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Simulation and experimental validation of particle trapping in microfluidic magnetic separation (MMS) system

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Abstract

Microfluidic magnetic particle trapping system was modelled, designed and manufactured to characterise and enhance the separation efficiency during sample preparation and analysis. Coupled multiphysics model of the evolving magnetic field, fluid dynamics and particle trajectories was implemented in COMSOL Multiphysics. The movement and entrapment of magnetic beads in the microfluidic magnetic separation (MMS) system were analysed and the spatial distribution of the trapped magnetic particles were compared to experimental results. For functional validation the microfluidic system was manufactured in polydimethylsiloxane (PDMS) by soft lithography technique, and special Fe-Ni patterns were deposited to locally amplify the magnetic field. The measured flow and particle motion characteristics were in good correlation with the simulations.

Keywords: microfluidics; Lab-On-a-Chip; magnetic microfluidic system; MMS

1. Introduction

Precise manipulation of particles and cells in fluidic environment is a key issue in Lab-On-a-Chip systems which requires complex sample preparation steps, such as, sorting of the formed elements of blood or separation of special nano- or microparticles. Particle separation is challenging because these particles often have physical parameters

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(density, dielectric constant, etc.) similar to the solvent. Active separation techniques could offer several effective solutions, although they require an external field and power. Microfluidic Magnetic Separation (MMS) devices utilize the effective magnetophoresis based magnetic bead manipulation applying microfabricated paramagnetic patterns to locally amplify the magnetic field [1]. Regarding their functionality the design and reliable prediction of particle movement in the coupled magnetic and fluidic environment are essential [2].

2. Experimental

In the present work coupled Finite Element Modelling (COMSOL Multiphysics) was used to simulate particle manipulation by the combined hydrodynamic and magnetophoretic processes in complex microfluidic structures. According to the proposed application different laterally structured Fe-Ni layer geometries were implemented and their functional performance was analyzed. The evolving magnetic field incorporated with the paramagnetic (Fe-Ni) structure was calculated and laminar flow was considered to solve the velocity and pressure fields in the microfluidic system. Trajectories of magnetic particles in the microchannel were calculated. Experimental devices were fabricated and characterized to validate the results of numerical simulations. Fe-Ni metal patterns were fabricated by conventional micromachining on glass substrate and integrated in the microfluidic system developed by soft lithography technique in PDMS.

3. Results

The evolving magnetic field was visualized using ribbons (Fig. 1). The movement and the resulted local distribution of trapped magnetic beads were analysed (Fig. 3) and compared to the modelled behaviour (Fig. 4-5).

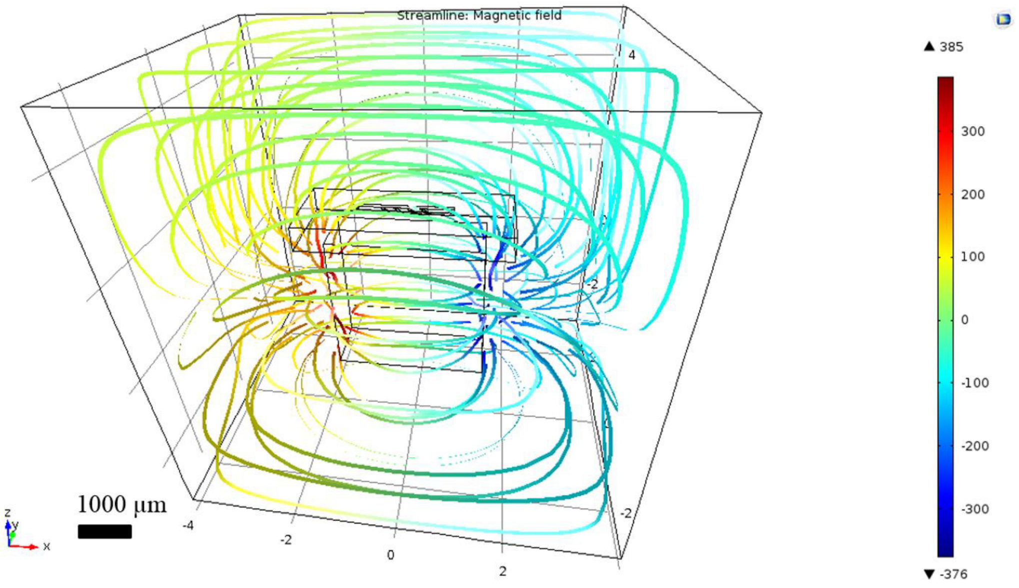

Figure 1. FEM modelled field lines of the evolving magnetic field.

Particle trajectories demonstrated the trapping effect caused by the grid type paramagnetic pattern in (Fig. 2). Some of the particles traveled further down the channel.

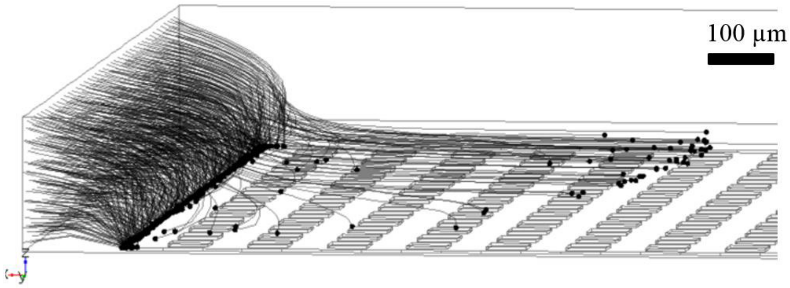

Figure 2. Particle trajectories over the grid type paramagnetic pattern in the MMS structure.

Experimental results showed the capturing effect of the paramagnetic grid (Fig 3.a). Untrapped particles followed the gridlines parallel to the flow direction (Fig 3.b) and maintained these trajectories after the pattern as well.

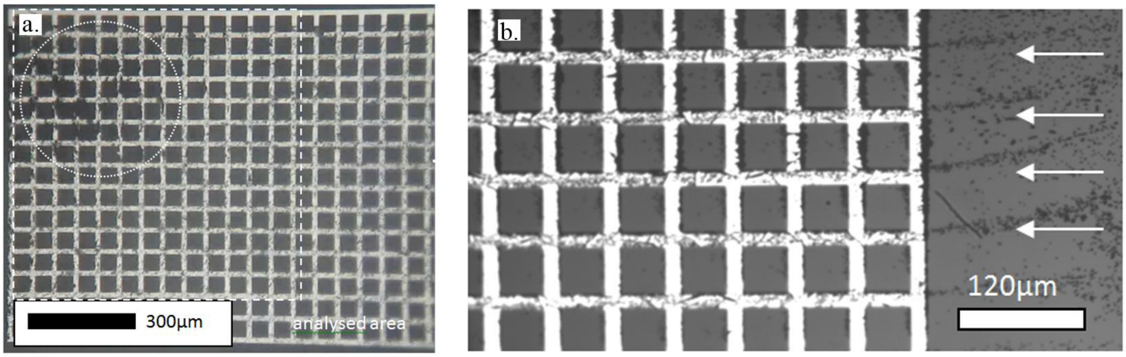

Figure 3. Movement of the magnetic beads over the paramagnetic pattern: trapped magnetic beads on the paramagnetic (Fe-Ni) pattern of the MMS chip (a), untrapped particles follow the grid lines parallel to the flow direction (b)

Distribution of magnetic particles was recorded using grid intensity analysis and compared to the FEM model results (Fig. 4). The FEM model captured well the trapping effect of the first grid lines. Relative spatial distribution was calculated along the channel (Fig. 5). The emphasized effect of the first gridline was observable.

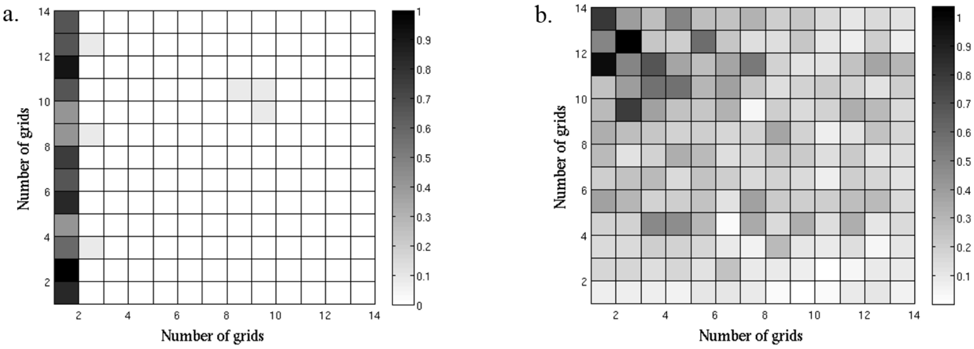

Figure 4. Trapped particle distribution at the grid points of the paramagnetic pattern. The darkness of the given squares represents the ratio of the trapped particles in case of modelling (a) and the surface coverage ratio in case of experiments (b) determined by intensity measurements. Note the limited particle number (100) used in the simulations.

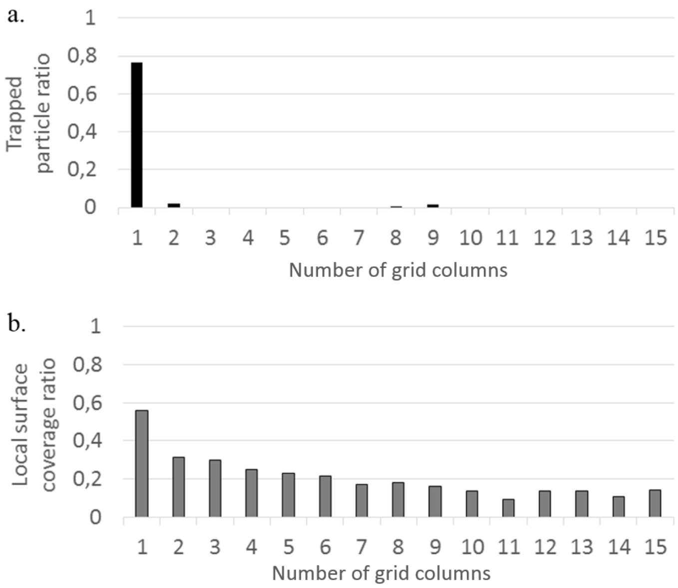

Figure 5. Modelled (a) and experimental (b) relative spatial distribution of the trapped particles as the function of the distance from the inlet. According to both the simulation and the experiments also most of the beads are trapped at the first grid-line.

4. Conclusions

Critical spatial distribution of the evolving magnetic field influenced by metal patterns was revealed and particle tracing clearly demonstrated their probable entrapment in the MMS system. The experimental and theoretical results are in agreement, proving the applicability of our modelling strategy to predict these complex physical effects in the proposed MMS system.

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