Simulation of Electrothermoplasmonic Flow Around an Array of Gold Nanoantennas for Plasmonic Sensing

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INTRODUCTION: Plasmonic-based biosensors have emerged as a powerful, cost effective and portable platform for phatogen and biomarker detection. In particular, Localized Surface Plasmon Resonance (LSPR) based systems, present high sensitivity, specificity and real time detection. Current approaches integrate the plasmonic sensors in microfluidic channels, providing a multiplexing platform where many different experiments can be run in parallel [1]. Although promising, the performance is strongly limited by the long times imposed by the diffusion-limited transport of the species.

In recent years, researchers have investigated a variety of approaches to solve this general and crucial issue, using optofluidics [2, 3] and electrokinetics effects [4].

Here, we present numerical simulations of the laser-induced heating of a single or array of gold nanoantennas which, in conjunction with an applied a.c. electric field, initiates rapid microscale fluid motion, termed electrothermoplasmonic (ETP) flow [5,6], and particle transport.

$$\mathbf{F}_{\mathrm{ETP}}(\mathbf{r}) = \frac{1}{2}\mathrm{Re}\left[\frac{\varepsilon(\alpha-\beta)}{1+i\omega\tau}(\nabla T(\mathbf{r})\cdot\mathbf{E})\mathbf{E}^{*} - \frac{1}{2}\varepsilon\alpha|\mathbf{E}|^{2}\nabla T(\mathbf{r})\right]$$

The numerical results are compared with experimental measurements and are also used to explore the influence of the different geometries for the nanoantennas array and the parameters of the external applied electric field [7].

COMPUTATIONAL METHODS: COMSOL Multiphysics has been used to solve the dynamics of electro-thermo-plasmonic flow (ETP) within a microchannel. Use has been made of the physical interfaces Creeping Flow and Heat Transfer in Fluids, with a volumetric ETP flow force. The fluid flow boundary conditions are of the wall type (u = 0); except when fluid is injected, where extreme contours are replaced by inlet and outlet conditions.

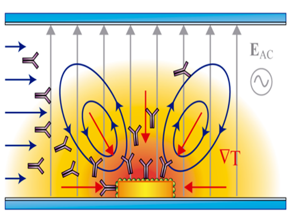

Figure 1. Schematics of LSPR sensor bio-detection process

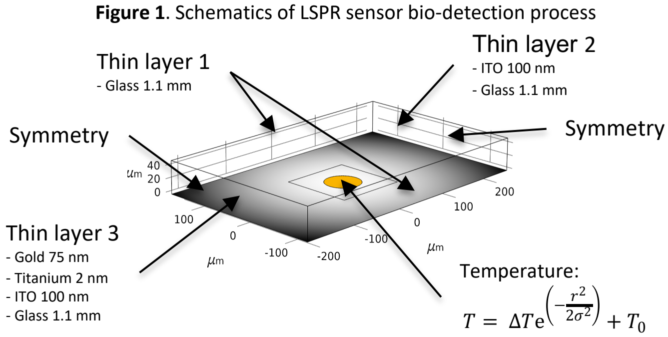

Figure 2 . Boundary conditions used for Heat Transfer in Fluids

RESULTS: The simulations carried out predict the generation of convective flow within the microchannel. In the absence of externally imposed flow, the simulations predict stable vortices around the region where a temperature gradient has been generated (Fig. 4). In the presence of an inflow, its superposition with the electro-thermo-plasmonic vortices gives rise to flow profiles like those shown in Fig. 5. These simulations coincide with the experimental observations (Fig. 7), which predict a improvement in detection when performing a biodetection experiment using LSPR [7].

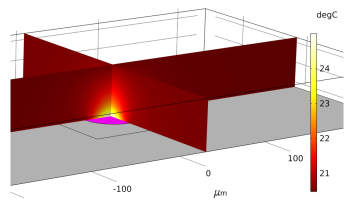

Figure 3. Temperature gradient in the microchannel.

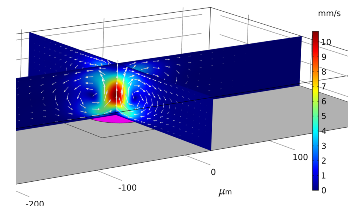

Figure 4. Fluid flow profile for static conditions.

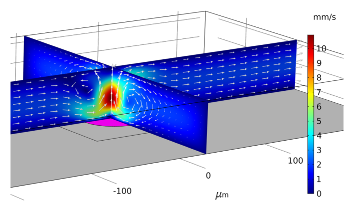

Figure 5. Fluid flow profile simulation for flow conditions.

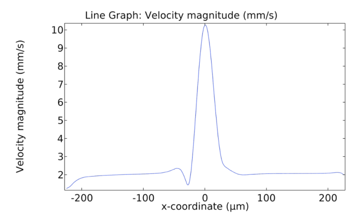

Figure 6. Flow velocity within the microchannel.

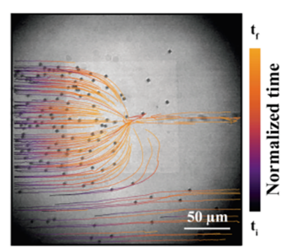

Figure 7. Experimental image of the trajectory of the particles for flow conditions (from top).

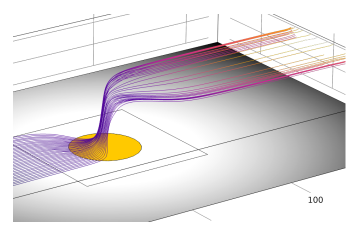

Figure 8. Trajectory of the particles for flow conditions.

CONCLUSIONS: The electro-thermo-plasmonic effect can be implemented in a biosensor in such a way that it is possible to overcome the limitations imposed by diffusion and to maximize the detection performance. The results obtained will allow the construction of optimized designs of lab-on-a-chip devices.

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