buoyant force

$$F_g = \frac{4}{3}\pi r^3(\gamma_2 - \gamma_1)g$$

COMSOL Multiphysics 3.5a



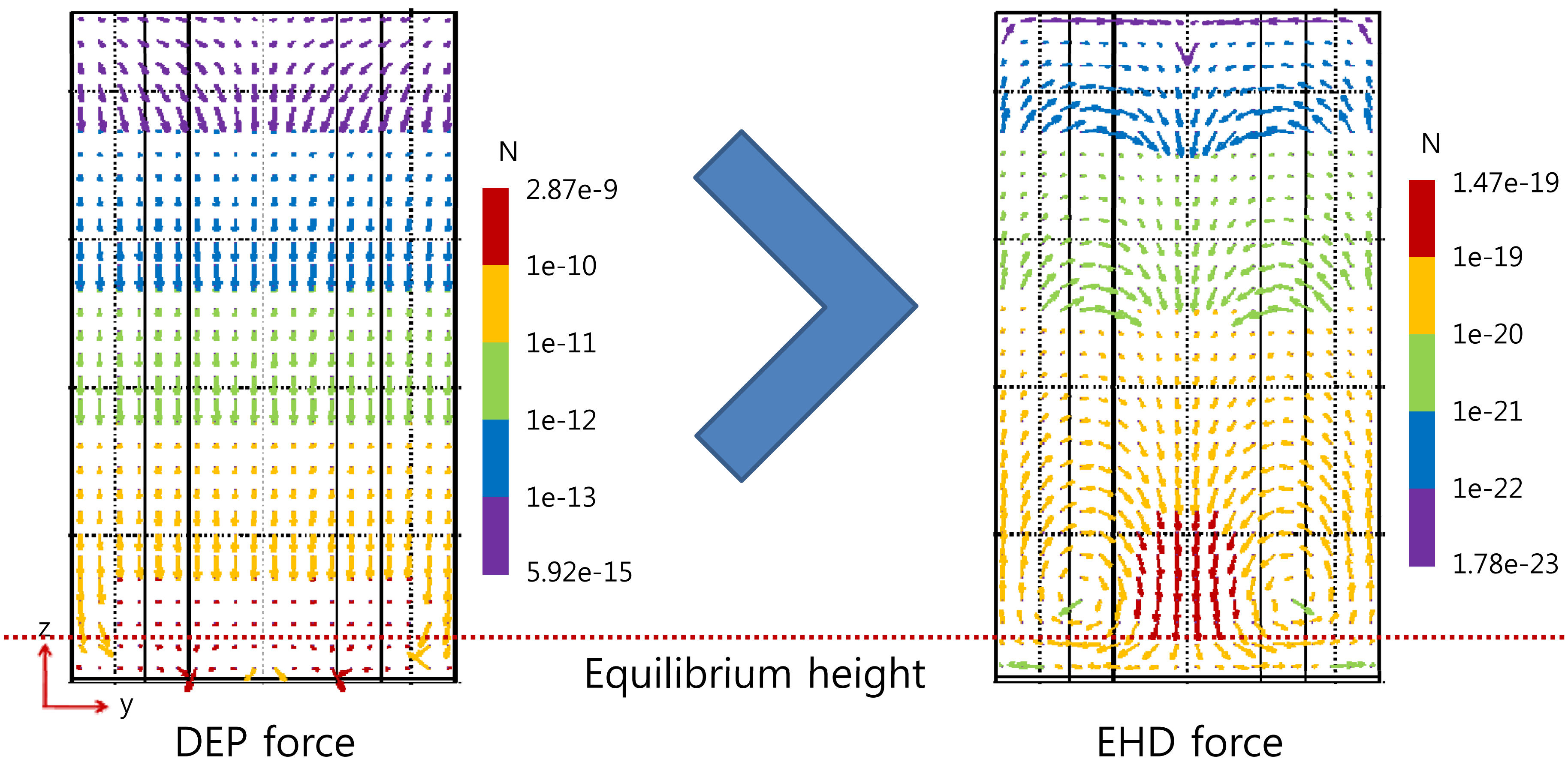
Results



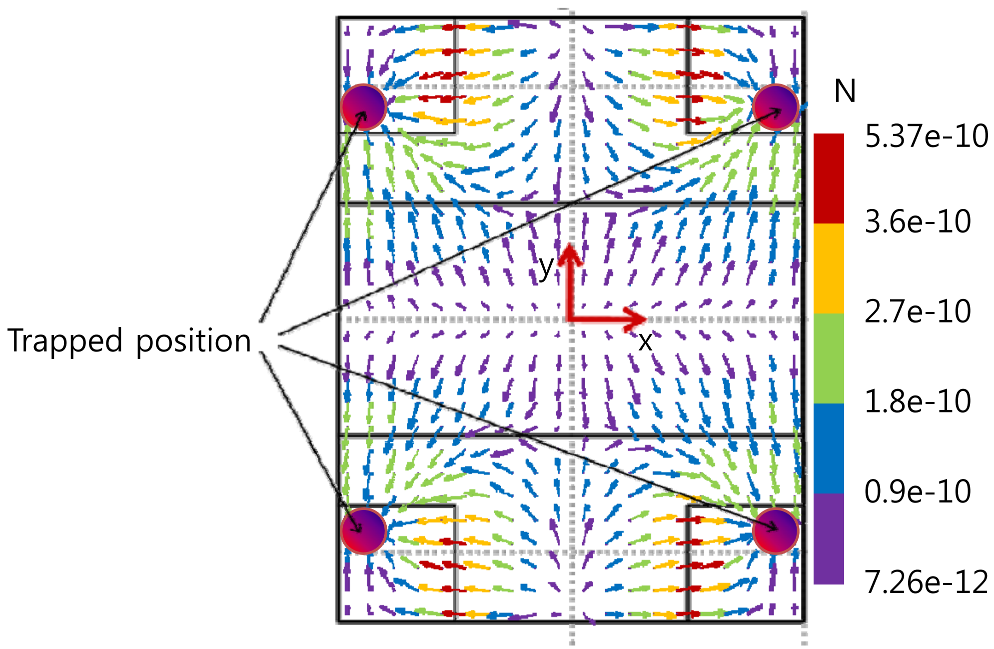
- Slice: Temperature
- Arrow: Total heat flux
- Streamline: Velocity field

Result – Positive DEP

- Equilibrium height: Particle radius

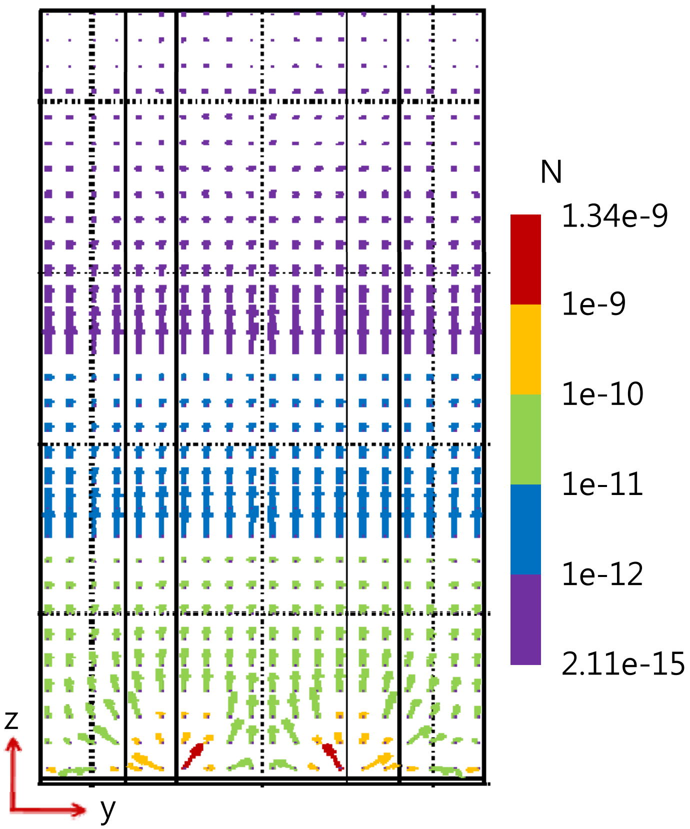


Result – Positive DEP

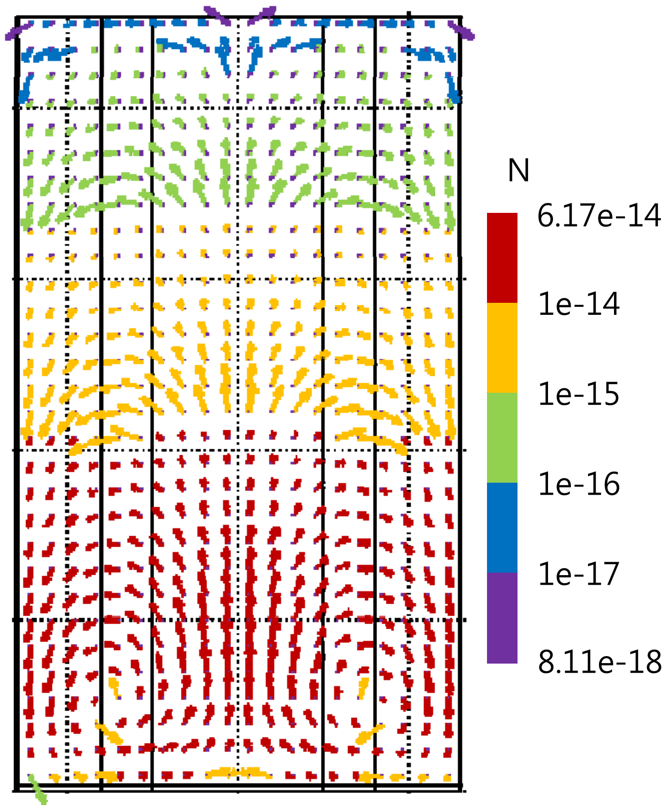


Result – Negative DEP

- Equilibrium height: Net force = 0



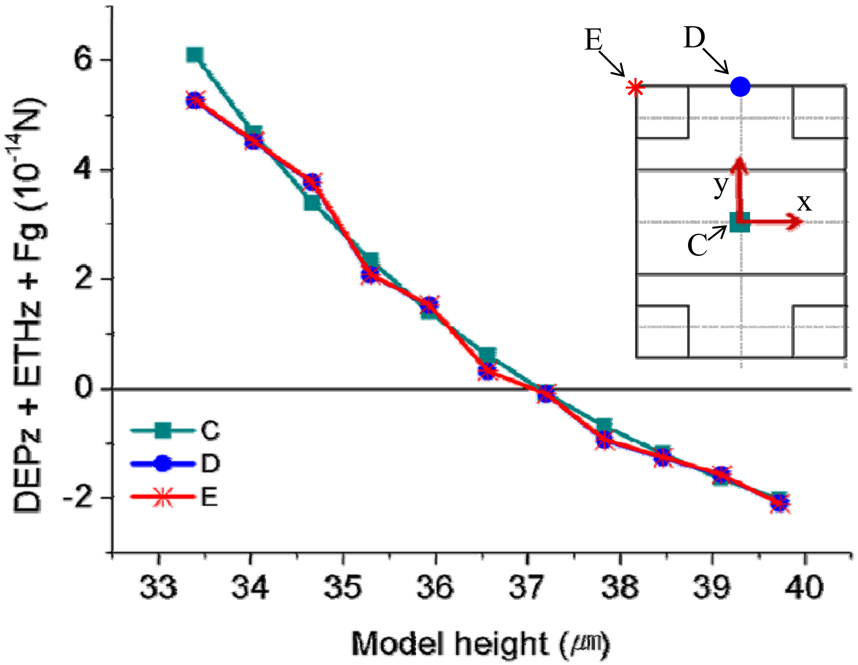
DEP force



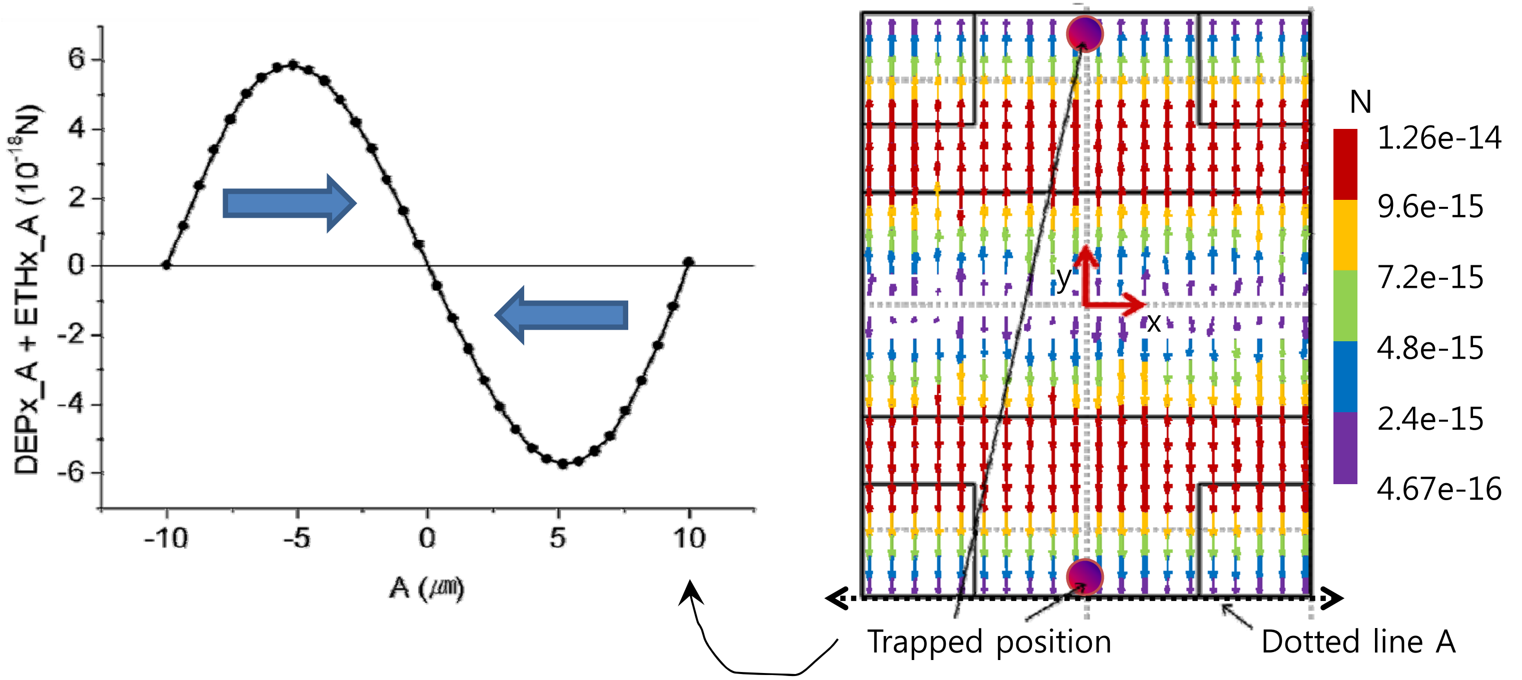
EHD force

Result – Negative DEP

- Equilibrium height: Net force = 0

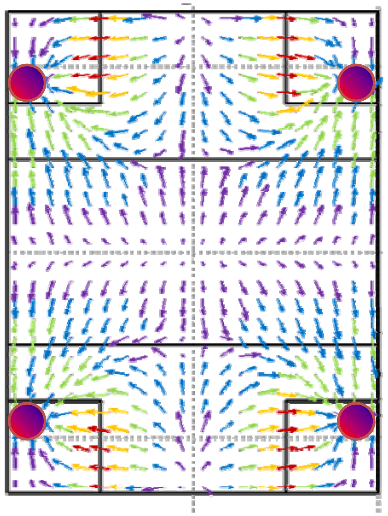


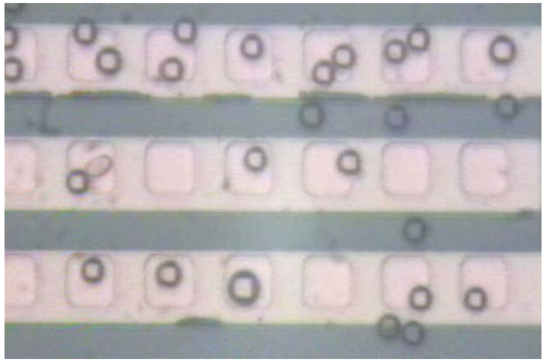
Result – Negative DEP



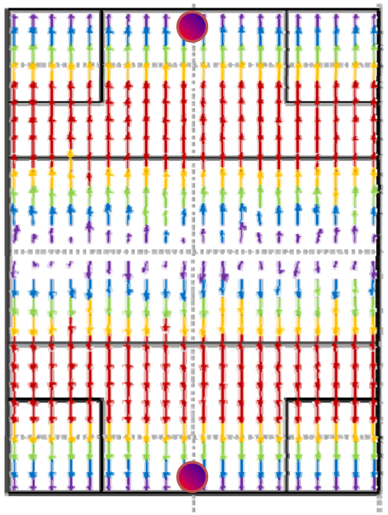
Simulation vs. Experiment

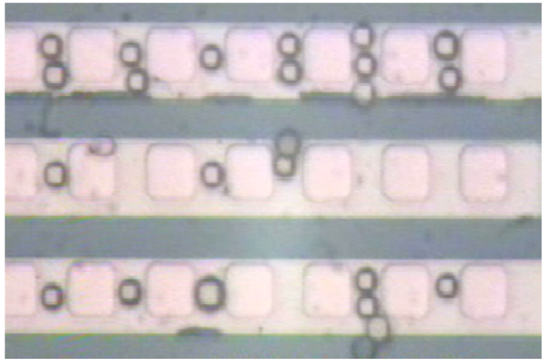
Positive DEP





Negative DEP



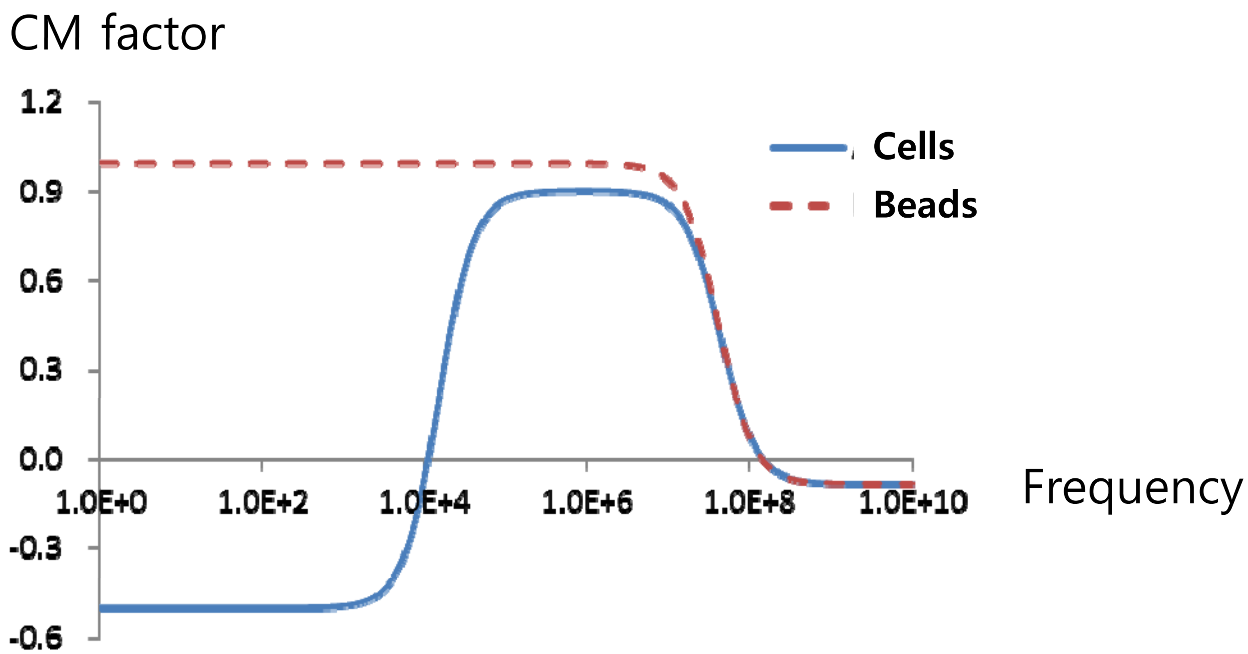


5µm polystyrene beads

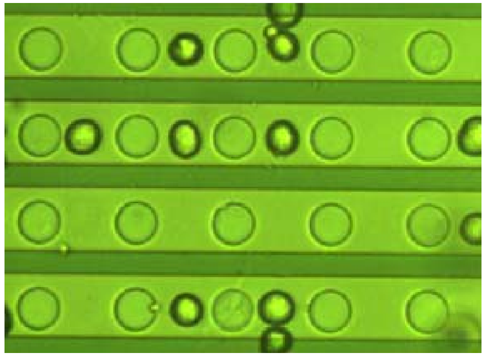
CM factor (Cells vs. Beads)

$$f_{cm} = \frac{\tilde{\varepsilon}_{cell} - \tilde{\varepsilon}_{medium}}{\tilde{\varepsilon}_{cell} + 2\tilde{\varepsilon}_{medium}}$$

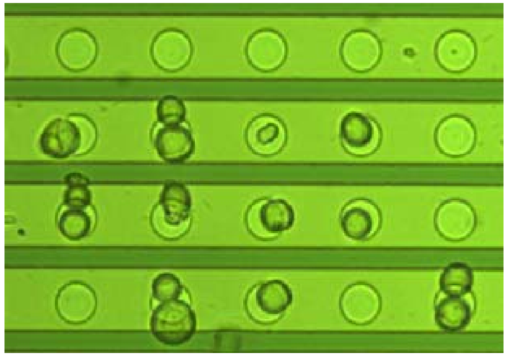
$$\tilde{\varepsilon}_{cell} = \tilde{\varepsilon}_{mem}\left[\left(\frac{r}{r-t}\right)^3 + 2\left(\frac{\tilde{\varepsilon}_{cyt} - \tilde{\varepsilon}_{mem}}{\tilde{\varepsilon}_{cyt} + 2\tilde{\varepsilon}_{mem}}\right)\right] / \left[\left(\frac{r}{r-t}\right)^3 - \left(\frac{\tilde{\varepsilon}_{cyt} - \tilde{\varepsilon}_{mem}}{\tilde{\varepsilon}_{cyt} + 2\tilde{\varepsilon}_{mem}}\right)\right]$$



DEP traps for single cell (B16F10)

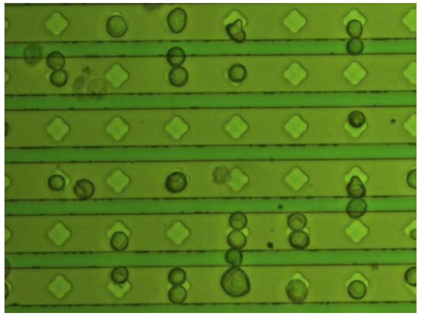


Negative DEP force ($3V_{pp}$, 1kHz)

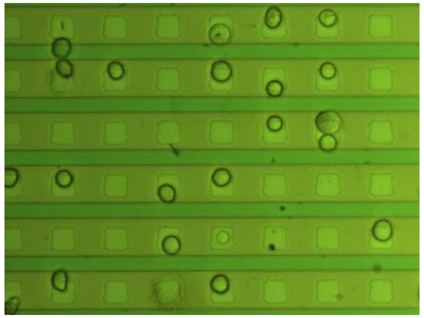


Positive DEP force ($3V_{pp}$, 100kHz)

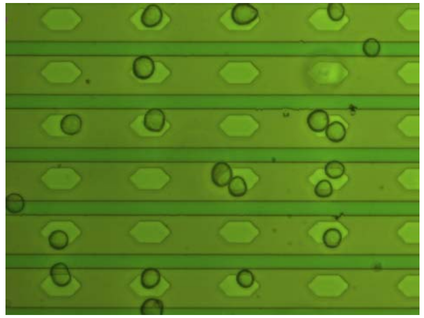
Positive DEP Trap in various window shapes



Rhombus



Square



Hexagon

Thank you