ELECTROHYDRODYNAMIC MODELING FOR MANIPULATION OF MICRO/NANO PARTICLES IN MICROFLUIDIC SYSTEMS

A. NECULAE, M. LUNGU, M. BUNOIU and R. GIUGIULAN

Faculty of Physics, West University of Timisoara, ROMANIA

Abstract

Studies developed over the past ten years, since the inception of microfluidics, showed that the electric force can be the ideal candidate for spatial precision control of the particles suspensions movement in an operating fluid (electrohydrodynamics). A very high electric field can be obtained and the electric force can be highly localized because the electrodes are placed cross a small distance (from sub-millimeter to a few microns). Dielectrophoretic (DEP) force is exerted when a neutral particle is polarized in a non-uniform electric field, and depends on the dielectric properties of the particle and those of the suspending medium. The integration of DEP and microfluidic systems permits numerous applications in different areas as micro/nano particles manipulation and filtration, nanoassembly, biosensors, cell therapeutics, drug discovery, medical diagnostics.

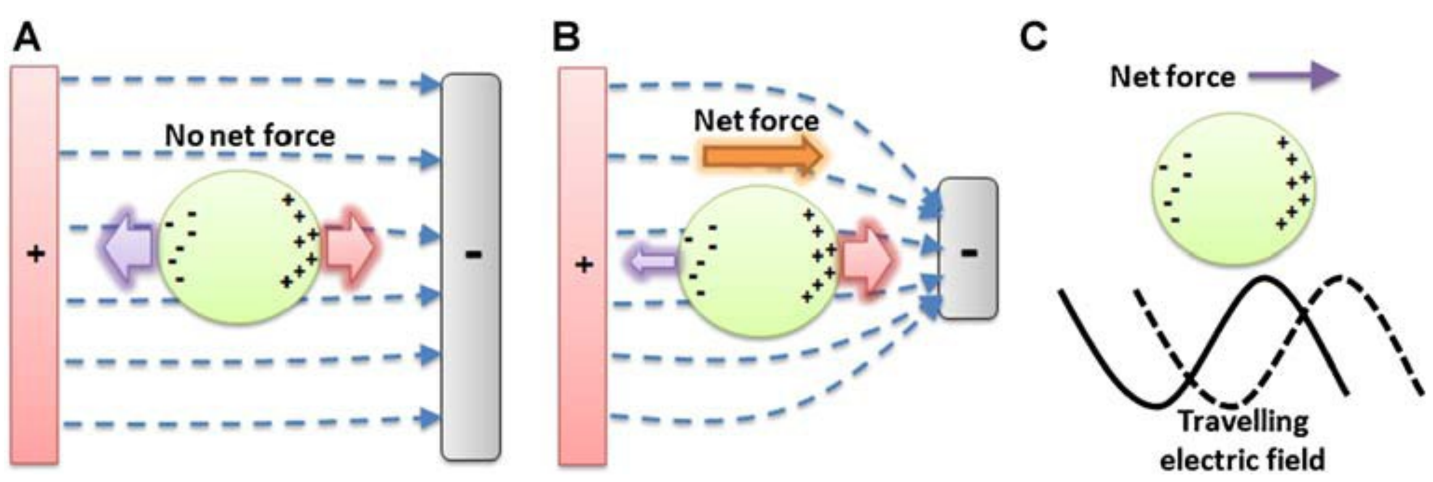
This paper presents the basics of the dielectrophoresis theory, different examples of electrodes configuration and the applications of such systems for particle manipulation together with a set of numerical results obtained in the frame of a two-dimensional mathematical model. The numerical solutions are computed using the finite element method.

Dielectrophoresis (DEP)

Phenomenon in which a force is exerted on a dielectric particle subjected to a nonuniform electric field

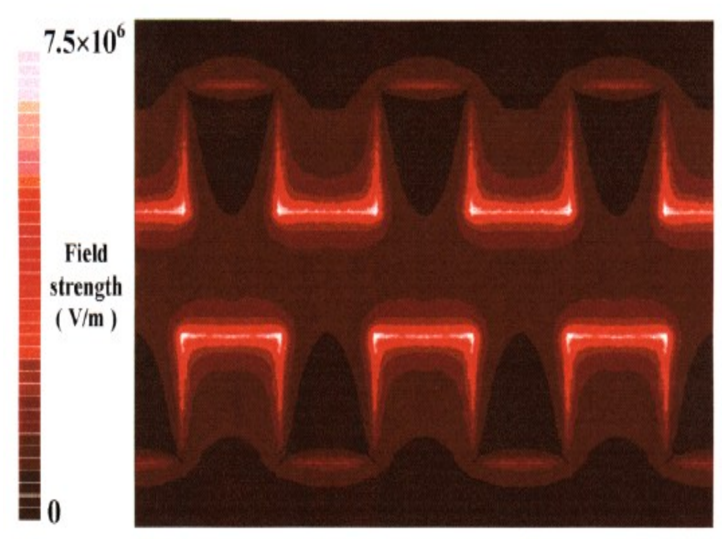
Principle of dielectrophoretic manipulation:

In spatially non-uniform AC electric fields, dielectric particles move as a consequence of the interaction of the dipole induced in the particle and the applied field gradient

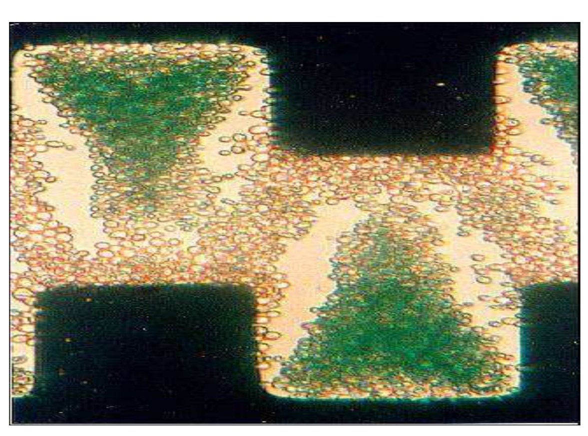


(a) A particle experiences zero net force while suspended in a uniform electric field. (b) A particle experiences the DEP force because of the magnitude of the gradient of the electric field. (c) A particle experiences the DEP force because of the electric field phase gradient [3]

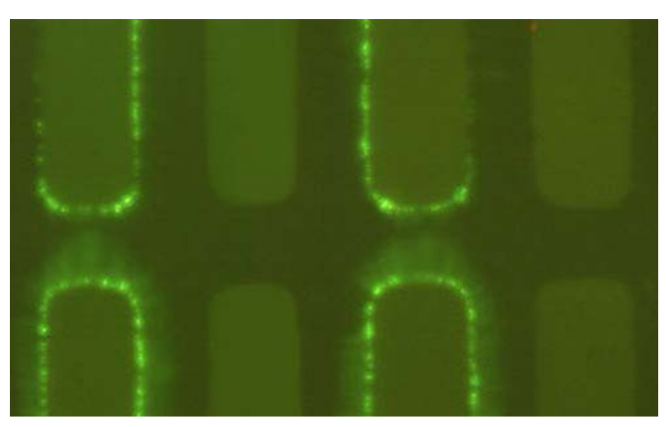
Castellated microelectrode for nanoparticle separation (electrode gap= 4 microns)



Electric field distribution for a castellated electrode array

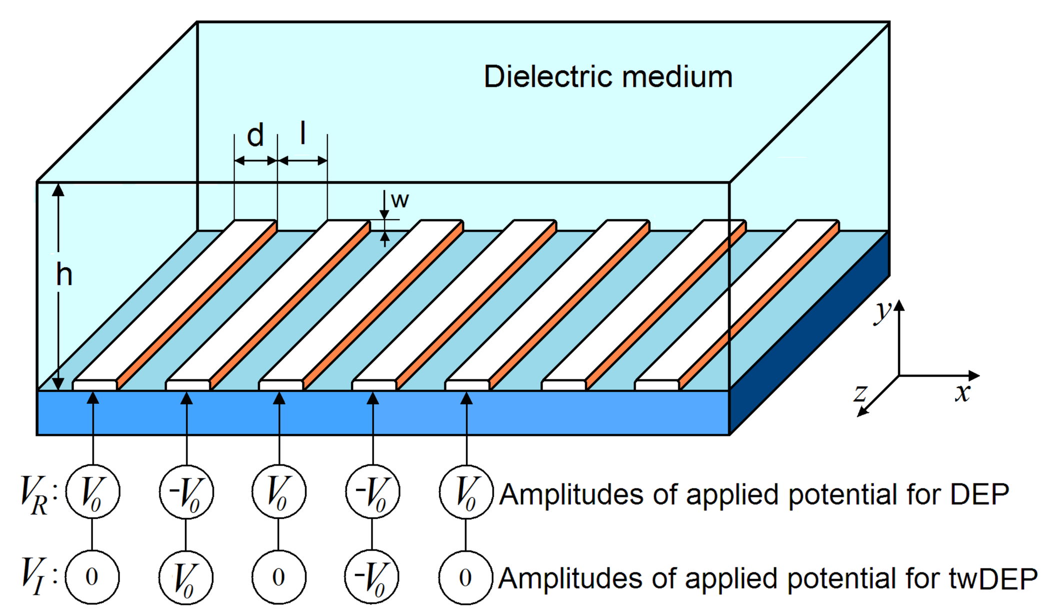


Viable yeast cells collecting by positive DEP into pearl chains, and "stained" nonviable cells collecting by negative DEP into triangular aggregations levitated above the electrode plane [5]



Fluorescence image of DNA molecules attached to selected electrodes by use of DEP trapping [3]

Mathematical model



Schematic representation of the computational domain

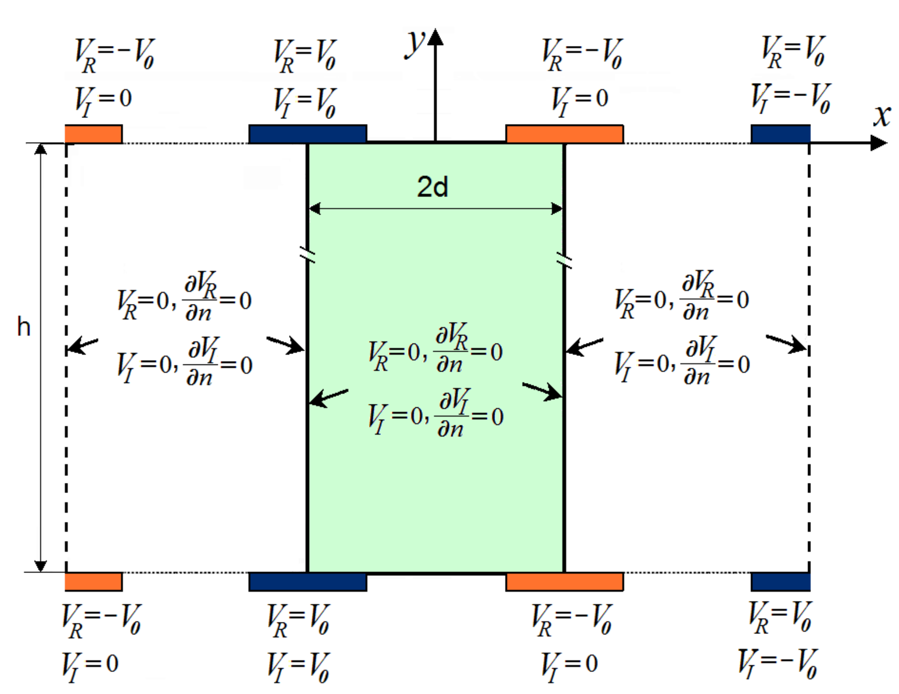
Equations:

$$V(\mathbf{x},t)=\mathrm{Re}\{\tilde{V}(\mathbf{x})e^{j\omega t}\}$$

$$\tilde{V}=V_R+jV_I$$

$$\nabla^2 V_R=0 \quad \text{and} \quad \nabla^2 V_I=0$$

Boundary conditions:



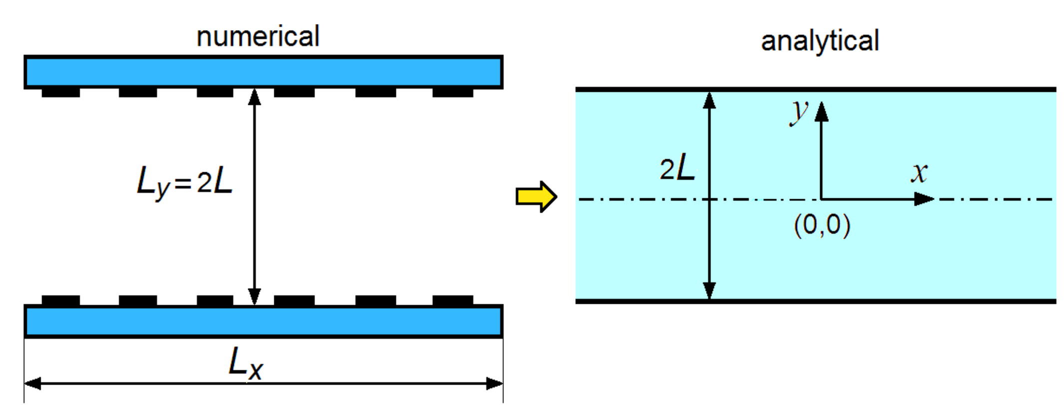
Dielectrophoretic forces:

$$\langle \mathbf{F}_{DEP}\rangle=\frac{3}{4}\varepsilon_m\tilde{k}_r\nabla\left(|\nabla V_R|^2+|\nabla V_I|^2\right)$$

$$\langle \mathbf{F}_{twDEP}\rangle=-\frac{3}{2}\varepsilon_m\tilde{k}_i\left(\nabla\times\left(\nabla V_R\times\nabla V_I\right)\right)$$

Validation:

Computational domain:



Boundary condition:

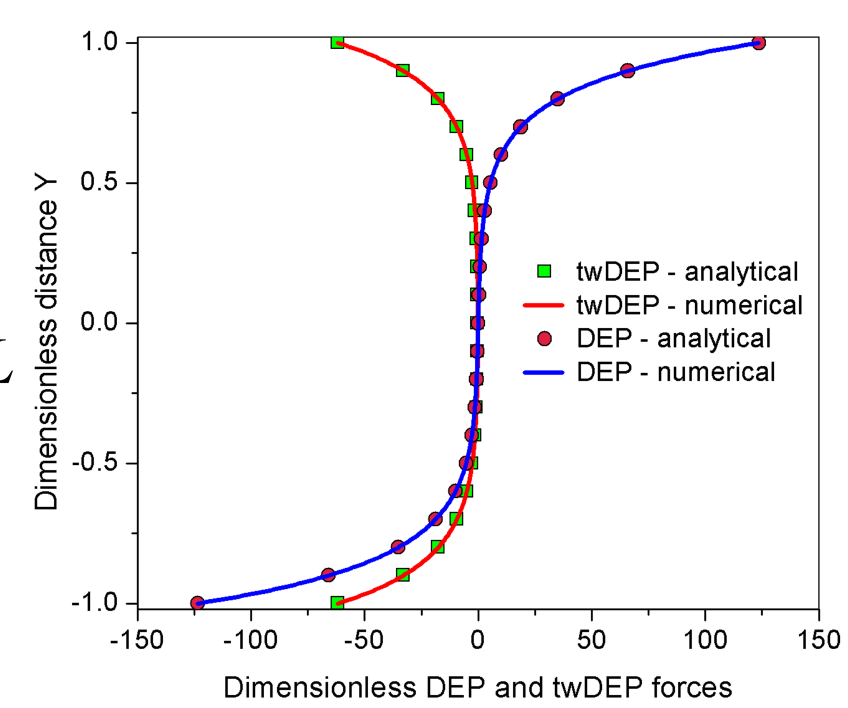
$$\tilde{V}=V_0\exp(i\omega t-qx)$$

Analytical solutions:

$$\tilde{V}(\vec{r})=V_0\exp(-iqx)\cosh qy/\cosh qL$$

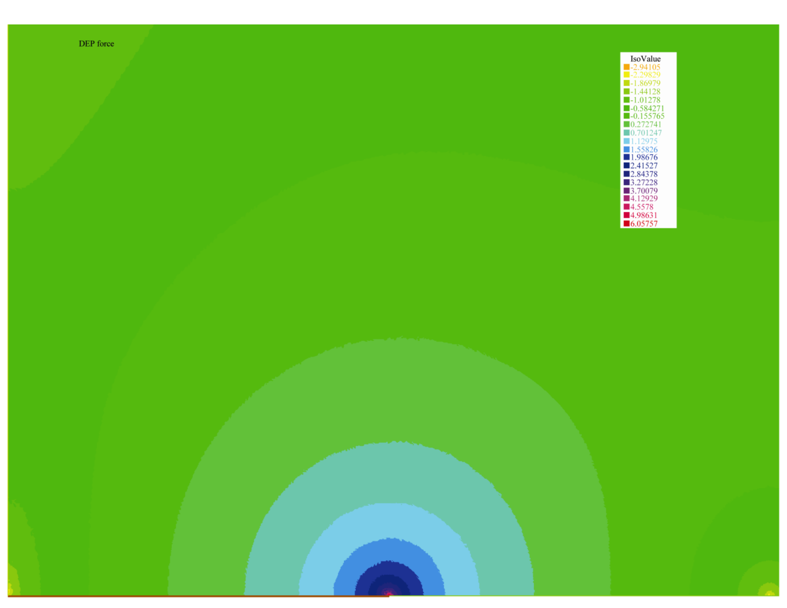
$$\mathbf{F}'=F_0\left(k'\cosh by,\sinh by,0\right)$$

$$F_0=3\varepsilon_m V_0^2 q^3 k_R/2\cosh^2(b/2)$$

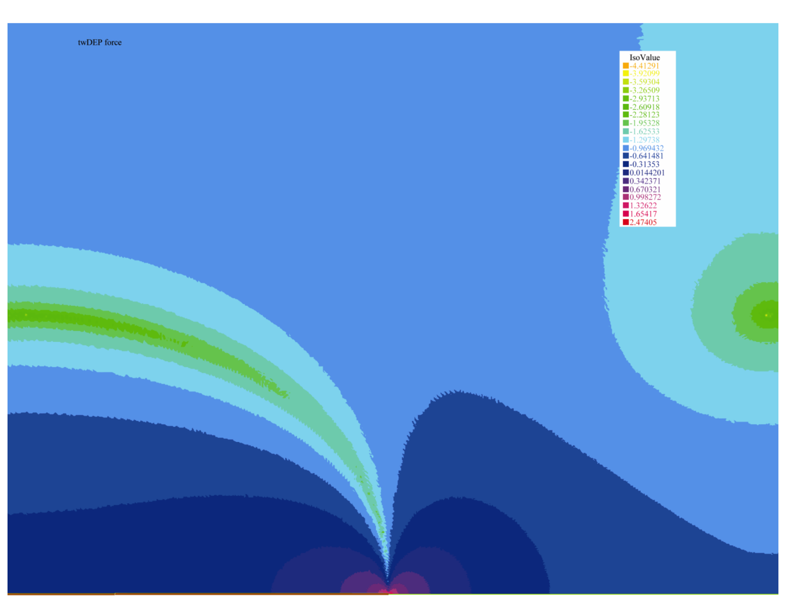


Analytical versus numerical solutions for the dielectrophoretic forces

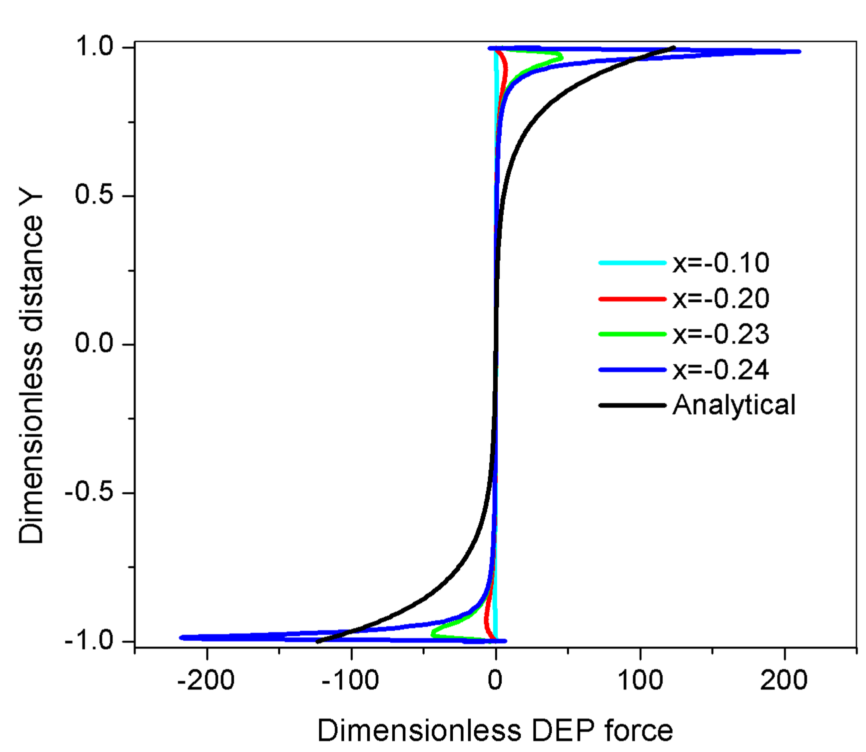
Numerical results



Detail: Calculated amplitude of the dimensionless DEP force in the vicinity of the electrode (logarithmic scale)



Detail: Calculated amplitude of the dimensionless twDEP force in the vicinity of the electrode (logarithmic scale)



Transverse variation of the calculated dimensionless DEP force for different longitudinal coordinates. Note: the dimensionless value x=0 corresponds to the middle of the electrode while the value x=-0.25

Acknowledgements

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