ME 517: Micro- and Nanoscale Processes

Lecture 32: Electrokinetics - III

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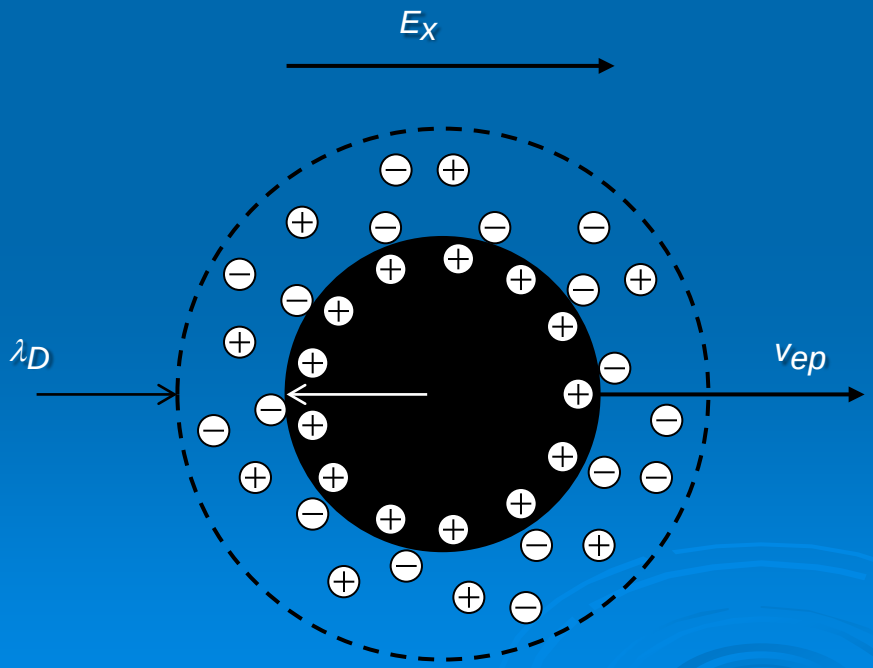
DC Electrophoresis (EP)

- Particle/ion manipulation using EDL and electrical field
  - Common technique called ‘capillary electrophoresis’ (CE) used to sequence DNA, ala OJ Simpson or Human Genome Project



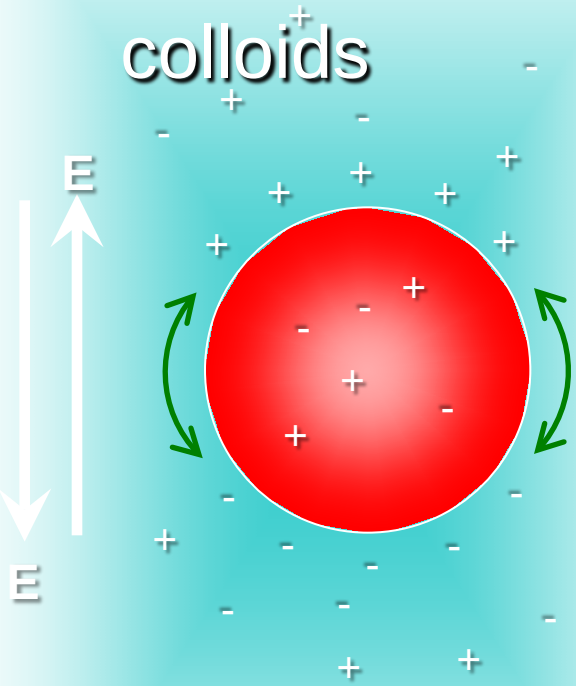
$$u_{\text{ep}} = \frac{2}{3}\frac{\varepsilon\zeta E_{\text{el}}}{\mu}, \lambda_D \gg d_p$$

$$u_{\text{ep}} = \frac{\varepsilon\zeta E_{\text{el}}}{\mu}, \lambda_D \ll d_p$$

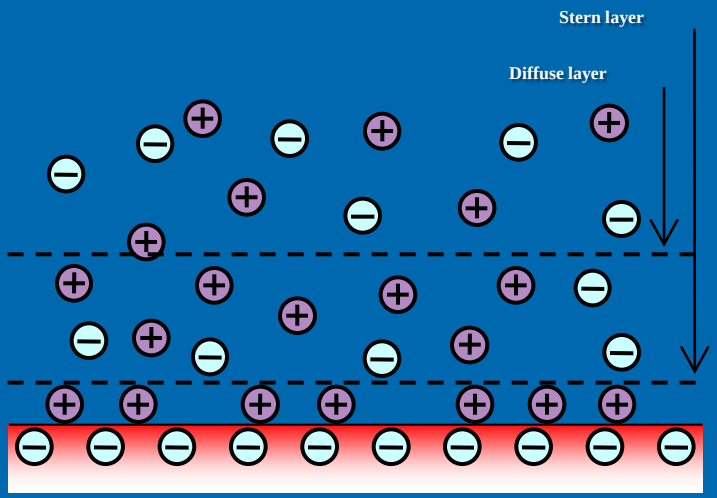
$$\mu_{ep} = u_{ep} / E_{el}$$

Particle Electrokinetics

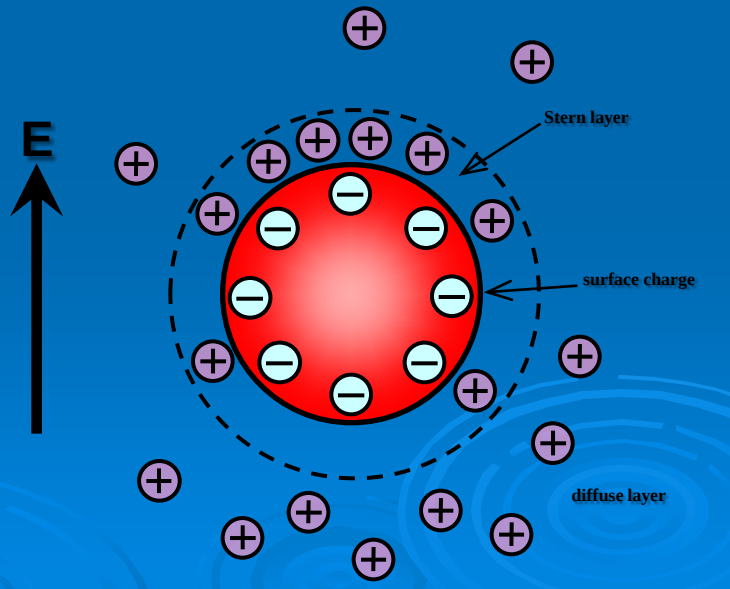
- Polarization of colloids



Relaxation at high AC frequencies



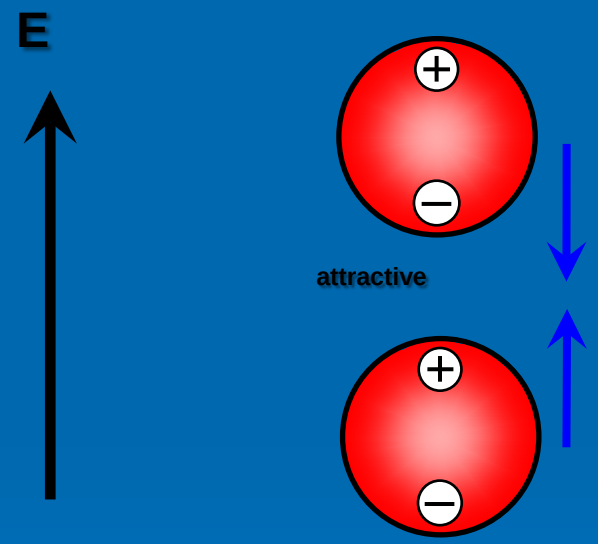
Electric Double Layer polarization



Lyklema, J., *Fundamentals of Interface and Colloidal Science, vol. 2* (1995)

Interparticle Forces

- Dipole-Dipole Interactions



'Pearl Chaining'

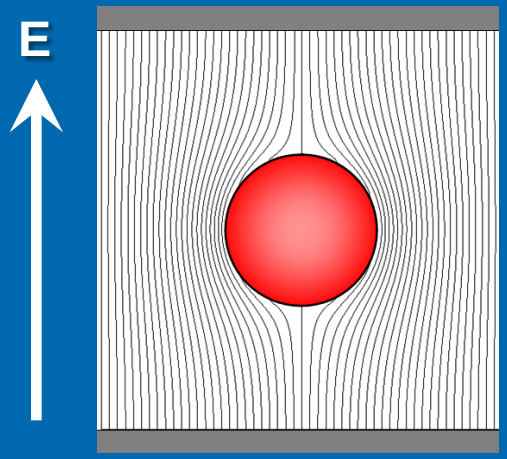
Dipole-Dipole repulsive force

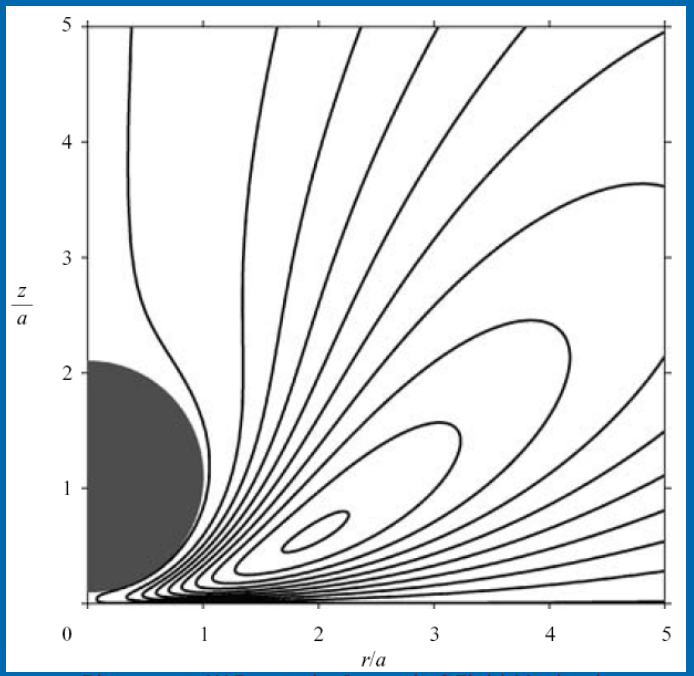
$$F = 3\pi\varepsilon_{\mathrm{m}} a^6 E_o^2 / r^4$$

Nadal, F., et al., *Phys. Rev. E* (2002)

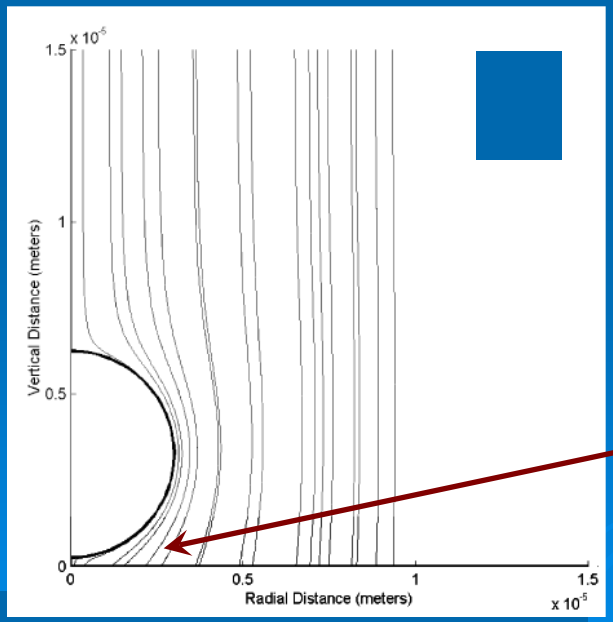
Background: AC Electrokinetics

- Particles themselves will alter electric field





Ristenpart, W.D., et al., *Journal of Fluid Mechanics* (2007)

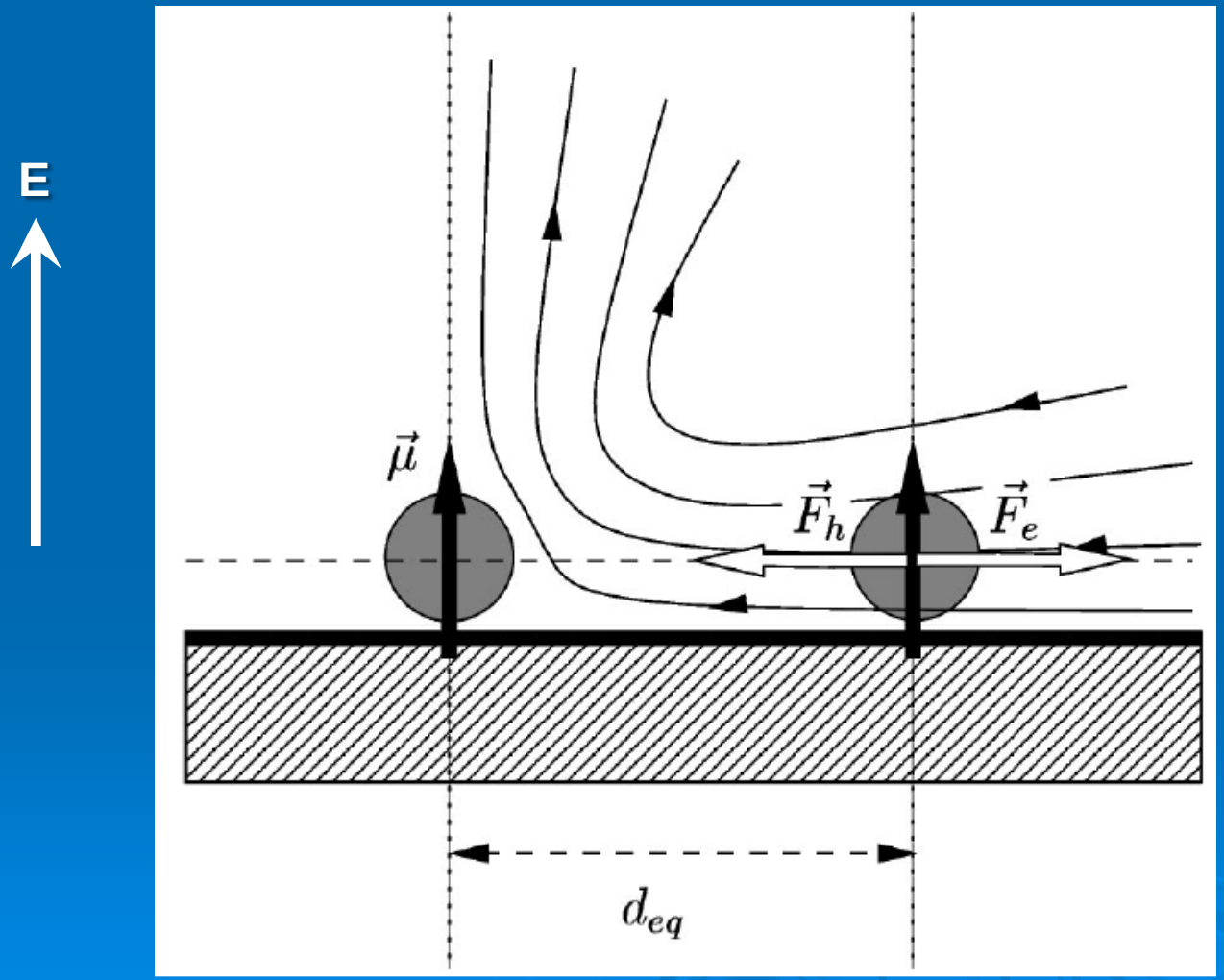


Fagan, J. A., et al., *Langmuir* (2004)

- Distortion leads to a tangential component of the electric field over the electrode surface.
- This generates electrohydrodynamic flow (ACEO)

Background: AC Electrokinetics

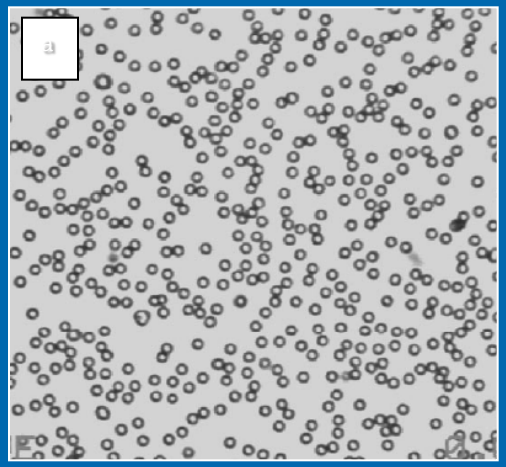
- Particle-Particle interactions



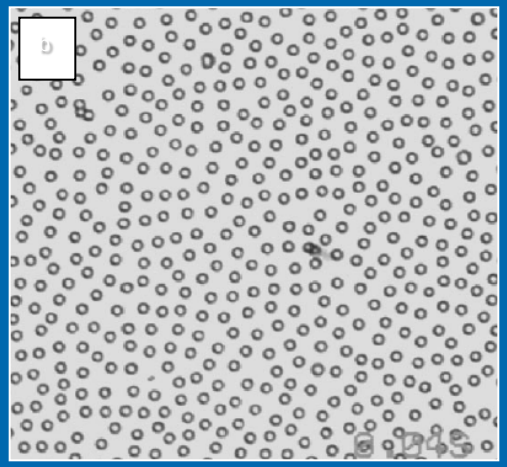
Nadal, F., et al., *Physical Review E.* (2002)

Background: AC Electrokinetics

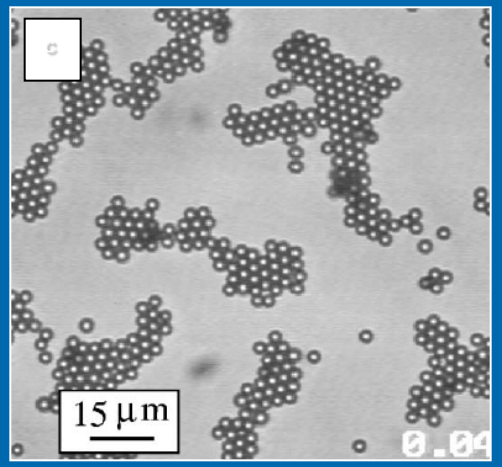
No electric field



f = 2 kHz, E = 185 V cm^{-1}



f = 400 Hz, E = 185 V cm^{-1}

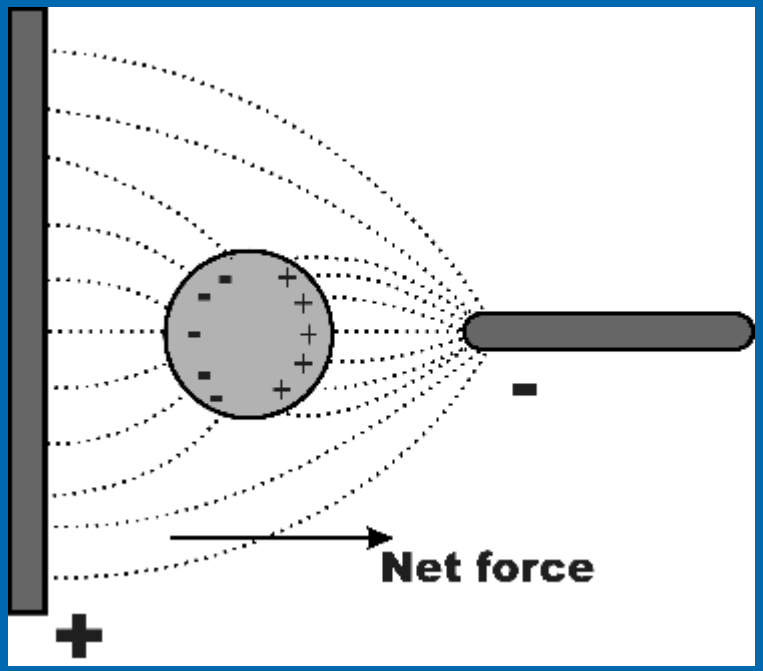


Overcome dipole-dipole repulsive forces at lower frequencies

Assembly of 1.5 µm particles in an aqueous solution of NaOH (10^{-4} M)

Nadal, F., et al., *Physical Review E* (2002)

Dielectrophoresis Schematic



- AC phenomenon
- Neutral particles polarized by electric field
- Polarity switches, charge distribution pushes against new electric field

Dielectrophoresis Background

- AC field induced motion in polarizable particles
  - Low Voltage Actuation
  - Suitable for biological systems
- Widely used first order approximation:

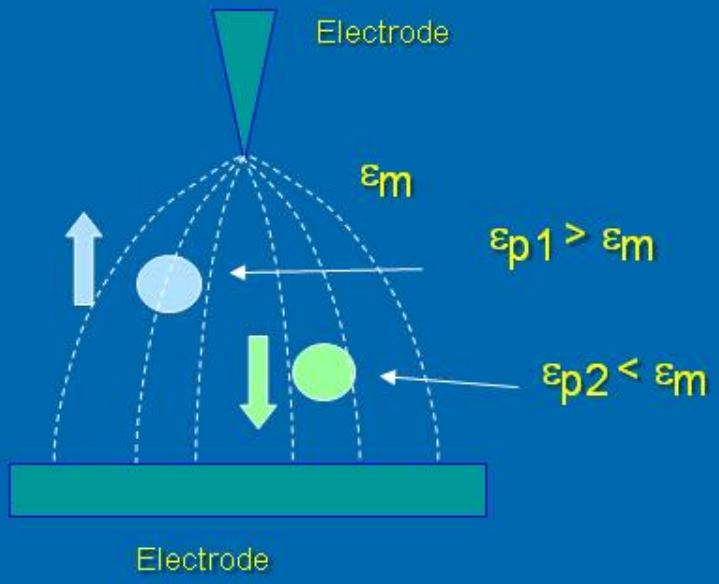
$$F = 2\pi\varepsilon_0\varepsilon_m r^3 \,\mathrm{Re}\left[f_{CM} \right] \nabla \left| E_{RMS} \right|^2$$

$$f_{CM} = \frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_p^* + 2\varepsilon_m^*}$$

- First order accuracy insufficient to predict dynamics of small particles near electrode edges

Interdigitated Electrodes

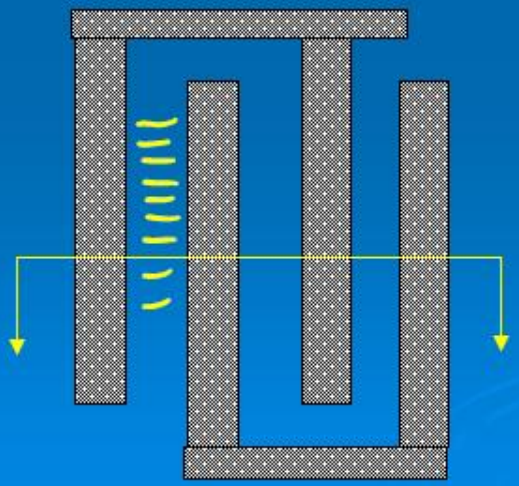
H. Li, R. Bashir, Sensors and Actuators B

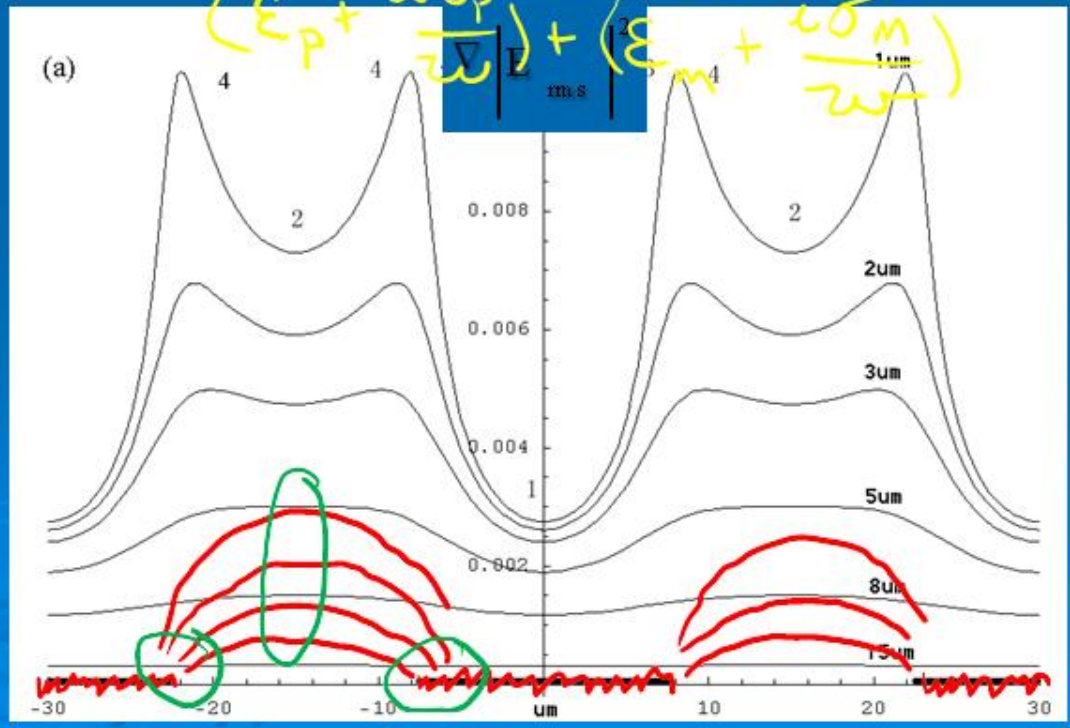


$$F = 2\pi r^3 \varepsilon_m \varepsilon_0 \mathrm{Re}[f_{CM}] \nabla \left| E_{rms} \right|^2$$

$$f_{CM}(\varepsilon_p, \varepsilon_m) = \frac{\varepsilon_p - \varepsilon_m}{\varepsilon_p + 2\varepsilon_m} \qquad \varepsilon_p = \varepsilon(\omega)$$

$$\frac{\varepsilon_p + i\frac{\sigma_p}{\omega} - (\varepsilon_m + i\frac{\sigma_m}{\omega})}{(\varepsilon_p + i\frac{\sigma_p}{\omega}) + (\varepsilon_m + i\frac{\sigma_m}{\omega})} \nabla \left| E_{rms} \right|^2$$

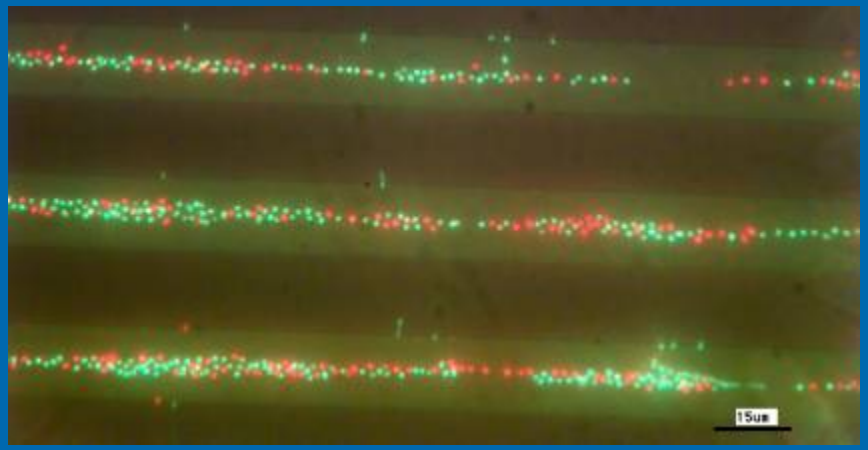




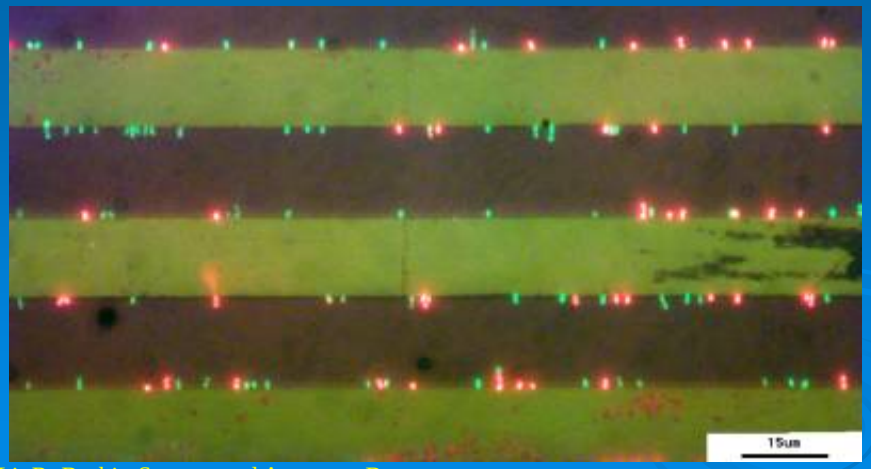
*H. Li, R. Bashir, Sensors and Actuators B

Manipulation of *L. innocua*

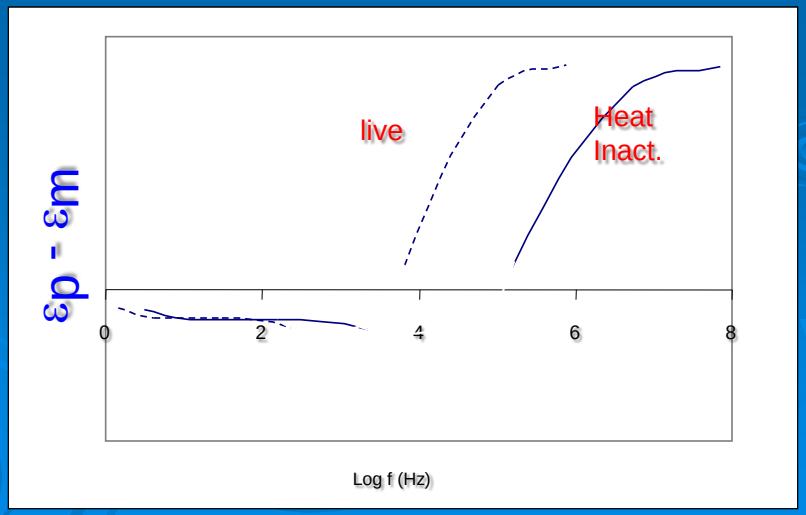
Negative DEP – AC voltage of 1V (V_{pp}) and 1KHz



Positive DEP – AC voltage of 1V (V_{pp}) and 100KHz



live cells (positive DEP), dead cells (negative DEP) 1V (V_{pp}) and 50KHz,



- H. Li, R. Bashir, Sensors and Actuators B