A1

Magnetostrictive Multilayers for Magnetoelectric Sensors

Jeffrey McCord, Dirk Meyners

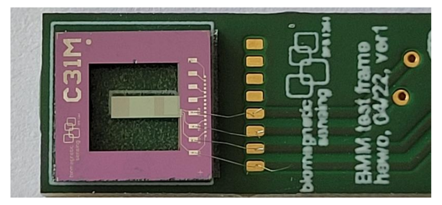
biomagnetic sensing SFB 1261

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

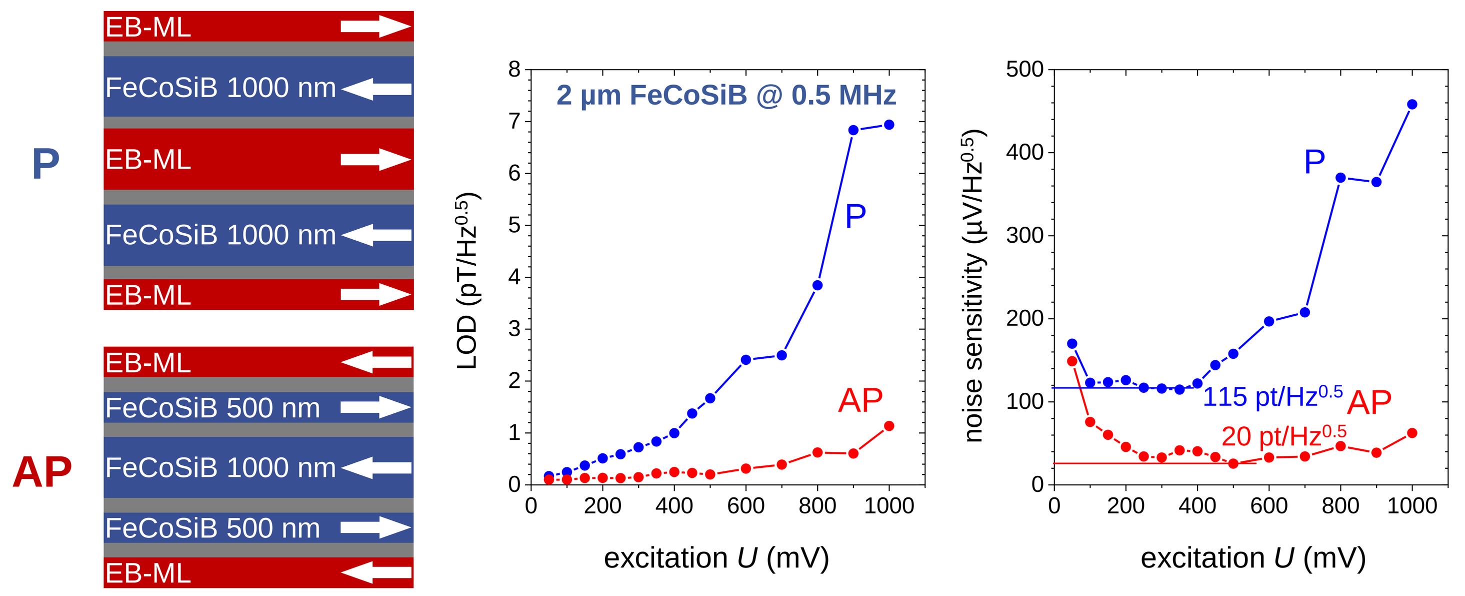
Main objectives: High sensitivity and minimal magnetic noise
Zero bias-field detectivity
Directional sensor response

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

Results of the Second Funding Period

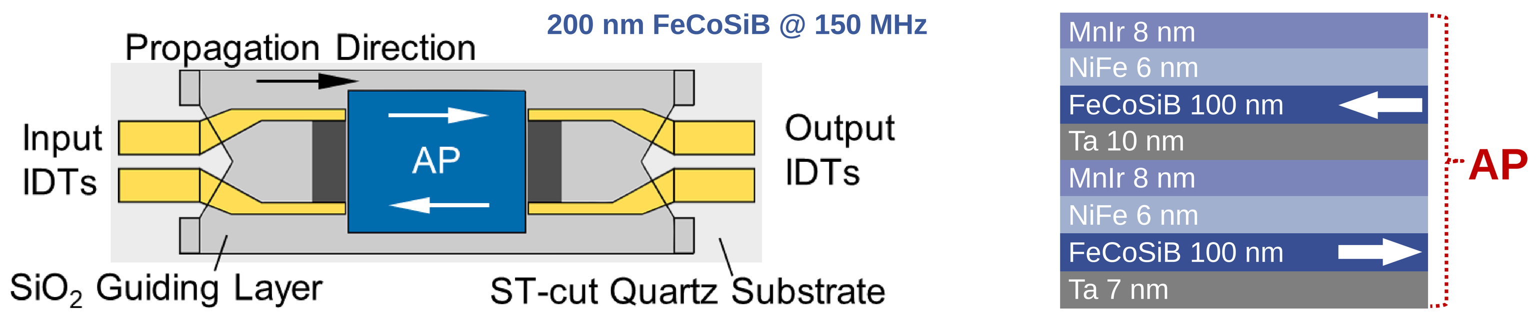
Design and fabrication of multilayers for single domain states

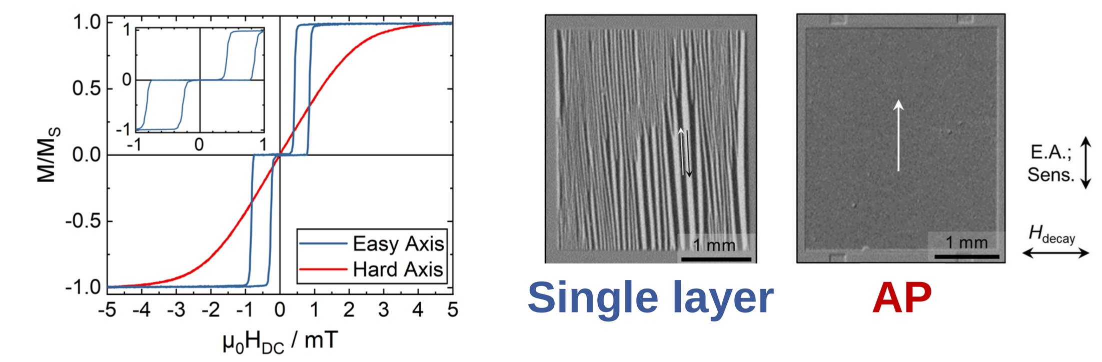
Converse ME sensor



- 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

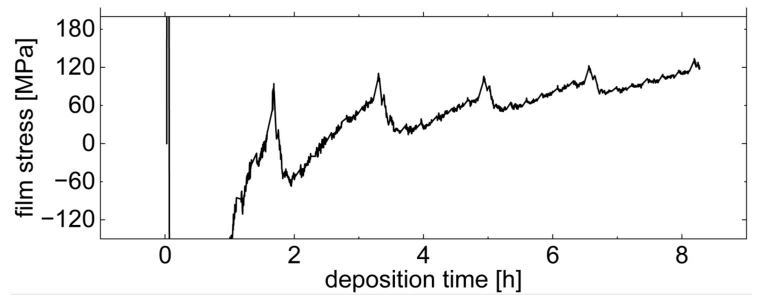




deposition process tuned to minimize self-heating of the quartz substrate

- 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)

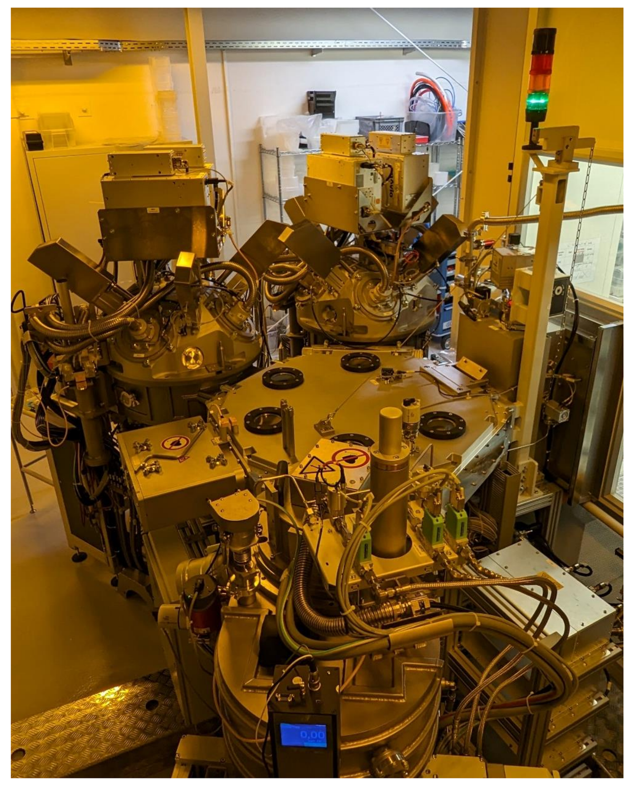
Monitoring and control of layer stresses



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

Work Plan for Third Funding Period

Research methods

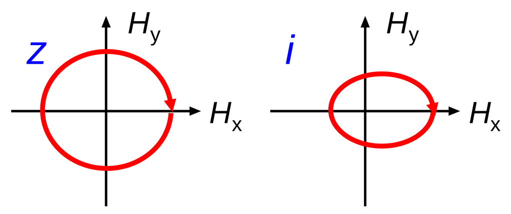


- 2 cluster deposition tools with 9 magnetrons each
- Layer-wise adjustable magnetic fields
- Post-deposition (magnetic field) annealing with *in-situ* magnetic imaging
- Magnetometry in rotatable fields
- VSM, BH-looper, magneto-optical and pulse inductive magnetometry
- Magnetooptical imaging at sensor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

Work plan

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, CoFeC 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

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

WP4 Tailored multilayers for converse ME effect sensors

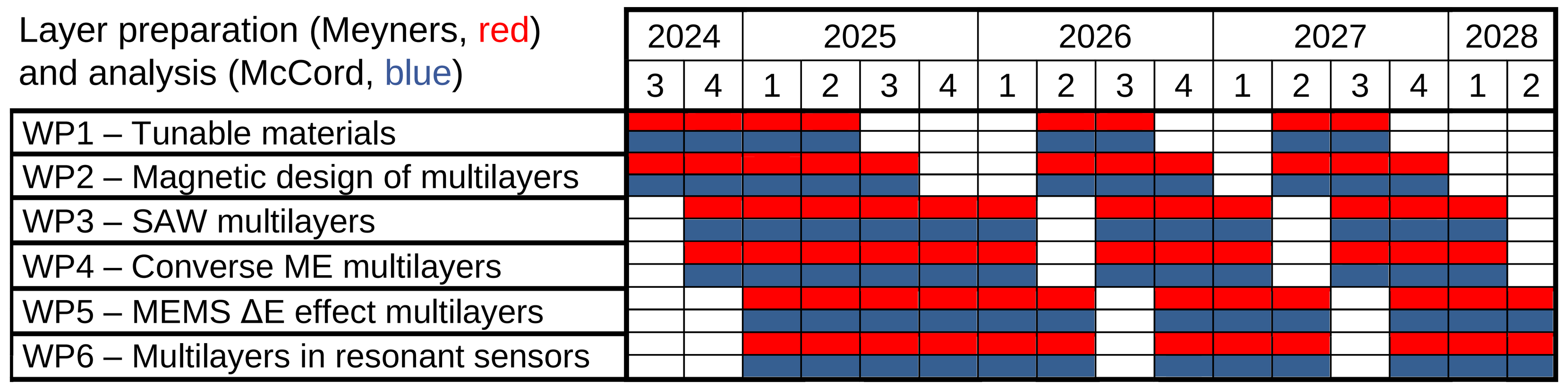
Extras: Layer thickness, robustness against stress-induced variations

WP5 Tailored multilayers for MEMS ΔE effect sensors

Extras: Miniaturization, demagnetization effects, layer integration

WP6 Tailored multilayers for resonant sensors

Extras: 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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