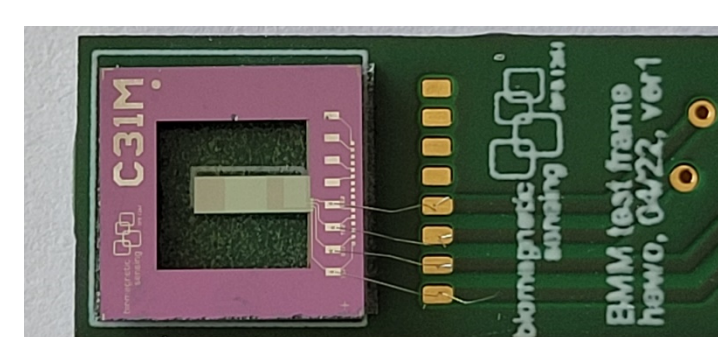


Motivation and Objectives

Sensor concepts and application scenarios strongly differ

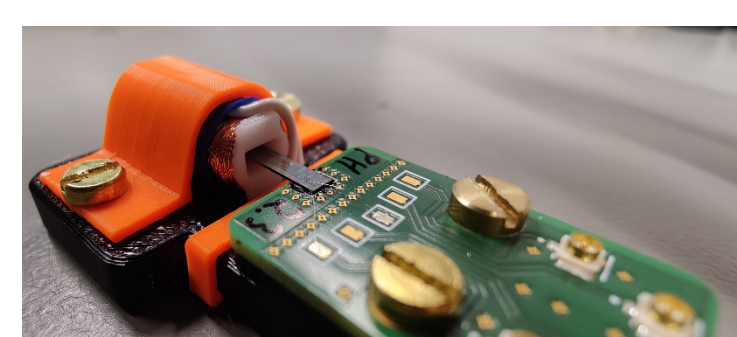
- Type and frequency of the excitation stimulus
- Sensor design, size, and magnetic layer thickness
- Robustness against environmental influences

Resonant and ΔE effect



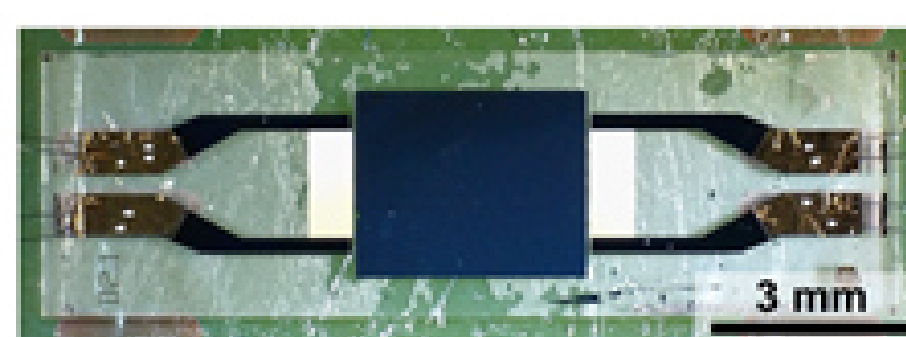
7 kHz to 10 MHz

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

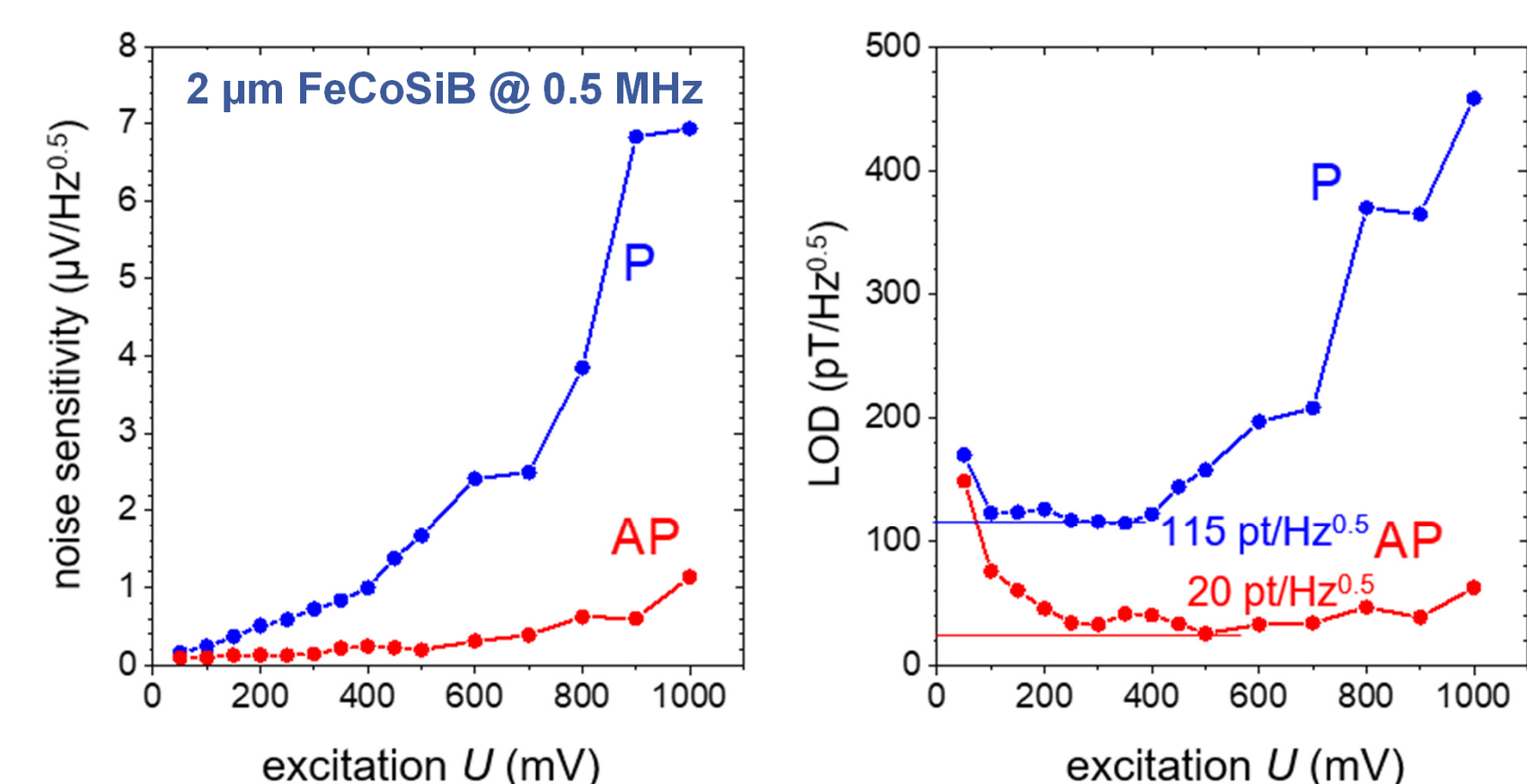
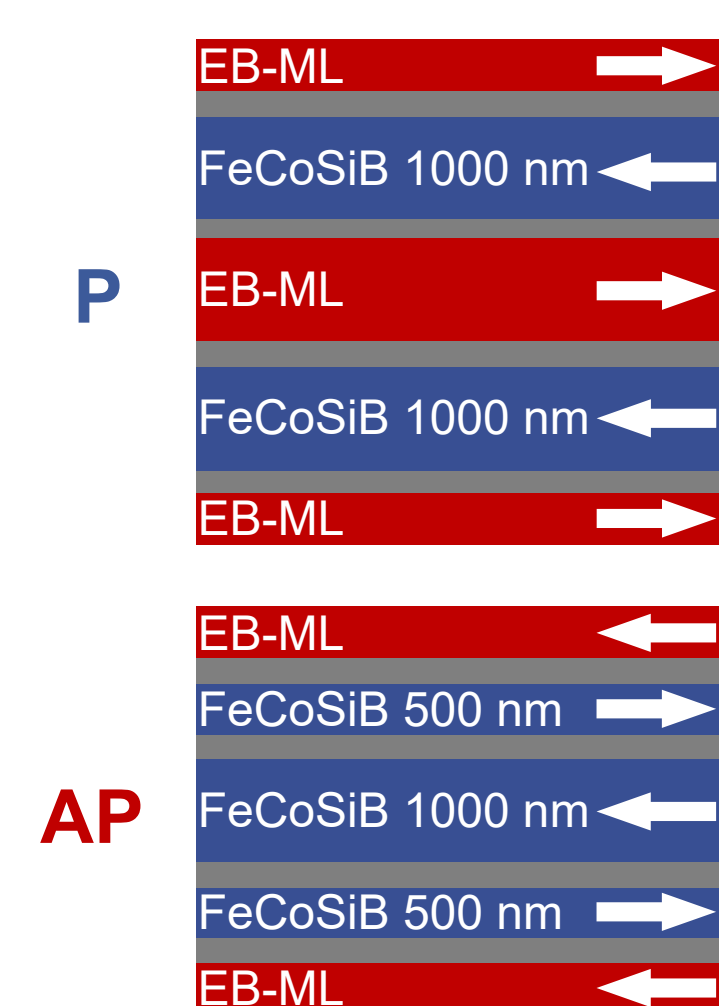
Approach:

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

Results of the Second Funding Period

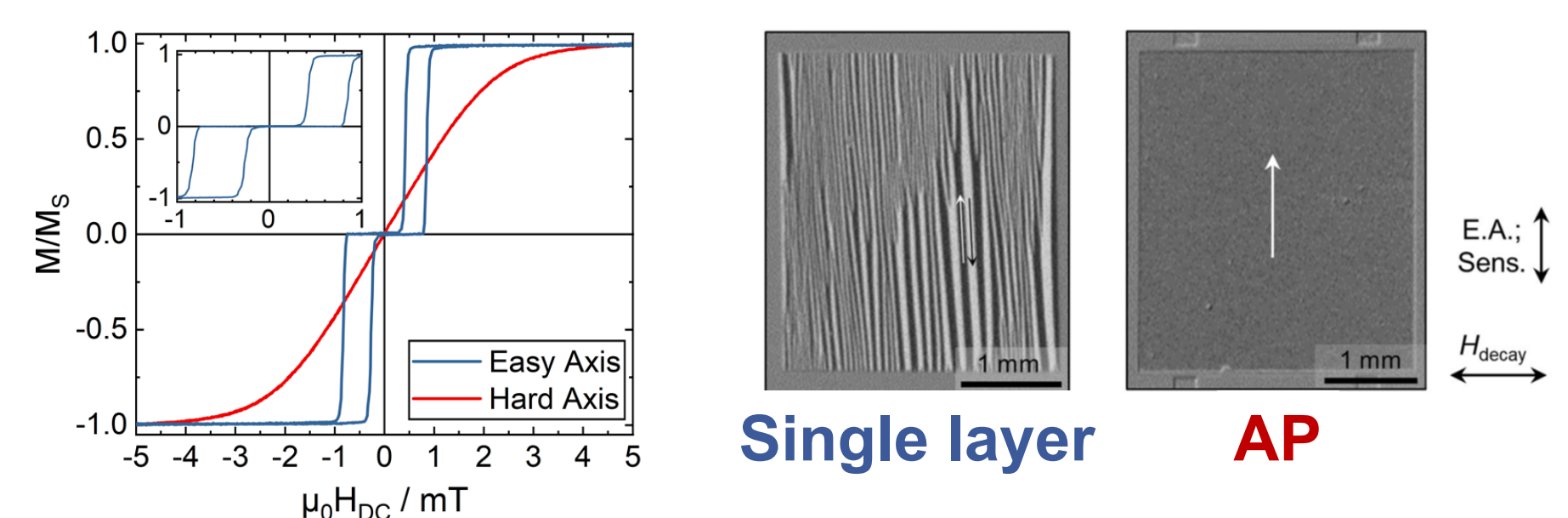
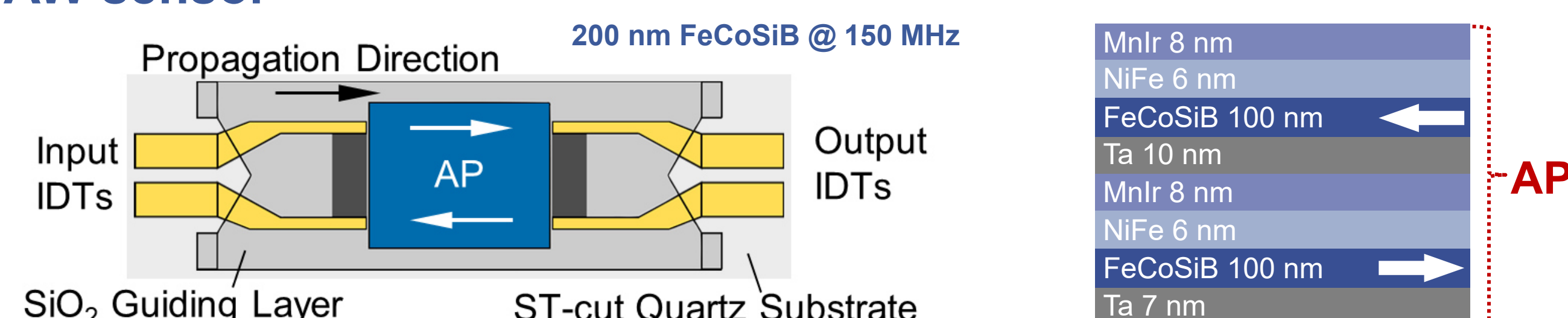
Design and fabrication of multilayers for single domain states

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

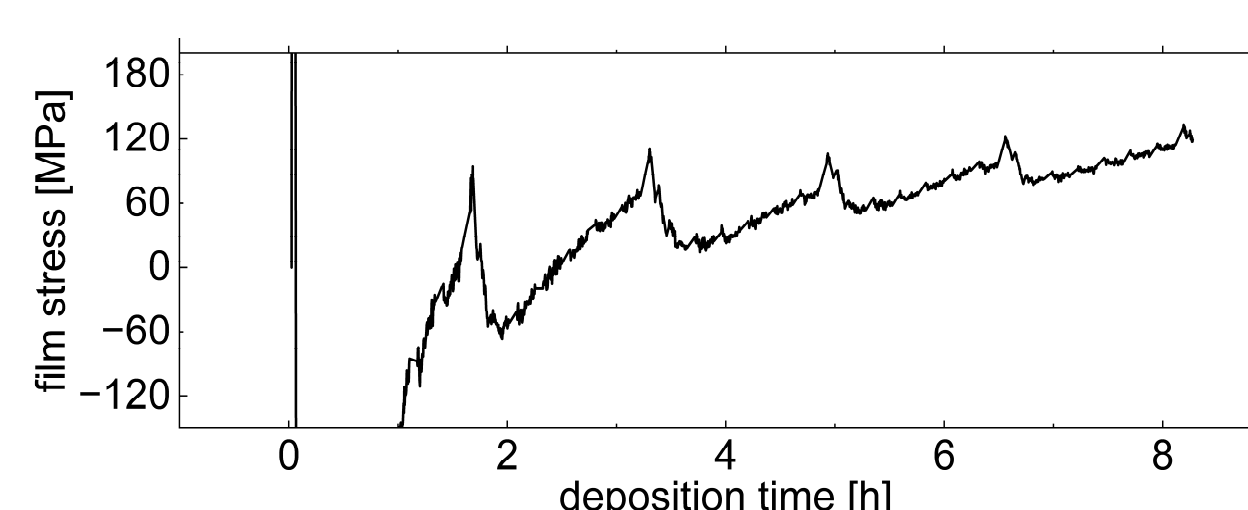
SAW sensor



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)

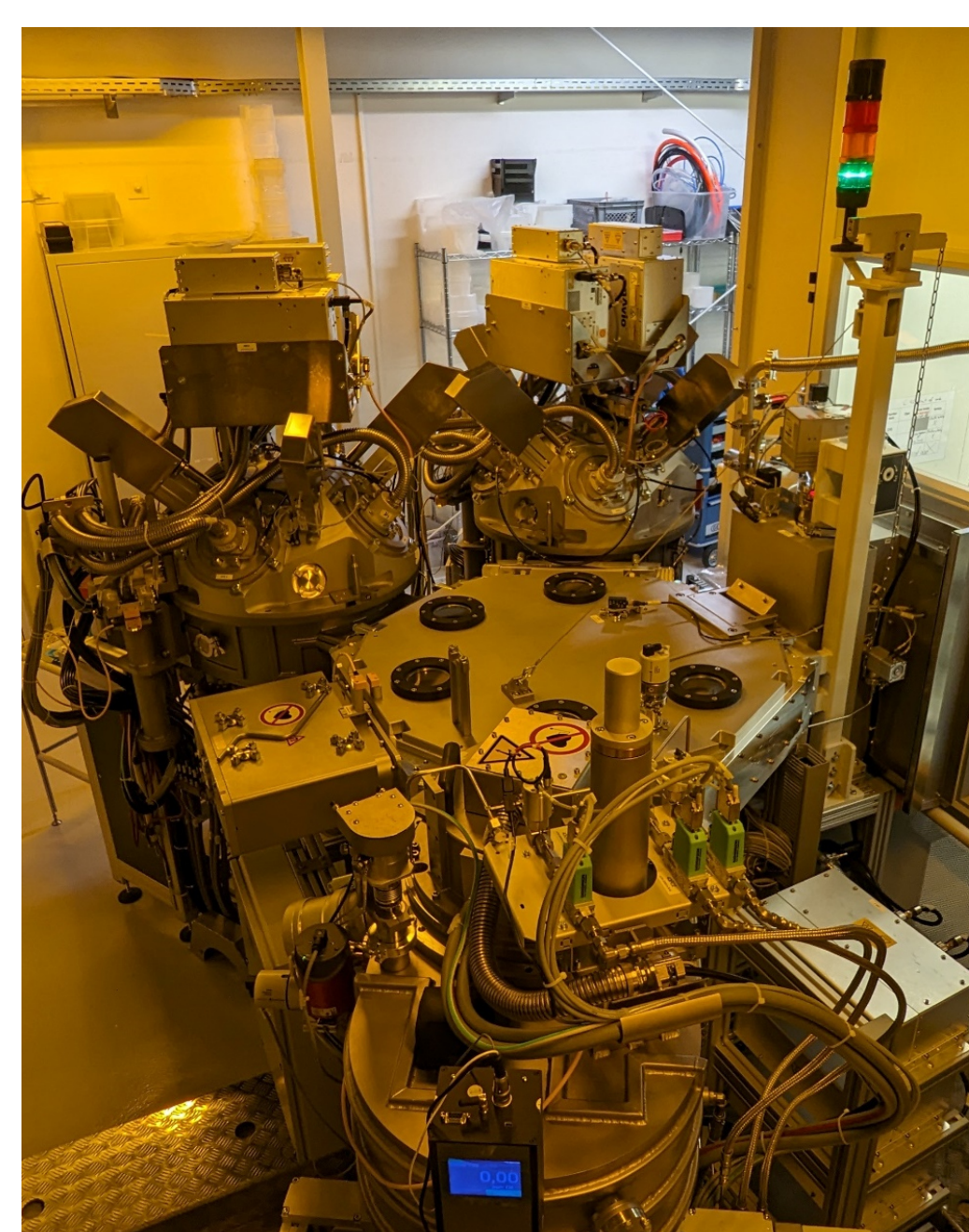
Monitoring and control of layer stresses



- 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
- Magneto-optical 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

- (Fe₉₀Co₁₀)₇₈Si₁₂B₁₀ 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

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

Layer preparation (Meyners, red) and analysis (McCord, blue)	2024		2025				2026				2027				2028	
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
WP1 – Tunable materials																
WP2 – Magnetic design of multilayers																
WP3 – SAW multilayers																
WP4 – Converse ME multilayers																
WP5 – MEMS ΔE effect multilayers																
WP6 – Multilayers in resonant sensors																

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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[A1-10] Özden, M. Ö., Teplyuk, A., Gümüş, Ö., Meyners, D., Höft, M., & Gerken, M. (2020). *AIP Advances*, 10(2). DOI: 10.1063/1.5136239 (open access). – **A1, A8, Z1, Z2**