Simulation of an Immunodetection System Based on Magnetic Nanoparticles

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Abstract

Magnetic nanoparticles are commonly used in numerous applications such as magnetic resonance imaging (MRI), local hyperthermia treatment, magnetic separation, information storage, and medical diagnostics using magnetic immunoassays [1]. The latter field has become increasingly popular in the last years because of the favorable properties of magnetic particles. In fact, the particles can be used both for magnetic actuation as well as for magnetic detection of biomolecules. In the case of immunoassays, the magnetic beads are bound to the biological target substance using the highly specific antibody-antigen interaction [2]. The most common assay format is the sandwich immunoassay in which the analyte is captured by an immobilized primary antibody and the streptavidin-coated magnetic particles are bound to the analyte by a biotinylated secondary antibody.
The challenge is to measure the magnetic marker particles with high accuracy and with high selectivity. The magnetic frequency mixing technique [3] is very well suited for this purpose, thus allowing using it for immunoquantification.
In a joint project, UPMC and FZJ cooperate on the development of magnetic detection techniques for magnetic nanoparticles on a microfluidic platform (Figure 1). To achieve this, a selective magnetic micro-detection unit shall be combined with a microfluidic structure for the first time. The microfluidic approach will allow using small quantities of analyte and reagents and will enable quick analysis. The aim is to create a simple and portable analysis platform for magnetic immunoquantification which may be applied for diagnosis of illnesses, prevention of pandemia, as well as food monitoring, environmental protection, etc.
In a first approach towards application of the magnetic frequency mixing technique to microfluidic structures, planar micro-coils have to be designed. A COMSOL Multiphysics® electrical model (Figure 2) along with an analytical calculation is used in order to optimize the dimensions of the coil so that a proper distribution and value of magnetic flux density can be achieved at the sample area.
Along with this electrical simulation, a microfluidic simulation (Figure 3) and a heat transfer simulation (Figure 4) will be used so that we can optimize the microstructure for future usage with biological entities that are sensitive to temperature (hence there will be a limit in the used current).
This paper is focused on the multiphysics simulation of the biological diagnostic microstructure. The challenge is to find the best dimensions that ensure an even

distribution of flow, sufficiently low temperatures in the reservoir, a homogeneous magnetic field distribution and optimum coil sensitivity.

Reference

[1] U. Häfeli et al., Scientific and Clinical Applications of Magnetic Carriers, Plenum, New York (1997)
[2] K. Kriz et al., Advancement toward Magneto Immunoassays, Biosensors & Bioelectronics, Vol. 13, p. 817 (1998)
[3] H.-J. Krause et al., Magnetic Particle Detection by Frequency Mixing for Immunoassay Applications, J. Mag. Magn. Mater., Vol. 311, p. 436 (2007)

Figures used in the abstract

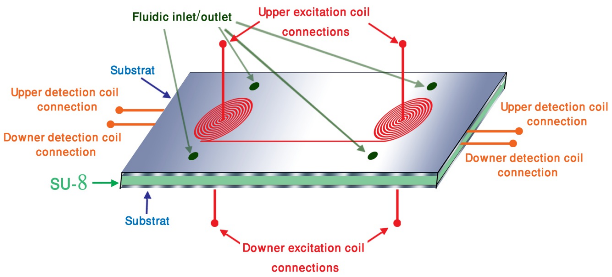

Figure 1: Schematic representation of the integrated excitation and detection coils in a microfluidic structure.

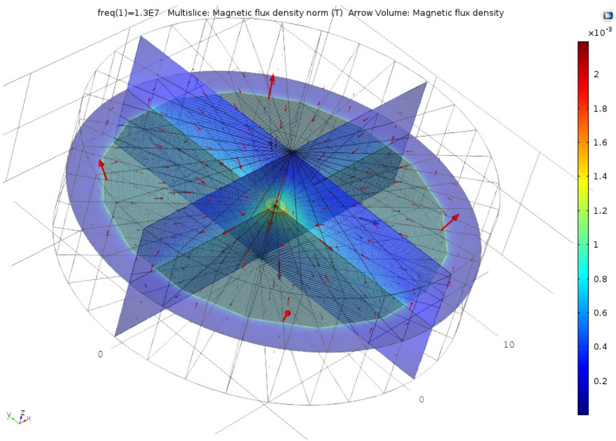

Figure 2: COMSOL Electromagnetic AC simulation of the spiral flat coil.

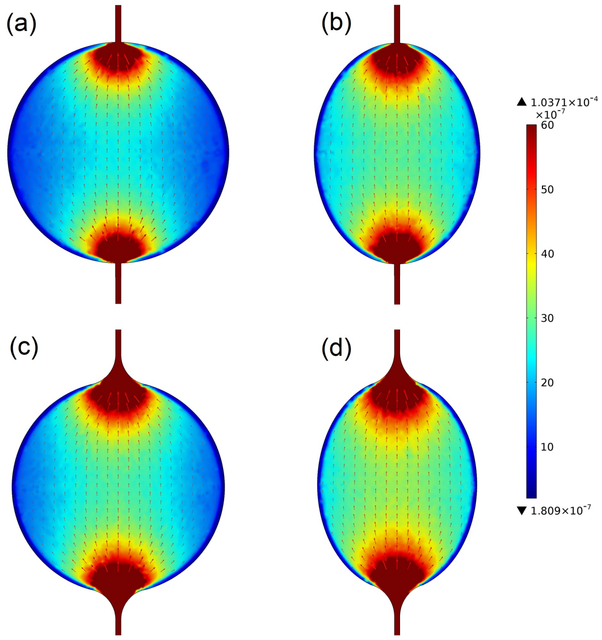

Figure 3: COMSOL simulation of the fluid flow homogeneity relative to the reservoir shape.

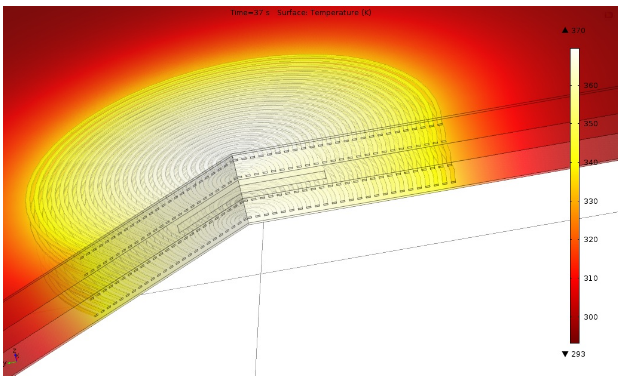

Figure 4: Heat transfer simulation using COMSOL Heat Transfer Module and contribution of the set of coils to the rising temperature of the microfluidic reservoir.