SIMULATION AND OPTIMIZATION OF A MAGNETIC FREQUENCY MIXING DETECTION OF MAGNETIC NANOPARTICLES FOR IMMUNOQUANTIFICATION IN A MICROFLUIDIC STRUCTURE

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1. Aim:

The challenge is to measure the magnetic marker particles with high accuracy and selectivity. The magnetic frequency mixing technique [1] is very well suited for the detection of magnetic nanoparticles on a microfluidic platform. The detection structure is composed of microplanar coils (excitation and detection) and a micro-reservoir containing the targeted sample. (Figure 1)

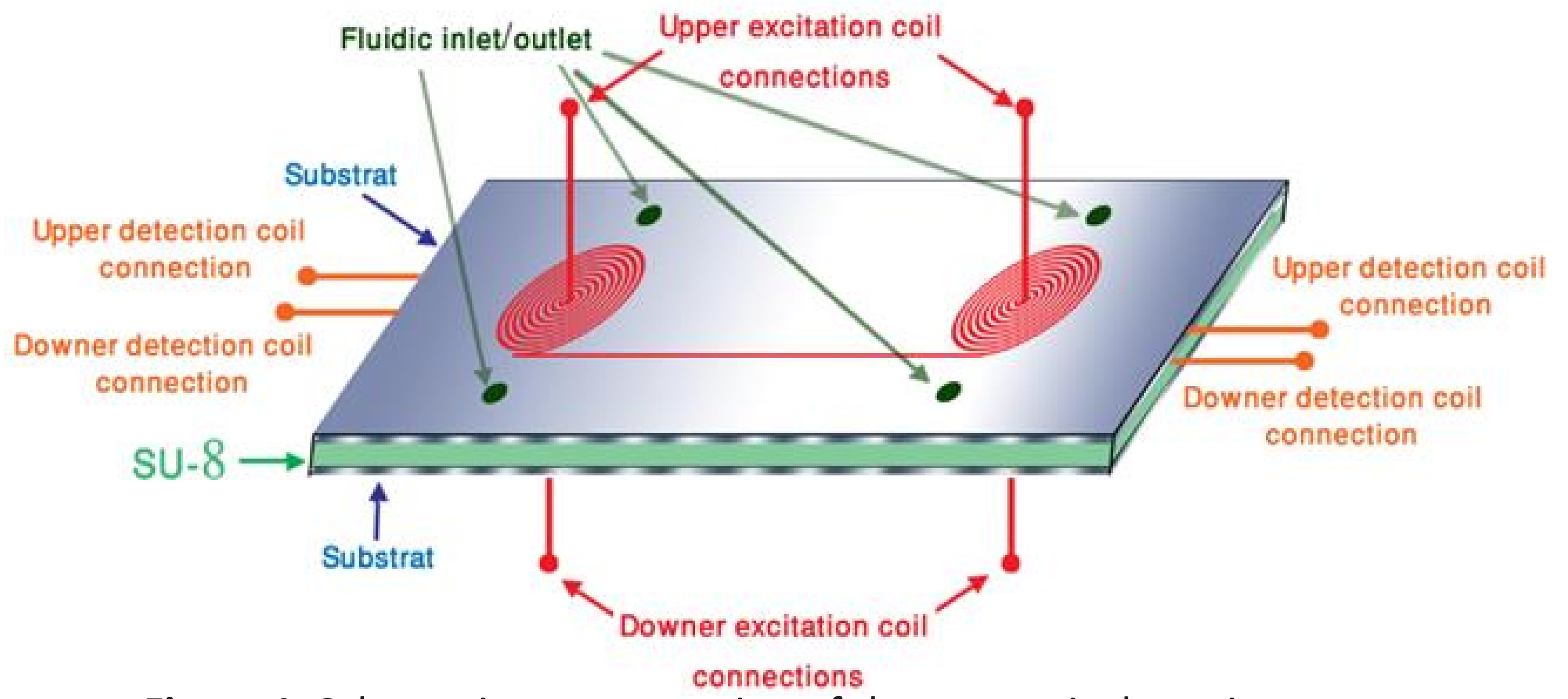

Figure 1. Schematic representation of the magnetic detection structure.

2. Methodology:

In a first approach towards application of the magnetic frequency mixing technique [1] to microfluidic structures, microplanar coils have to be designed along with sample reservoir. For this, a Comsol Electrical model (figure 2) along with an analytical calculation is used in order to optimize the dimensions of the coil. This is to ensure a proper distribution and value of magnetic flux density in the sample area.

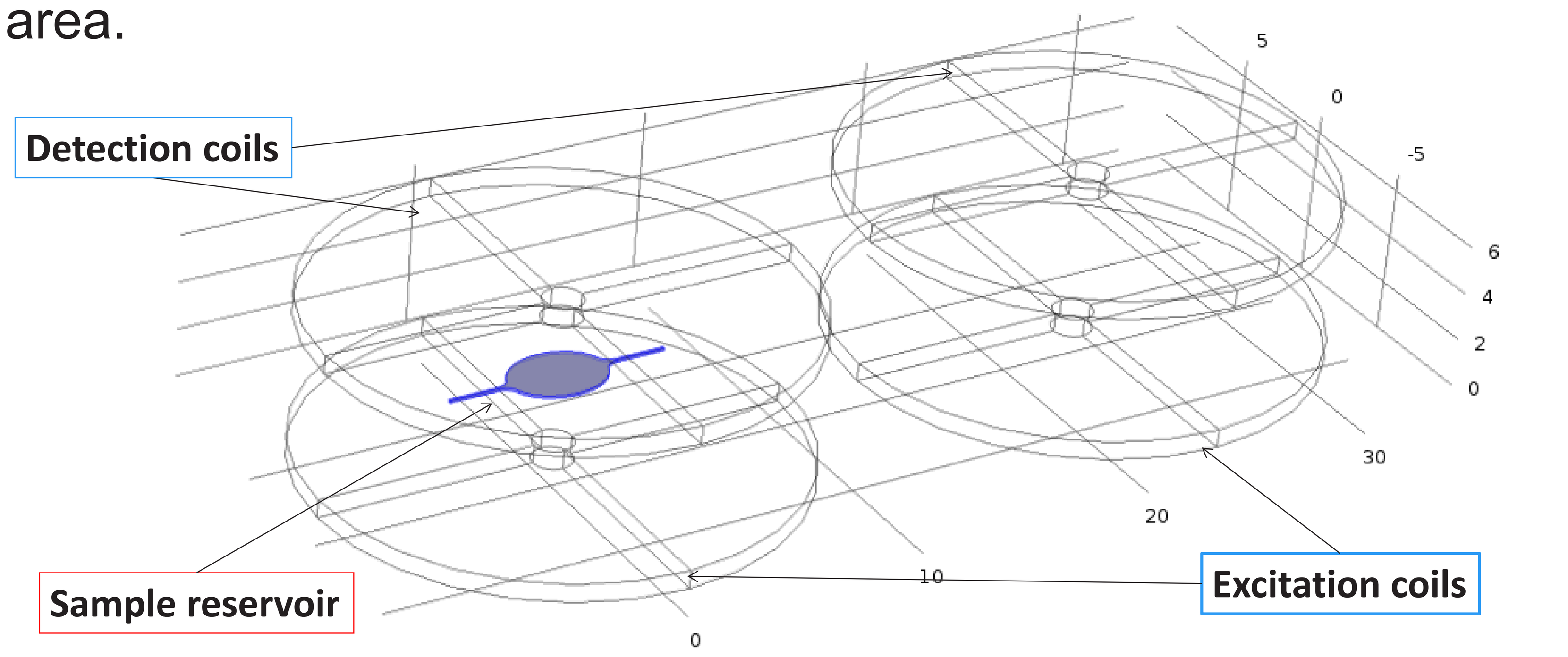

Figure 2. Electrical 3D model (AC/DC and electrical circuit Nodes)

Another Multiphysics model uses the heat transfer module and the electrical module to study the effect of the excitation current on the temperature variation of the reservoir. At last, to ensure a good distribution of fluids in the sample reservoir, the microfluidic module is used.

3. Results:

• Magnetic simulations:

The objective here is to investigate the effect of the parameters of the coils and the ferrofluid concentration on the detected signal. Using magnetic permeability and its relation with the concentration of "Fe" element in nanoparticles based fluid sample [2], we can simulate the change of magnetic flux density related to the corresponding concentration (Figure 3). Table 1 give the various geometrical characteristics considered for the coils and microfluid structure in the simulations.

Coils	Copper width/Isolation (μm)	Thickness (μm)	Number of turns per layer (N_L)	Total number of turns (N_{Tot})	Inside Radius (mm)	Materials
Low frequency coil	100	35	59	236	0.8	FR4 (substrat), Copper
High frequency coil	100	35	62	248	0.8	
Pick-up coil	100	35	46	184	0.8	

	Small diameter of reservoir (mm)	Big diameter of reservoir (mm)	Height of reservoir (μm)	Total volume of reservoir (μL)	Channel width (μm)	Number of inlets	Materials
Microfluidic structure	3.5	13	200	7.15	200	2	Glass (substrate), PDMS

Table 1. Various geometrical characteristics considered for the coils and the microfluid structure for the simulations.

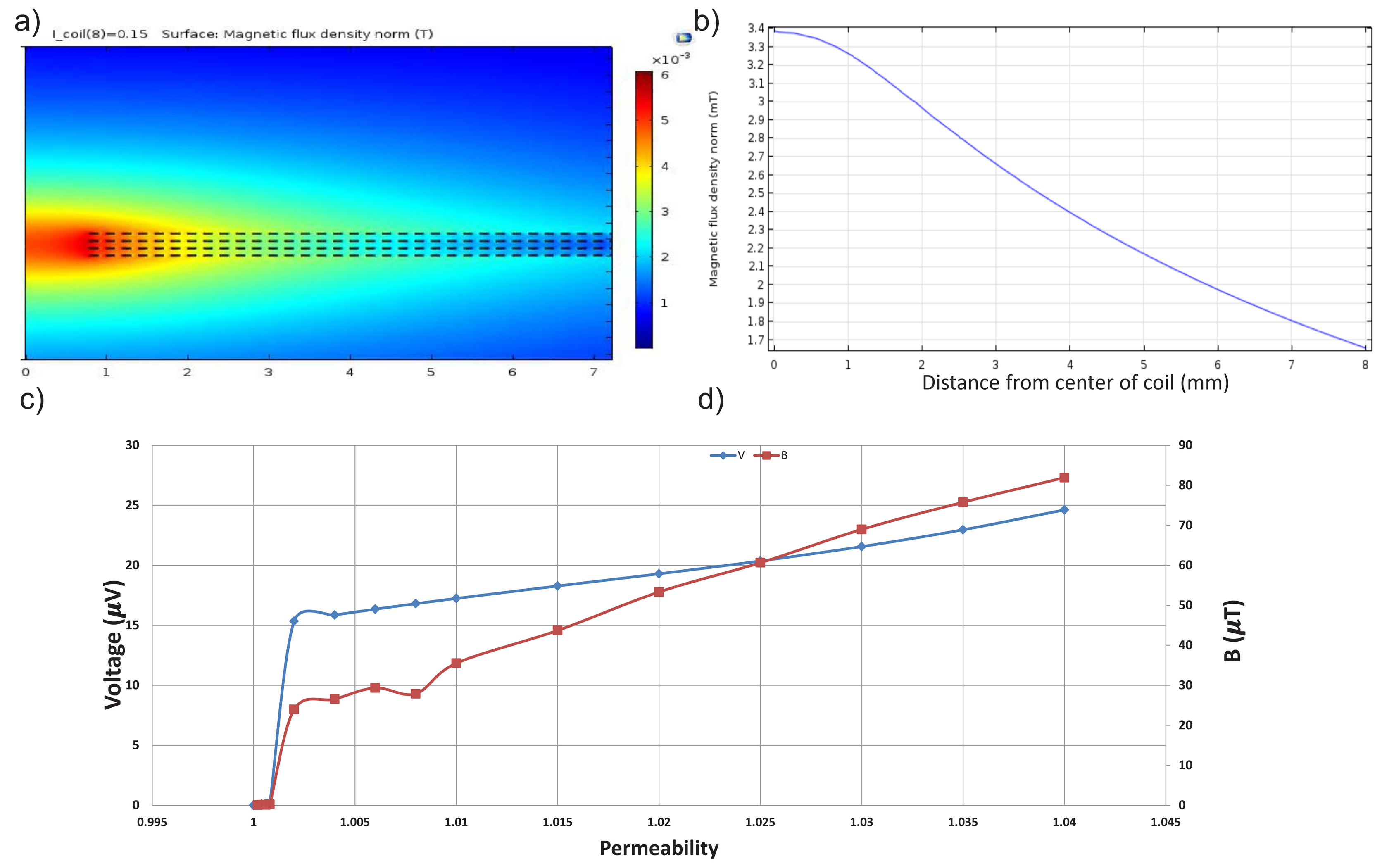

Figure 3. Electromagnetic simulations, a) magnetic flux density distribution in the vicinity of the excitation coil (I=0,15A) , b) Change of magnetic excitation field over horizontal axe, c) effect of ferrofluid permeability on the induced voltage in the sensor, d) effect of ferrofluid permeability on the magnetic flux density (point chosen in the center of the reservoir). Load impedance 50 Ω was used to calculate induced voltage.

• Heat transfer and microfluidique simulations:

Heat transfer (figure 4) and mircofluidic simulations (figure 5) have been achieved to optimize the designed structure for the future microanalysis application of biological entities that are quite sensitive to temperature variation. In fact the amplitude of the electrical current used for the magnetic excitation should be optimized with the cooling possibility of the system.

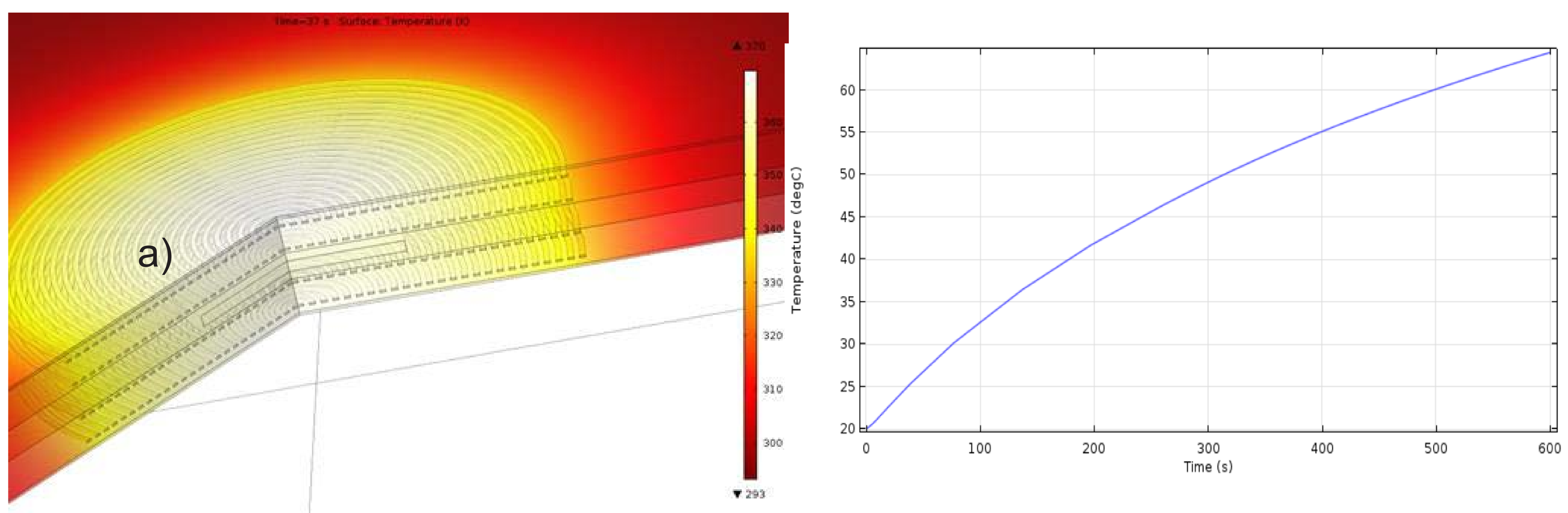

Figure 4. Heat transfer simulations showing the temperature distribution after 37 second in the set of coils close to the microfluidic reservoir (a) and temperature variation versus time of the reservoir (b)

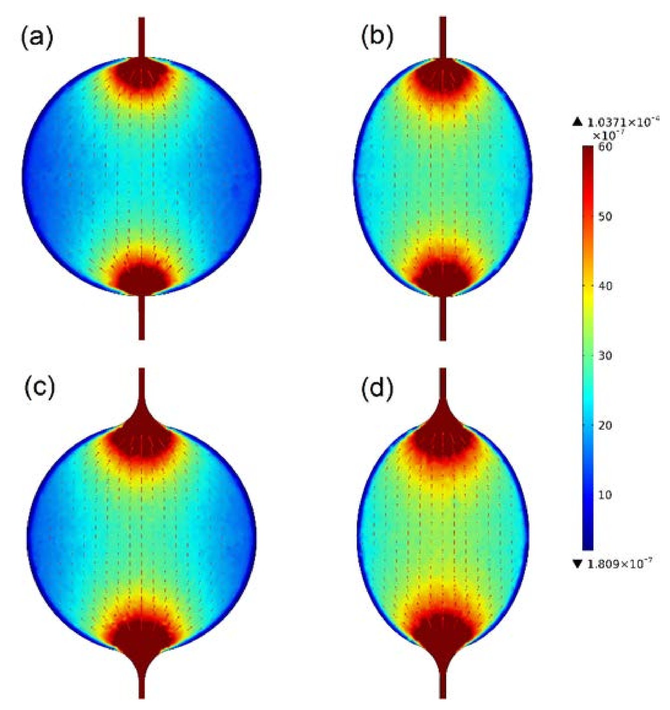

Figure 5. Microfluid simulations showing the flow distribution relative to the reservoir shape from circular (a) to more elliptical (d).

4.Conclusion:

Various types of simulations (magnetic, thermal and microfluidics) have been implemented using Comsol Multiphysics in order to study and optimize an embedded magnetic sensing structure. The combination of different results will allow the full miniaturization of the structure. Experimental tests are in progress in order to validate the efficiency of the structure.

References:

1. H.-J. Krause, N. Wolters, Y. Zhang, A. Offenhäusser, P. Miethe, M.H.F. Meyer, M. Hartmann, M. Keusgen, "Magnetic particle detection by frequency mixing for immunoassay applications", J. Mag. Magn. Mater. Vol. 311, 1, pp. 436-444, (2007).
2. A.Özbey, M.Karimzadehkhouei, S. E. Yalcin, D. Gozuacik, & A. Koşar, "Modeling of ferrofluid magnetic actuation with dynamic magnetic fields in small channels." Microfluidics and Nanofluidics , Vol.18, 3, pp.447-460, (2015).