A8

Modelling of Magnetoelectric Sensors

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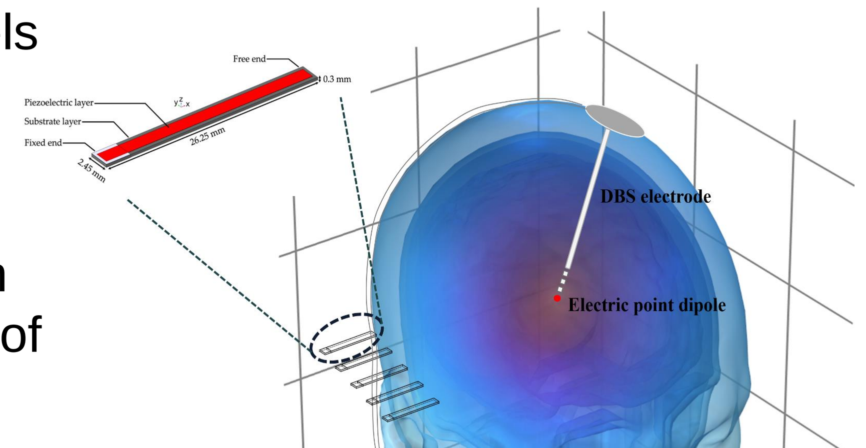
biomagnetic sensing SFB 1261

Motivation and Objectives

Main objectives:

- Development of simulation models and methods to investigate the response of ME sensors to time-varying biomagnetic fields, e.g., those acquired during deep-brain stimulation or periodic excitation of magnetic nanoparticles (MNPs)
- Improving ME sensors performance, e.g., sensitivity and spatial resolution for accurate detection of small biomagnetic signals
- ME sensor system modelling



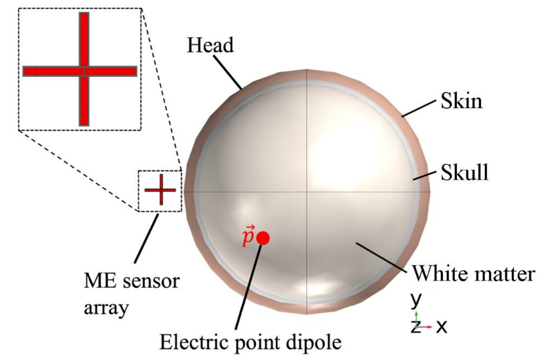
Approach:

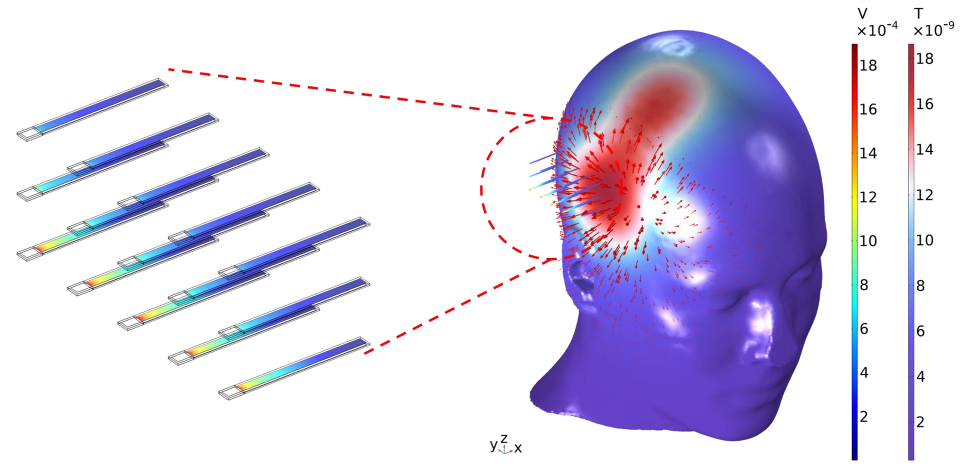
- Combination of analytical and finite-element method (FEM) simulations
- Collaboration with experimental projects in establishing models

Results of the Second Funding Period

3D head model for ME sensor application [A8-9, A8-11a]

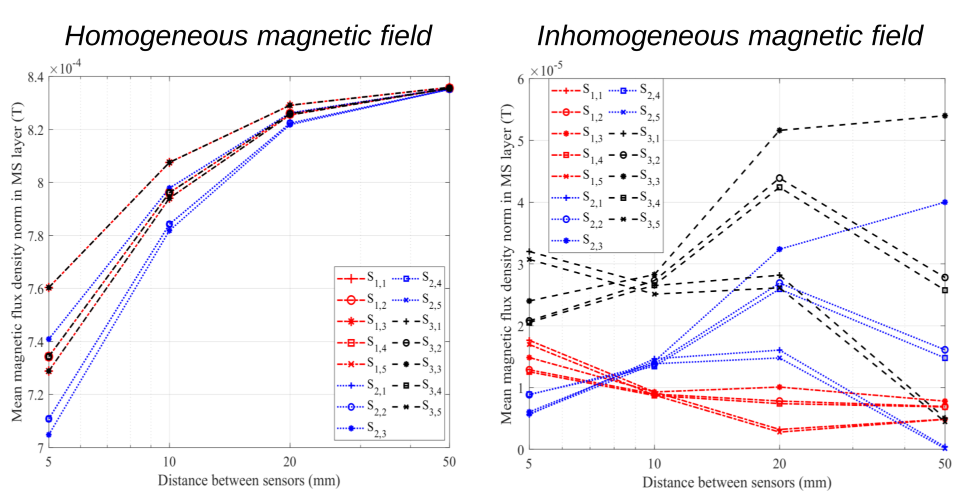
- Three concentric layers with proper material parameters replicating the head tissues
- Vector ME sensor array simulation considering a resonance frequency of 848 Hz
- Strong location-dependent sensor response in inhomogeneous magnetic field





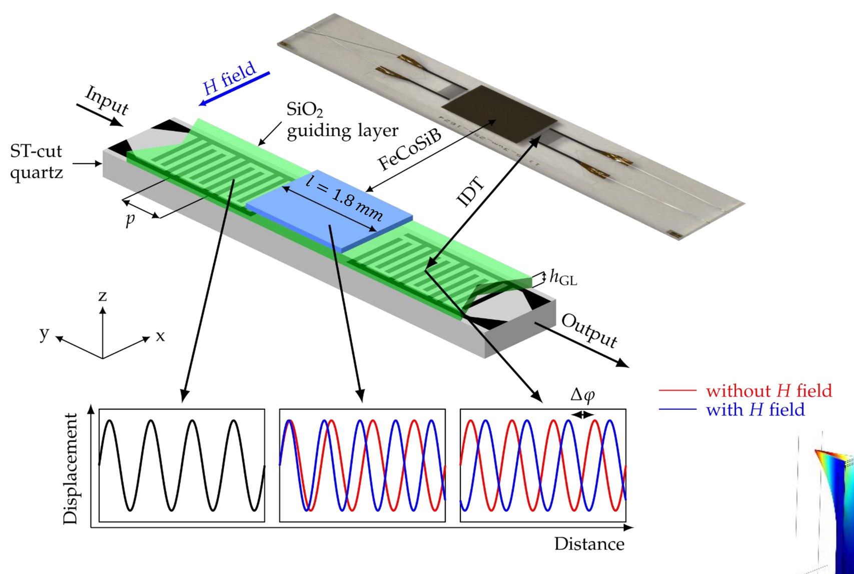
- 3D anatomic head model generated from MRI data
- Inclusion of an array of 15 sensors
- Evaluation of magnetic interactions between adjacent sensors

Cross-talk analysis considering 15 sensors array [A8-11a]

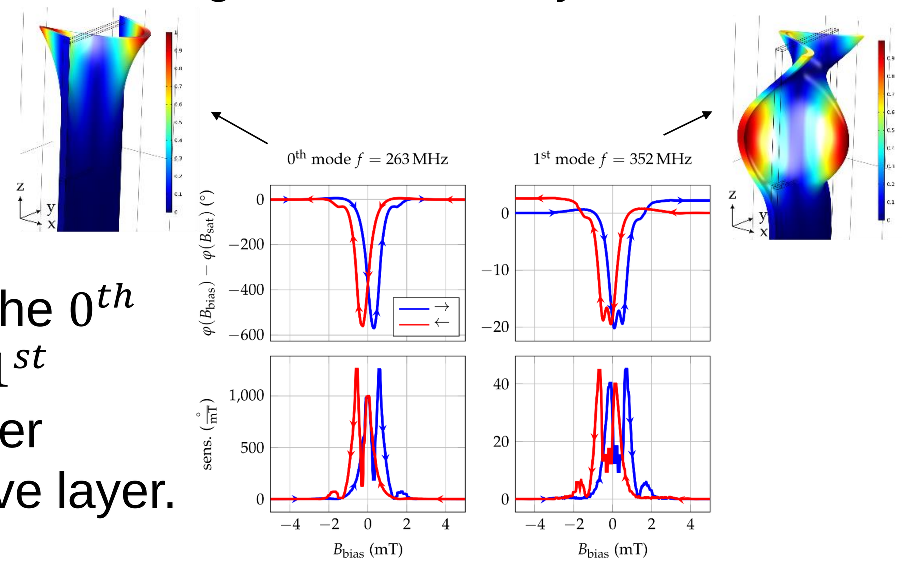


- Homogeneous: Visible cross-talk at 5 mm distance between sensors, and negligible cross-talk at 5 cm where $B \approx 8.37 \times 10^{-4}\ T$
- Inhomogeneous: Magnetic flux density pattern not predictable without simulation

SAW-based magnetic-field delay-line sensor [A8-5]



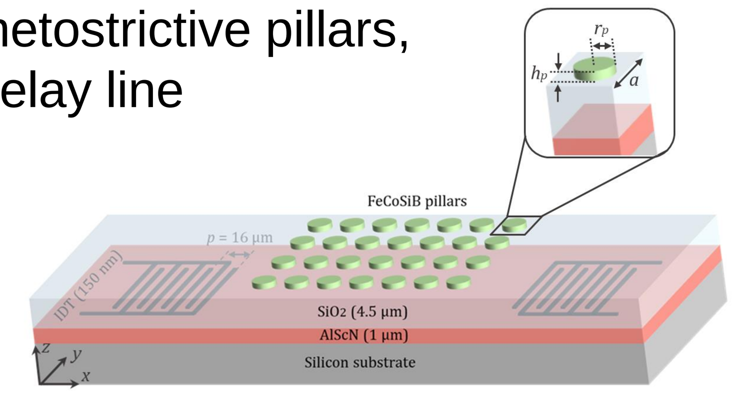
- Excitation and detection of the fundamental and first-order Love modes using two IDTs
- A phase change in the output signal with an applied magnetic field, due to the ΔE effect in the magnetostrictive layer

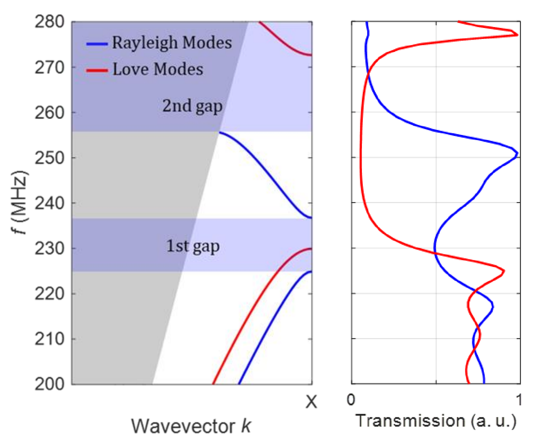


- Higher sensitivity obtained for the 0^{th} mode (1250°/mT) than for the 1^{st} mode (45°/mT) owing to a higher overlap with the magnetostrictive layer.

SAW-based magnetic field sensor with phononic crystals [A8-6]

- Integration of a periodic array of magnetostrictive pillars, i.e., phononic crystal (PnC), into the delay line





- Band diagram of the PnC with a reduced group velocity at the edge of the Brillouin zone
- A sensitivity of 138°/mT achieved via using PnC, compared to 77°/mT obtained with an unpatterned delay line of the same length (l = 77 µm)

Work Plan for Third Funding Period

WP1 Phononic crystals (PnC)

- Exploring the geometrical aspects of PnCs, e.g., anisotropy, and their influence on the sensor's sensitivity and LoD

WP2 Time-dependent effects

- Analysis of the transient behavior of the ME sensors, e.g. hysteresis phenomena and response times under time-varying magnetic fields

WP3 Acoustic metasurfaces

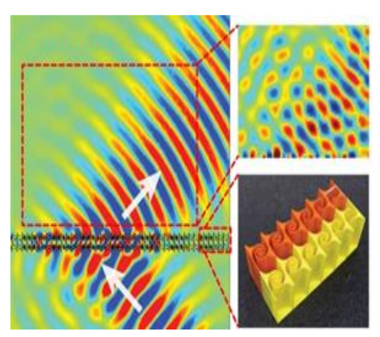


Image by Xie, Y., et al.
DOI: 10.1038/ncomms6553

- Incorporating acoustic metasurfaces into the SAW magnetic field sensors to improve the sensitivity via mitigating undesirable reflections and scattering at the boundaries
- Design of multi-functional sensors that respond selectively to various field orientations or strengths

WP4 Topological PnCs

- Investigation of topologically-protected edge modes that propagate at the interface of two PnCs with distinct arrangements
- Reducing undesired reflection and back scattering losses in PnC-based SAW magnetic field sensors using the topological effects

WP5 Functionalized MNP ensembles

- Analyzing the time response of an ensemble of functionalized MNPs during biomolecular binding and comparison with the experimental results from **B12(N)**
- Evaluating the effect of different matrices, on the time response of the ensemble during binding

WP6 Towards in-vivo ME sensors

- Development of an ME sensing system for in-vivo detection of unfunctionalized MNPs in collaboration with **B12(N)**
- Simulation of magnetic fields from the MNPs using the finite-element method

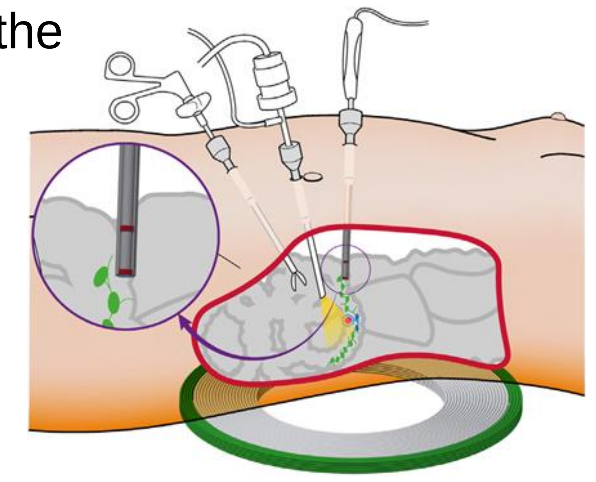


Image by van de Loosdrecht, M. M., et al.
DOI: 10.1016/j.jmmm.2018.12.012

WP7 ME biosensing system

- Modelling of an ME biosensing system including the excitation coils, the functionalized MNP implant in an MRI-derived torso model, biomarker concentration gradients, and the ME sensors for the detection of biomolecular binding in a hydrogel containing functionalized MNPs

Postdoctoral researcher (blue) / Doctoral researcher (red)

	2024		2025				2026				2027				2028	
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
WP1 – Phononic crystals (PnC)	■	■	■													
WP2 – Time-dependent effects				■	■	■	■									
WP3 – Acoustic metasurfaces								■	■	■	■					
WP4 – Topological PnCs												■	■	■	■	■
WP5 – Functionalized MNP ensembles	■	■	■													
WP6 – Towards in-vivo ME sensors				■	■	■	■	■	■	■						
WP7 – ME biosensing system											■	■	■	■	■	■

Collaborations

A1: Obtained magnetostrictive material parameters

A4: Joint analysis of time-dependent behavior of ΔE-Effect sensors

A6: Sensor and coil design for magnetic nanoparticles readout system

A9: Designs and experimental results of PnC SAW sensors

A10: Magnetic noise model obtained from A10. Layer deformation and full sensor calculations will be provided to A10

B1: Investigate the experimental results on sensor performance from B1

B2: Experimental data on the time-dependent behavior of sensors

B12(N): System design for functionalized magnetic nanoparticles readout

Funds Requested

1 Doctoral researcher, M.Sc. Giuseppe Barbieri (100%)

1 Postdoctoral researcher, Dr. Mohsen Samadi (100%)

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