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Maxwell stress tensor calculation of forces in AC Dielectrophoresis

Abstract. . *In the conventional DC electrokinetics, electrophoresis is used to separate different particles according to their different mobilities or distribution coefficients. DC electrokinetics need special high voltage supply devices, which are not easy to be integrated with other micro-devices, and high voltage may also cause significant temperature increase in the electrolyte solution. High voltage gradients in solution are sources of computational errors in computation of forces acting on dielectric particles. In this publication effective dipole moment for two-dimensional particles is developed and at the end some practical example is given.*

Keywords: Maxwell stress tensor, dielectrophoresis, finite element method.
Słowa kluczowe: Tensor naprężeń Maxwella, dielektroforeza, metoda elementów skończonych.

Introduction

In comparison to electrophoresis, by which we understand particle motion due to the force resulting from coupling between an applied external electric field and a charge particle, dielectrophoresis has the disadvantage that the polarization forces acting on polarized particle are quite weak. In general, efficient particle manipulation in microelectrode arrangement requires taken into account other factors, such as viscous, buoyancy, and electrohydrodynamic forces. This constitutes complicated system of mathematically coupled different physical fields, which results in mutually coupled system partial differential equations. From practical point of view only numerical methods can give, from practical point of view, satisfactory results

Maxwell Stress Tensor

Most general approach to dielectrophoretic force calculation is proposed by Sauer and Schloegl and is based on the Maxwell stress tensor formulation where the stress tensor is integrated over the any surface surrounded the particle [2]:

$$\mathbf{F}_{\mathrm{DEP}}(t)=\oint\left(\tilde{\mathbf{T}}\cdot\mathbf{n}\right)\mathrm{d}S \tag{1}$$

The time-averaged force on the particle using equivalent electric dipole moment is given by [1]

$$\begin{aligned}\langle\mathbf{f}(t)\rangle &= \mathrm{Re}\left[(\hat{\mathbf{p}}\cdot\nabla)\hat{\mathbf{E}}^{*}\right]= \\ &= 2\pi\varepsilon_1 r_0^3\left\{K_{\mathrm{R}}\nabla\left|\hat{\mathbf{E}}\right|^2+2K_{\mathrm{I}}\left[\nabla\times(\mathbf{E}_{\mathrm{I}}\times\mathbf{E}_{\mathrm{R}})\right]\right\}\end{aligned} \tag{2}$$

where $\mathbf{E}_{\mathrm{R}}$ and $\mathbf{E}_{\mathrm{I}}$ are real and imaginary parts of electric field $\mathbf{E}$ and K_{R} and K_{I} are real and imaginary parts of the well-known Clausius-Mossotti complex factor defined as

$$\hat{K}(\hat{\varepsilon}_1,\hat{\varepsilon}_2)=\frac{(\hat{\varepsilon}_2-\hat{\varepsilon}_1)}{\hat{\varepsilon}_2+2\hat{\varepsilon}_1} \tag{3}$$

Computational results

It was assumed that tumor occurs in liver as in Fig.1 right. The amount of $10\,\mathrm{mg/cm^3}$ nanoparticles was injected into tumor and uniformly inside distributed. Geometrical dimension are given in Fig.1. Exciting wirers with current have parameters $I_{\max}$ = 1e4 [A], r_5 = 0.01 [m] and frequency f = 100 [MHz], Physical parameters of blood are as follows: ρ_b = 1060 [kg/m^3], C_b =3639 [J/(kg·K)], T_b = 310.15 [K], ω_b= 0.005 [1/s]. Physical parameter of tissues are given by: relative permittivity ε_r = 29.6 in body, 70 in tumor and 5.8 in liver, electric conductivity σ = 0.02[S/m] in tumor, body and skin and 0.002[S/m] in liver. The hysteresis loss for one loop is $5\cdot10^{-4}$J/g when H_0=35kA/m. The frequency was assumed f = 100kHz. The exciting current was so adjusted to attain specific loss power 400, 450 and 500 mW/cm^3.

Results

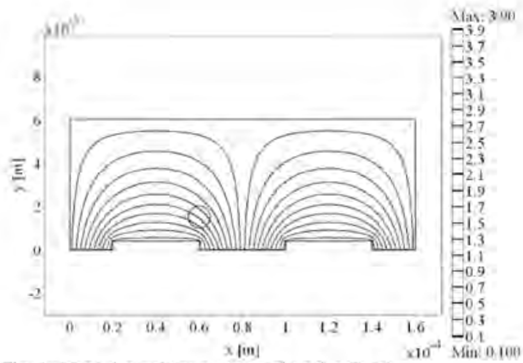

Fig.1. Modulus of the potential in the fluid

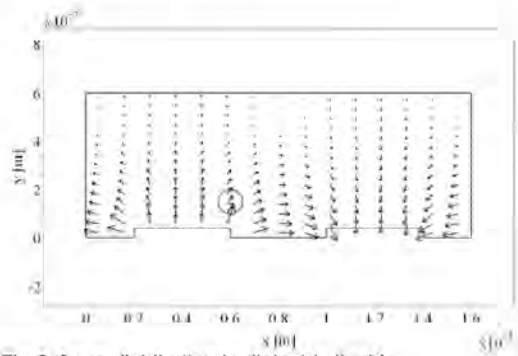

Fig.2. force distribution in dielectric liquid.

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