A1 Magnetostrictive Multilayers for Magnetoelectric Sensors

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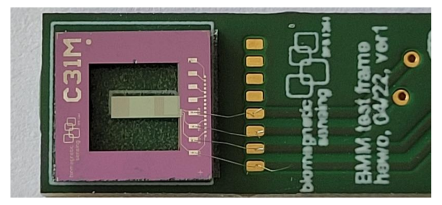
biomagnetic sensing SFB 1261

Motivation and Objectives

Sensor concepts and application scenarios strongly differ

- Type and frequency of the excitation stimulus
- Sensor design, size, and magnetic layer thickness
- Robustness against environmental influences

Resonant and ΔE effect



7 kHz to 10 MHz

Converse ME

100 kHz to 10 MHz

SAW sensor

100 MHz to 2 GHz

Specific magnetic layer solutions for maximum sensor performance

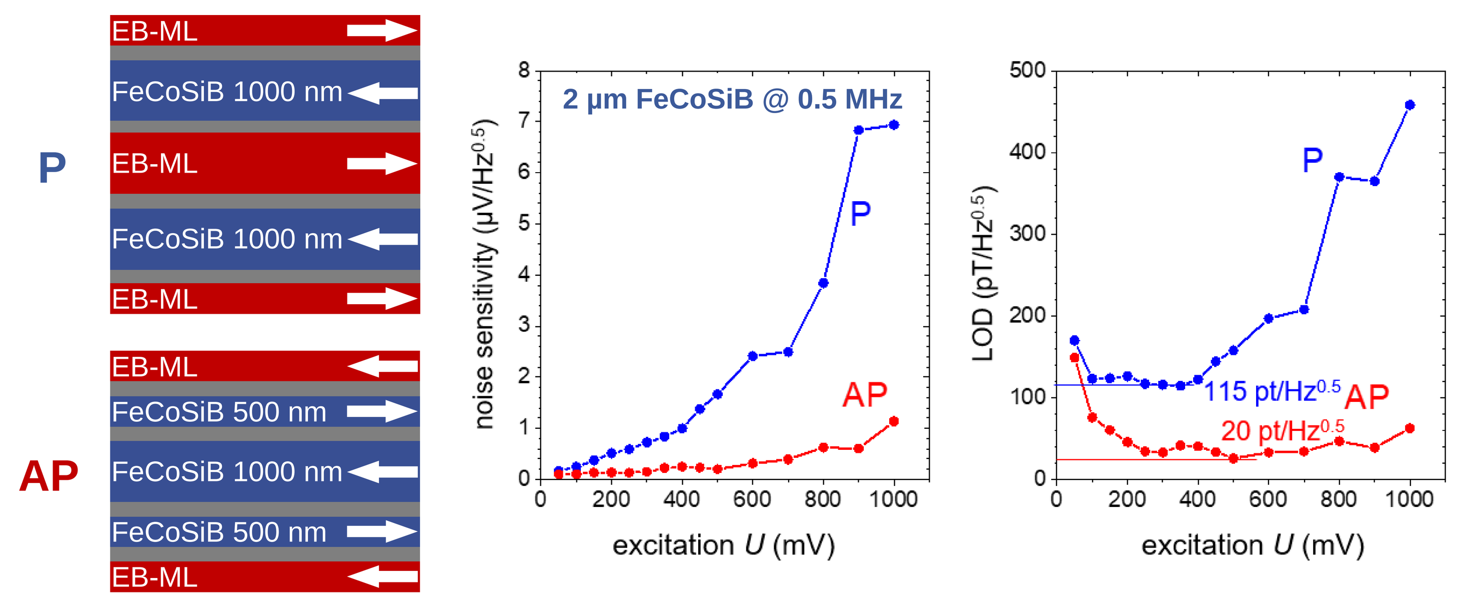
Main objectives:
- High sensitivity and minimal magnetic noise
- Zero bias-field detectivity
- Directional sensor response

Approach:
- Complex multilayers with high design freedom
- Magnetic property tunable layer structure
- Stress control

Results of the Second Funding Period

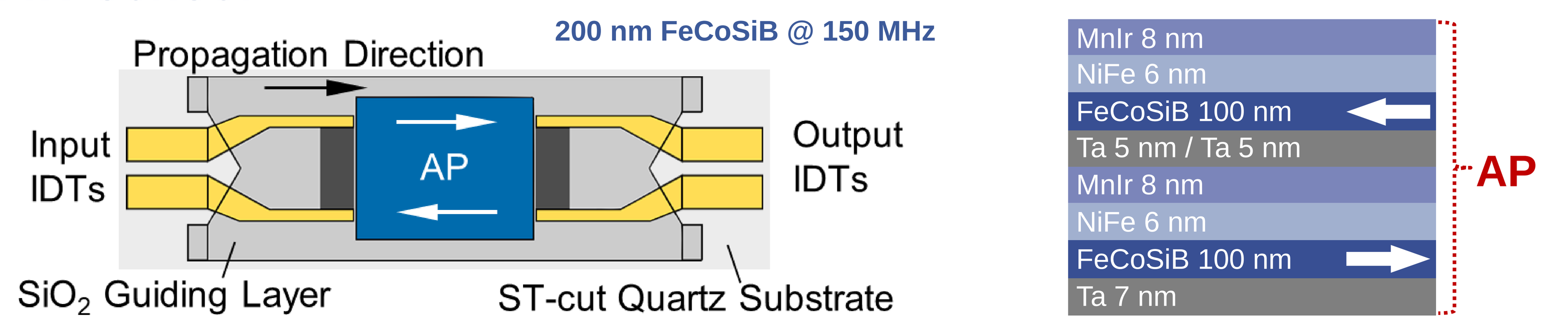
Design and fabrication of multilayers for single domain states

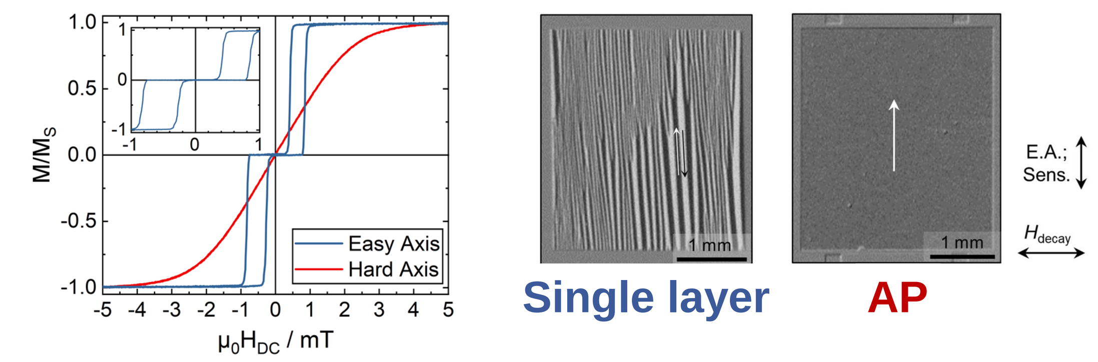
Converse ME sensor



- Scalable layer stacks with parallel (P) and antiparallel (AP) alignment of FeCoSiB layer magnetization
- AP alignment with deposition in parallel magnetic field
- Elimination of carrier signal and connected phase noise contribution

SAW sensor

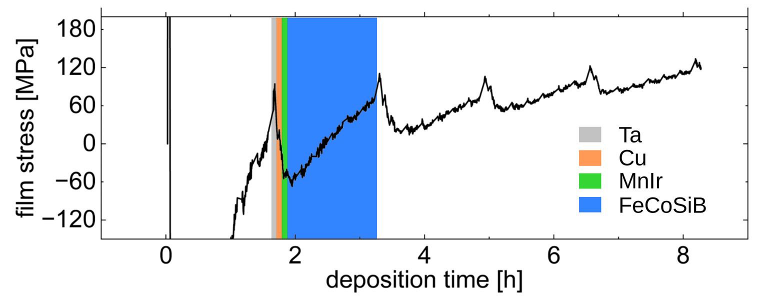




Deposition process tuned to minimize self-heating of the quartz substrate

- Magnetic flux closure prevents magnetic domain formation
- Reduction of $1/f$ noise by about 8 dB with AP
- Power dependent detection limit (28 pT/Hz$^{1/2}$ at 10 Hz and 5 dBm)

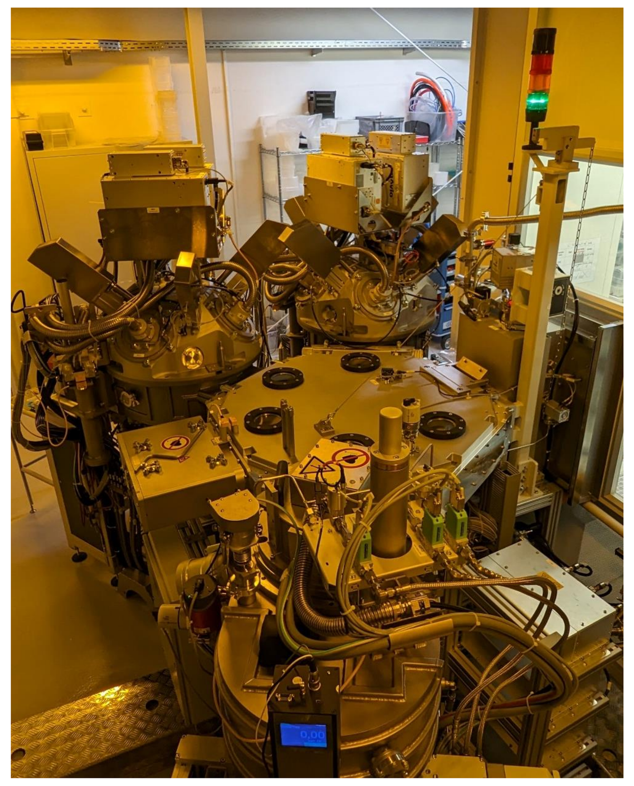
Monitoring and control of layer stresses



- Multi-beam optical sensor in cluster deposition tool
- Control of film stress during layer growth (resolution 2.9·10^{-5} m^{-1})
- Enabling of stress compensation

Work Plan for Third Funding Period

Research methods

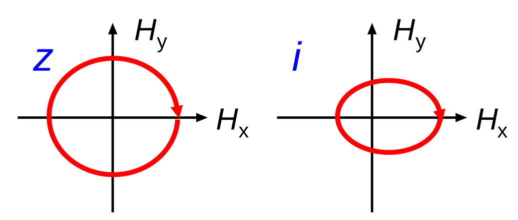


- 2 cluster deposition tools with 9 magnetrons each
- Layer-wise adjustable magnetic fields
- Post-deposition (magnetic field) annealing with *in-situ* magnetic imaging
- Magnetometry in rotatable fields
- VSM, BH-looper, magneto-optical and pulse inductive magnetometry
- Magnetooptical imaging at sensor operating frequencies (DC … GHz)
- Macro-spin modelling for ME behavior
- Elastic recoil detection analysis (HZDR)

WP1 Tunable magnetostrictive layer materials

Layer-by-layer tuning of magnetic properties
In operando trimming of ME response and working point

- $(Fe_{90}Co_{10})_{78}Si_{12}B_{10}$ base material, FeCoC temperature-stable alternative (N. Sun, Northeastern University, Boston)
- Ion beam deposition on quartz (S. Cardoso, INESC-MN, Lisbon)
- Hard magnetic layers (NiFe 5nm/ MnIr 2.2nm)$_n$
- Field annealing in pre-biased magnetic field
- Wafer mapping of fabrication tolerances



WP2 Magnetic design of multilayers

Conceptual design for directional magnetostrictive response and zero magnetic field operation with highest sensitivity

- Magnetostatic coupling and exchange bias
- Canted magnetizations
- Eddy current reduction by insulating interlayers

WP3 Tailored multilayers for high frequency SAW sensors

Specifics: Bulk piezoelectric substrates, carrier signal suppression, high frequency losses, property changes over operating time

WP4 Tailored multilayers for converse ME effect sensors

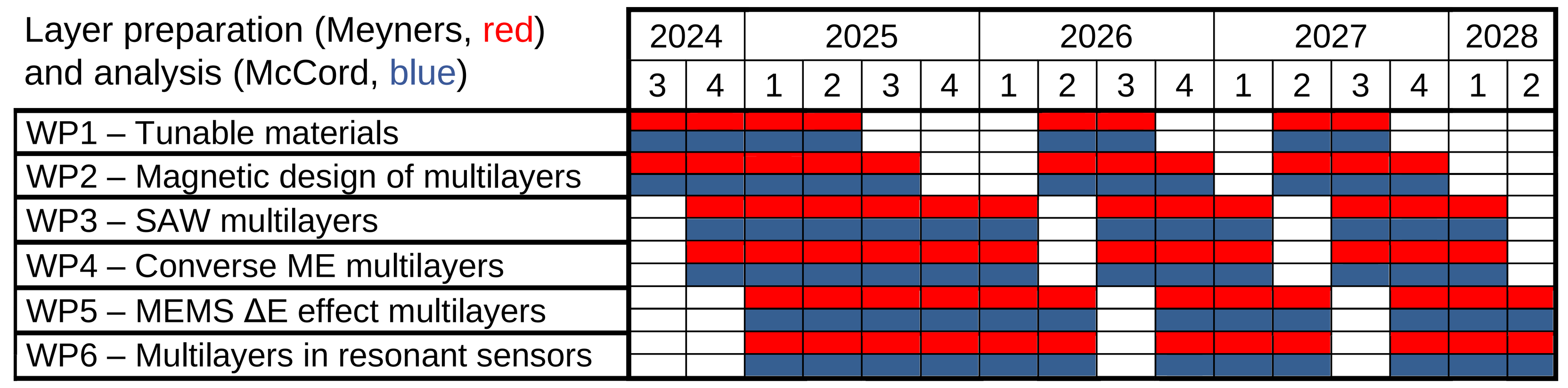
Specifics: Layer thickness, robustness against stress-induced variations

WP5 Tailored multilayers for MEMS ΔE effect sensors

Specifics: Miniaturization, demagnetization effects, layer integration

WP6 Tailored multilayers for resonant sensors

Specifics: Layer-by-layer alternating anisotropies



Collaborations

A4:	Magnetic multilayers and fluxguides for ΔE effect sensors
A6:	Chemical and structural properties, thermal stability
A7:	Advanced magnetic multilayers for converse ME sensors
A8:	Magnetostrictive material properties
A9:	Advanced magnetic layers for SAW sensors
A10:	Magnetic noise effects and magnetic layer design
B1:	ME noise analysis, directionality, and zero field operation
B2, B9:	Feedback on the use of resonant sensors
B13N, Z1:	Characterization of magnetic powder MEMS
Z1:	Device integration, ME substrates for investigation of novel layer designs
Z2:	ME characterization (sensitivity, LOD, directivity)

Participation in focus groups

F1: Magnetic layers **F2:** Modelling **F3:** Comparison of sensor concepts
F4: Magnetoelectric sensors **F5:** Concepts based on ΔE effect

Funds Requested

2 Doctoral researchers, consumables: 97 k€

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