Simulation of CMOS Compatible Sensor Structures for Dielectrophoretic Biomolecule Immobilization

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Abstract

The aim of this paper is to optimize with COMSOL Multiphysics® simulation, the design geometry of a near field biosensor which could be used for dielectrophoretic (DEP) immobilization and simultaneous sensing of biomolecules of the order of nanometers to micrometers. COMSOL Multiphysics® was utilized with its various potential modules such as AC/DC, CFD and Particle Tracing Modules. DEP technique has been widely used in conjunction with microfluidics for many biological applications. However, using the sensor structure additionally for dielectrophoretic immobilization has not been explored. In this work, interdigitated electrode (IDE) structures previously used for radio frequency biosensors were used to model the dielectrophoretic structure.

Tracing of particles based on DEP force is primarily dependent on amplitude and frequency of the applied potential, spatial gradient of the electric field due to the applied potential and structure geometry, as well as dielectric properties of particle and fluid medium. Therefore, in order to optimize the sensor which could be capable of DEP immobilization of biomolecules of different sizes, applied AC voltage was kept to CMOS compatible ranges, while the influence of AC frequency and fluid flow velocity were studied. In addition the effect of geometrical parameters of the IDEs on tracing and trapping of the particles were simulated and studied.

In this model a medium consisting of particles is pumped through the channel from inlet port and past the electrode array which are located on the bottom of the channel. An AC source is applied across the electrode to generate a non-uniform electric field. DEP is the interactive force between the induced dipoles and the non-uniform electric field and as result particles are able to move and rotate in the solution to follow the direction of the electric field lines. Biomolecules can move towards the highest electric field gradient depending on the relative permittivity of biomolecules and medium as a result of the positive DEP (pDEP) or in reverse due to negative DEP (nDEP).

In this study different geometrical parameters of electrodes such as width and space between adjacent fingers of IDEs were modeled. The medium for suspension of the biomolecule is considered to be blood in the simulation. Due to non-Newtonian nature of blood, a creeping flow model was used. The Electric Current physics interface was used to simulate the electric field in the channel. Particle Tracing for Fluid Flow in conjugation with Drag and Dielectrophoretic Forces were used as the physics interfaces to drive the particle motion.

The results demonstrate that by reducing the particle size, the AC frequency had to be increased and the flow velocity had to be decreased in order to achieve immobilization of the particles. Results from systematic simulation of geometrical electrode parameters showed that the smaller the spacing between adjacent electrodes a bigger electrode width is required for trapping of particles on electrodes and in reverse. This trend was the same for all simulations even with increasing or decreasing the voltages, frequencies and fluid flows.