The XV European Magnetic Sensors and Actuators Conference 2026

July 6 – 9 2026,
Eindhoven, the Netherlands

EMSA
Eindhoven, 6 - 9 July 2026

Book of Abstracts

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About the EMSA 2026

The European Magnetic Sensors and Actuators Conference (EMSA) is a consolidated European forum that serves to assess the status, recent progress, and development in the field of magnetic sensor technology and magnetic actuators. It was first held in 1996 in Iasi (Romania) and since then has continued every two-three years in different European cities. The aim of the conference is to generate an overview of research in magnetic sensors and actuators, to recognize their relevance in modern industry and to identify potential future collaborations. EMSA 2026 will provide an excellent opportunity to bring together scientists and engineers from universities, research institutes and industry to present and discuss their most recent results covering both fundamental and applied aspects of magnetic sensors and actuators.

Conference topics

1. **Magnetic Sensors**
   Hall Effect, GMI, Induction, Scalar Magnetometers, xMR, Magnetoelastic, and others
2. **Magnetic Actuators & MEMS**
   Magnetostrictive, Magnetic Shape Memory, Electromagnetic, Magnetocaloric, and others
3. **Biomedical Applications of Sensors & Actuators (S&A)**
   Biosensors, Magnetic Separation, S&A for Mechanobiology and Organs-On-Chip
4. **Quantum-based Sensors**
   Including NV centers, SQUIDs, and others
5. **Magnetic Sensor Circuit Interfaces**
6. **Metrology Techniques**
   Magnetic Sensors for Metrology or Systems for Inspecting Magnetic Materials
7. **Hybrid Sensing Technologies**
   Magnetoelectric Coupling, Phonon-Magnon Coupling for RF Applications, Superconductor-Magnetic Systems, Hybrid Magnetic/Piezo-MEMS, and others
8. **Flexible Platforms for Magnetics**
   Including Flexible Magnetic Sensor, Flexible Actuators, Robotics Systems and others
9. **Modeling & Simulation**
   Including AI-Based Simulation Platforms
10. **Novel Magnetic Materials and Other Applications**
    Including Applications of Spin Phenomena, New Sensing Concepts and End Applications
11. **Standards in Magnetic Sensors and Systems**
12. **Industrial Magnetic S&A Applications**
    Use Cases: Current Sensing, Integrated Electromechanical Devices, Motor Positioning, Automotive, Space, and others

Language of the conference is English.

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I	EMSA	July 22–24, 1996	National Institute of Research & Development for Technical Physics, held in Iasi, Romania
II	EMSA	July 13–15, 1998	The University of Sheffield, held in Sheffield, UK
III	EMSA	July 19–21, 2000	Institut für Elektrotechnik, Technische Universität Dresden, held in Dresden, Germany
IV	EMSA	July 3–5, 2002	National Technical University of Athens, held in Athens, Greece
V	EMSA	July 4–6, 2004	Wolfson Centre for Magnetics, Cardiff University, held in Cardiff, UK
VI	EMSA	July 3–5, 2006	Institute of Materials Science of Madrid, held in Bilbao, Spain
VII	EMSA	June 30–July 2, 2008	Université de Caen Basse-Normandie, held in Caen, France
VIII	EMSA	July 4–7, 2010	Department of Physics, Uludag University, held in Bodrum, Turkey
IX	EMSA	July 1–4, 2012	Faculty of Electrical Engineering, Czech Technical University, held in Prague, Czech Republic
X	EMSA	July 6–9, July 2014	Institute of Sensor and Actuator Systems, Vienna University of Technology, held in Vienna, Austria
XI	EMSA	July 12–15, 2016	INRIM, the Italian National Research Institute for Metrology, held in Torino, Italy
XII	EMSA	July 1–4, 2018	Athens, Greece
XIII	EMSA	July 5–8, 2022	Faculty of Physics of the Complutense University, held in Madrid, Spain
XIV	EMSA	June 24-27, 2024	University of Pavol Jozef Safarik in Kosice, Slovakia

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Part 1

Invited oral presentations

AI-aided flexible, printable, and eco-sustainable magnetoelectronics for smart skins, smart textiles, and soft-bodied robots

Denys Makarov

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Motion sensing is the primary task in industrial robotics, prosthetics, virtual and augmented reality appliances. In rigid electronics, rotations, displacements and vibrations are typically monitored using magnetic field sensors. Here, we will discuss the fabrication of flexible, stretchable and printable magnetoelectronic devices and address robustness of the sensor responses based on advanced signal processing also using deep learning methods. The technology platform relies on high-performance magnetoresistive and Hall effect sensors deposited or printed on polymeric foils [1]. These conformal flexible and printable magnetosensitive elements enable touchless interactivity with our surroundings based on the interaction with magnetic fields, which is relevant for human-machine interfaces including smart skins [2,3] and smart textiles [4], as well as soft robotics [5]. For the latter, soft sensors assess the magnetic state at the actuator location and decide on the desired actuation patterns as well as enable communication with external devices for self-guided assembly [5,6]. We will present approaches to realize magnetic composites based on materials revealing high degree of spin polarization and electrical percolation, which result in printed magnetic field sensors [6,7,8]. We will introduce a technology to realize self-healable magnetic field sensors, which can be repaired upon mechanical damage, hence extending the life-time of magnetoelectronics and reducing the amount of toxic magnetic waste [9,10]. This opens new perspectives for magnetoelectronics in smart wearables, interactive printed electronics and motivates further explorations towards the realization of recyclable magnetoelectronics [11]. For the latter, we will discuss eco-sustainable, namely biocompatible and biodegradable magnetosensitive devices, which can help to minimise electronic waste and bring magnetoelectronics to new application fields in medical implants, health monitoring, and realization of self-aware soft-bodied robots [12].

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Computational tools for the design and optimization of sensors and actuators

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In most cases the fabrication of prototypes within the design process is a lengthy and costly task, and reliable computer tools capable of precisely simulating the multifield interactions are of utmost importance. Arbitrary modifications of geometry and selective variation of material parameters are easily performed, and the influence on the behavior can be studied immediately. In addition, the simulation provides access to physical quantities that cannot be measured, e.g. the magnetic field in a solid body, and simulations strongly support the insight into physical phenomena.

The modeling of complex technical as well as medica systems leads to so called multi-field problems, which are described by a system of nonlinear partial differential equations (PDEs). The complexity consists of the simultaneous computation of the involved single fields as well as the coupling terms, which in most cases introduce additional nonlinearities, e.g. moving/deforming conductive bodies within an electromagnetic field.

With a special focus on electromagnetics, structural mechanics, acoustics, and heat transfer, we have developed the open-source software for coupled field simulations *openCFS* [1, 2] allowing high-end computations of many coupled fields. A key feature is its support for sophisticated coupling strategies, enabling both volume and surface coupling between different physical fields. In addition to standard finite element formulations based on isoparametric elements, the framework provides higher-order finite elements. These elements achieve optimal convergence rates and thereby enhance computational efficiency, particularly for problems requiring high accuracy. Furthermore, flexible discretization strategy based on non-conforming grid techniques are possible, which allows computational meshes in adjacent subdomains to differ significantly. This approach not only reduces numerical errors but also substantially simplifies the preprocessing of complex geometries. The software also incorporates moving domain capabilities through an Arbitrary Lagrangian–Eulerian (ALE) formulation, which enables the treatment of domain motion and the computation of displacement-dependent effects. Finally, *openCFS* includes a state-of-the-art optimization framework featuring density-based topology and material optimization methods with solver options tailored to various physical models. The optimization environment is readily extensible via *pyCFS*, a Python framework, allowing customized implementations such as feature-mapped shape and topology optimization as well as solving inverse problems based on the adjoint method.

The importance of advanced tools for the development of sensors and actuators will be demonstrated by three applications: (1) MEMS speaker; (2) electromagnetic brake; (3) magnetic camera.

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Integrated micro-magnets: enabling the next generation of MEMS and sensors

Nora M. Dempsey[1,*], Frederico Orlandi Keller, Richard Haettel and Thibaut Devillers

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NdFeB-based magnets are key components of a range of macroscopic devices (motors, generators, actuators...) and hold enormous potential for the development of micro-scaled devices (MEMS) with applications in fields as diverse as telecommunications, energy management, Internet of Things, and bio-technology. The emergence of magnetic micro-systems or MEMS using high performance hard magnetic materials such as NdFeB requires micro-magnet fabrication techniques which preserve the excellent extrinsic magnetic properties achieved in bulk and films [1], while being compatible with the cleanroom microfabrication techniques used to make MEMS. The techniques also have to be up-scalable, to allow massively parallel fabrication of devices. We have demonstrated that high-rate triode sputtering can be used to fabricate coercive NdFeB micro-magnets of thickness 50 µm, on Si substrates of diameter 100 mm [2]. In this talk we will present a general overview of both the fabrication and characterization of NdFeB films and micro-magnets. We will then give examples of the use of our micro-magnets in a range of bio-related studies and their integration into electro-mechanical prototypes including a vibration energy harvester [3]. We will finish up by discussing the prospects for using other hard magnetic materials in devices.

Acknowledgements

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Wednesday, July 8, 09:00-09:30
Senaatszaal, Auditorium building

Invited oral presentation

Magnetic actuation for biomedical applications

Jaap M.J. den Toonder[1,2,*]

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Biomedical applications such as point-of-care diagnostics, continuous biomarker monitoring, organ-on-chip, and cell analysis, often require controlled manipulation of fluids or precise application of forces at the microscale. We have developed magnetic micro-and nano-actuators that enable these functions, integrated in biomedical devices.

Inspired by biological cilia, we have developed magnetic artificial cilia, magnetically actuated micro- and nano-hairs, made from novel magnetic polymer materials using a combination of chemical synthesis and micromolding [1,2]. We have demonstrated that these actuators can generate substantial microfluidic fluid flow in a controlled fashion [3], and we have shown that they can be used to clean surfaces [4], to transport particles in a controlled manner [5], and to create anti-biofouling surfaces. We have cultured cells on the carpets of nanoscopic magnetic artificial cilia, in a platform that provides controllable dynamic mechanical stimulation to single cells, suitable for investigating large cell populations and enabling live cell imaging [6]. Cell morphology is strongly influenced by the artificial cilia, cellular forces can be quantified, and cellular responses can be monitored real-time while actuating cilia. Additionally, we have been able to create artificial embryonic nodes using combinations of active and passive nanoscopic cilia, and we have carried out quantitative flow characterization of the embryonic flow generated by these cilia; combined with numerical simulations, these experiments have resulted in novel insights into the effect of ciliary flow on embryonic development [7].

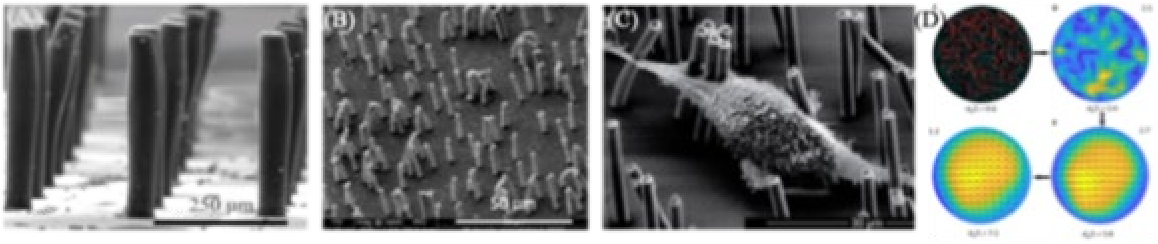

Fig. 1 (A) Magnetic artificial micro-cilia; (B) magnetic artificial nano-cilia; (C) MG-63 cell attaches to and pulls on artificial nano-cilia; (D) artificial embryonic node flow patterns.

Acknowledgements
This study was supported by H2020 Marie Sklodowska-Curie Grant 754462 and European Research Council–funded Project Bio-Plan under Advanced Grant 833214.

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Integrated Broadband Current Sensing: Circuit Design and Limitations

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Isolated broadband current sensing is a cornerstone technology in modern power electronics and automotive systems, driven by the need for faster, smarter, and more reliable control and protection mechanisms. High-bandwidth, low-latency current measurement enables not only real-time overcurrent protection, but also advanced control strategies and predictive diagnostics based on current signature analysis, which are crucial for next-generation electric drives and fault-aware systems.

Among available technologies, Hall-effect sensors stand out for their intrinsic compatibility with standard CMOS processes, offering a scalable and cost-effective path toward integration. Yet, this apparent simplicity conceals significant challenges: achieving low offset, wide bandwidth, and fast response requires carefully engineered analog front-end circuits that push the limits of design.

This talk will present an overview of the state of the art in Hall-based current sensing, highlighting recent advances and typical bottlenecks. It will investigate the challenges in the design of the analog front-end and delve into the interplay between magnetic sensing elements and circuit design, revealing how performance can be shaped by the readout architecture.

Acknowledgements
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Magnetometry to unveil fundamental questions, from the moons formation to habitabilty zones

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Magnetometry is a powerful geophysical tool for the non-invasive investigation of geological processes on Earth and other planetary bodies [1]. Magnetic measurements preserve a record of past geological and environmental conditions, making magnetometry particularly valuable in planetary exploration, where direct sampling and dense in situ observations are severely limited or entirely absent.

A fundamental limitation of magnetometry is that, unlike imaging techniques, magnetic sensors cannot “zoom in.” The spatial resolution of magnetic observations is directly controlled by the distance between the sensor and the sources generating the field. Consequently, in orbital magnetometry smaller or shallower structures are progressively attenuated with increasing observation altitude. On Earth, this limitation can be mitigated through multi-altitude surveys, which provide complementary perspectives of the magnetic field. In contrast, planetary missions to bodies such as the Moon and Mars are currently restricted to orbital and, in limited cases, surface measurements, resulting in reduced magnetic contrast and incomplete spatial characterization.

An additional challenge intrinsic to magnetometry is the determination of magnetic sources from the observed magnetic field. Multiple source configurations can reproduce the same magnetic signal [2]. This non-uniqueness complicates the geological interpretation of magnetic anomalies and makes it necessary to incorporate additional constraints to reduce the range of admissible solutions.

Moreover, magnetometry should not be restricted solely to the measurement of the field generated by magnetized bodies. Magnetic susceptibility, defined as the capacity of materials to acquire magnetization, provides complementary information that is crucial for identifying magnetic carriers and their physical and chemical states [3]. In this context, the development and deployment of new magnetic instrumentation become essential to achieve a more complete magnetic characterization.

Despite the limitations, magnetometry remains an exceptionally powerful tool for unraveling geological processes across a wide range of environments. Its sensitivity to variations in rock magnetization allows the identification of impact structures, volcanic systems, tectonic boundaries, and mineralogical variations, even when surface expressions are subtle, denudated or obscured [4]. Furthermore, magnetic data provide insights into the temporal evolution of planetary interiors, including the existence, intensity and extinction of core dynamos, and their role in shaping surface environments.

Several terrestrial and planetary analogue studies illustrate this potential. Magnetic investigations of proposed impact structures, such as an structure in Almería, southeastern Spain, reveal subsurface heterogeneities consistent with high-energy events. In volcanic and tectonic settings, the Antarctic Deception Island offers a unique example where magnetometry records crustal accretion, geomagnetic reversals, and tectonic reorganization linked to subduction rollback and rifting processes. In astrobiologically relevant environments, the Río Tinto basin—a widely recognized terrestrial analogue of Mars—demonstrates how magnetic surveys can identify iron-sulfate and manganese-rich deposits associated with redox processes and microbial activity, minerals also detected on Mars.

In this work, we combine experience gained through field campaigns and laboratory experiments with the development of new magnetic instrumentation and forward modeling approaches based on geological and morphological constraints. While these efforts are directly relevant to future planetary exploration, the methodologies and technologies discussed are equally applicable to a broad range of scientific and technological problems, underscoring the versatility of magnetometry as a key tool for investigating processes across diverse contexts.

Acknowledgements

This work has been funded by the Spanish State Research Agency the grants of references: RTI2018-099615-B-100, PID2020-119208RB-I00 and PID2024-160725OB-I00.

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Magnetic sensing with NV centers in diamond and application to extreme conditions

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Magnetic sensing based on nitrogen-vacancy (NV) centers in diamond has emerged as a versatile platform for high-sensitivity measurements under ambient and extreme conditions. A key strategy to enhance sensitivity to magnetic fields relies on increasing the density of NV centers, enabling the detection of very weak magnetic signals through collective spin readout.

In this talk, I will first discuss recent advances in high-density NV ensembles. While increased concentrations improve sensitivity, they also introduce challenges such as spin–spin interactions, inhomogeneous broadening, and reduced coherence times. In addition, optimizing the optical collection efficiency plays a crucial role in maximizing the signal-to-noise ratio. I will present approaches to address these limitations through material engineering, improved photonic structures, and tailored control protocols.

I will then describe the use of NV-based sensors for magnetic imaging of micrometer-sized samples, with particular emphasis on experiments performed under extreme conditions in diamond anvil cells. These configurations enable spatially resolved measurements of magnetic fields in regimes of high pressure, opening new opportunities for the study of condensed matter systems and phase transitions at the microscale.

Together, these developments highlight the potential of NV-based quantum sensors to combine high sensitivity with spatial resolution in challenging environments, paving the way toward new experimental capabilities in quantum sensing and high-pressure physics.

Acknowledgements
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Comparison of Racetrack and Dual-rod Cores for Usage in Micro-fluxgates

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[2] *Department of Electronic and Computer Engineering, NTUST, Taipei, Taiwan*
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While the only commercially available micro-fluxgate (DRV425 by Texas Instruments) uses dual-rod core [1], we believe that racetrack is a better shape since it is magnetically closed, and thus the excitation field for the same excitation current is higher. On the other hand, racetrack has a higher demagnetization factor, which could negatively affect the sensitivity. We first compared the performance of racetrack and dual-rod using FEM simulation, and now we present actual measurement results.

The micro-fluxgate used for this research is described in [2]. The layout of the coils allows to insert either racetrack or dual-rod cores with 8 mm length. The cores are made of Vitrovac 6025F ribbon thinned to 10 µm using a custom process. The low thickness is required to achieve deep saturation at high frequencies, which are required to reach high sensitivity [3].

The results in Fig. 1 show that the highest sensitivity is achieved around 1.6 MHz in both cases and has a very similar value of almost 8000 V/T. Most importantly, in Fig. 2 we can see that the dual-rod requires 2 times higher excitation current (the optimal operation point, where the core is completely saturated, is slightly behind the maximum sensitivity). The microfabricated coils have a high resistance (20 Ω, as reported in [2]); therefore, the Joule heating of the excitation coil is the dominant contributor to its power consumption. The 2 times lower current needed with racetrack core therefore reduces the power consumption 4 times. Minimal achievable noise is similar in both cases, less than 1 nT/√Hz, as reported for racetrack in [3]. The difference is that the dual rod requires higher current to achieve a low noise, which corresponds to the higher current required to saturate the core.

This research shows that a magnetically closed core is much more suitable for micro fluxgates, as there is a significant decrease in power consumption thanks to the lower excitation current needed to saturate the core. Even though the racetrack has higher demagnetization, the achieved sensitivity is similar for both shapes.

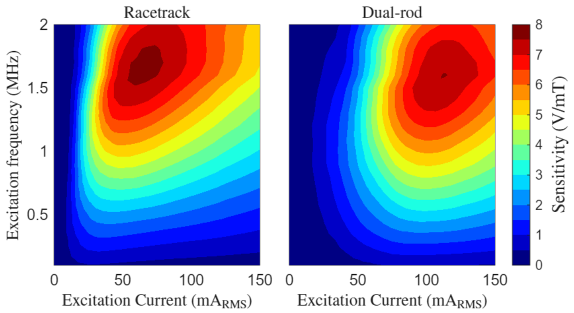

Fig. 1 Comparison of 2nd harmonic sensitivity of racetrack and dual-rod cores

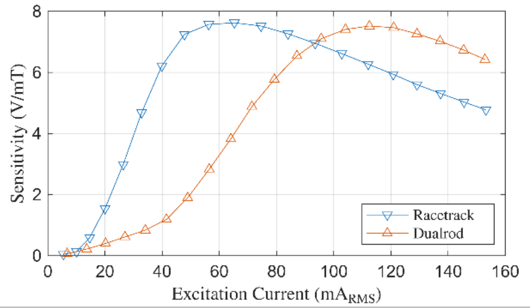

Fig. 2 Data from Fig. 1 shown for 1.6 MHz sinewave excitation

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Part 2

Special session with industry

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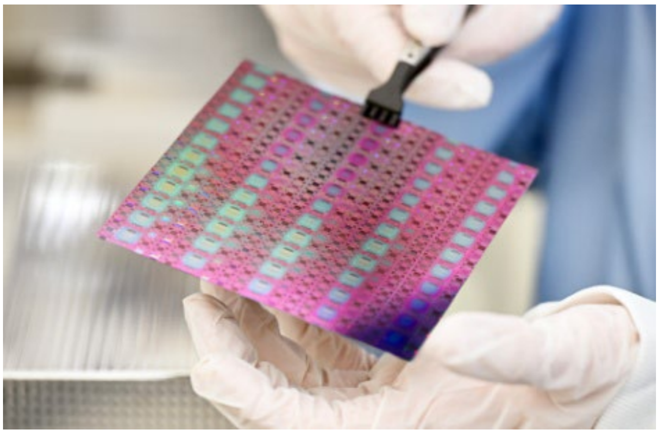

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Technological advances and challenges in Infineon's TMR sensors

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In the talk we will delve into the complexities of Tunnel Magnetoresistance (TMR) sensor fabrication. We will illustrate with some examples the contrast between simplified university demonstrators, typically featuring few MTJs in series, and the highly integrated and complex devices required for industrial applications. The presentation will also explore the opportunities for universities to support industry in overcoming these challenges, leveraging their expertise and resources to accelerate the development of innovative TMR sensor solutions. By bridging the gap between academic research and industrial requirements, we can unlock the full potential of TMR sensors and drive progress in this exciting field.

Magnetization technology for high precision magnetic encoder scales

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Magnetic encoders for length and angle measurement have experienced growing adoption across industrial applications due to their exceptional robustness in harsh environments. Traditionally, these encoders have been preferred where resistance to contamination, temperature extremes, and mechanical stress is required, but seldom employed in applications demanding very high accuracy. This limitation has confined magnetic encoders to less demanding applications, while high-precision tasks remained the domain of optical encoder systems.

Recent technological advances are fundamentally changing this landscape. The development of sophisticated magnetization equipment in combination with highly homogeneous hard magnetic coatings now enables magnetic encoders to achieve resolutions and accuracies comparable to high-precision optical systems while retaining superior robustness and resistance to environmental contamination.

Within a state-funded KMU-Innovativ R&D project, ITK Precisioning developed specialized magnetization equipment for linear encoder scales up to 5 metres in length (Fig.1). The development encompassed novel inductive and impulse magnetization heads alongside sophisticated calibration and compensation software [1]. When utilizing $SmCo_5$-based hard magnetic films, measurements according to ISO 230-2 demonstrate system accuracies better than 3 µm/m, placing these magnetic encoder scales firmly in the high-precision category.

These principles extend to rotary encoders, opening entirely new application fields for magnetic measurement systems in precision machinery, semiconductor manufacturing, and metrology applications previously dominated by optical technologies.

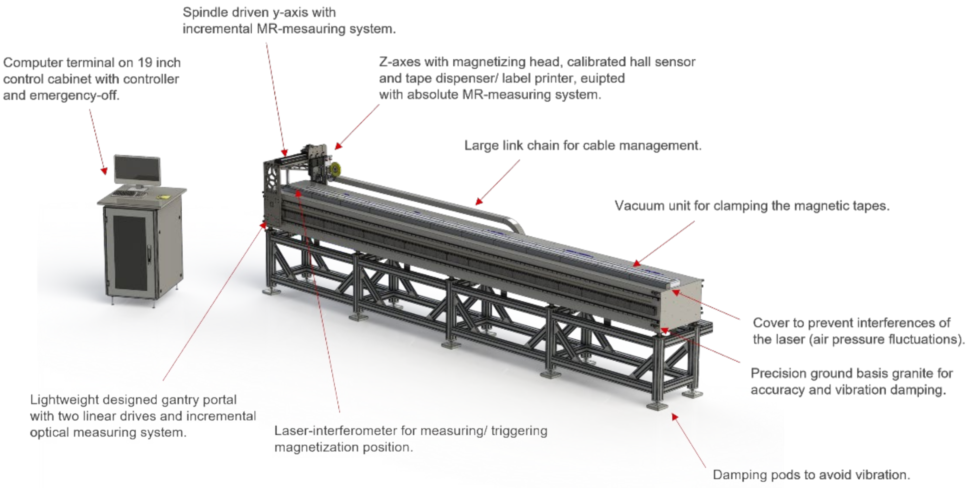

Fig. 1 LMP5000 linear magnetization machine (Source: ITK Precisioning GmbH)

Acknowledgements

The German BMBF funded the joint project „Entwicklung einer hochpräzisen Linear-Magnetisieranlage für die Beschreibung von magnetischen Maßstäben (ELM2)“, grant agreement 02P21K060, within the funding programme "KMU-innovativ: Zukunft der Wertschöpfung".

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Cross field influences for 3D magnetoresistive sensing

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In a lab, sensor concepts are usually optimized for a specifically intended measurement task and situation. In the wide range of real-world applications for magnetic sensors, these conditions can only rarely be achieved. Temperature effects, stray fields, assembly misalignment or inhomogeneity of the used magnets or magnetic scales are common challenges.

Typically, magnetoresistive sensors utilize in-plane anisotropies for the free- and pinning-layers, increasing the complexity of an on-chip solution for a 3D sensor. Furthermore, crosstalks for this type of stack need to be considered, since stray fields of pinned layer of a spin valve structure will add to the error of this stack.

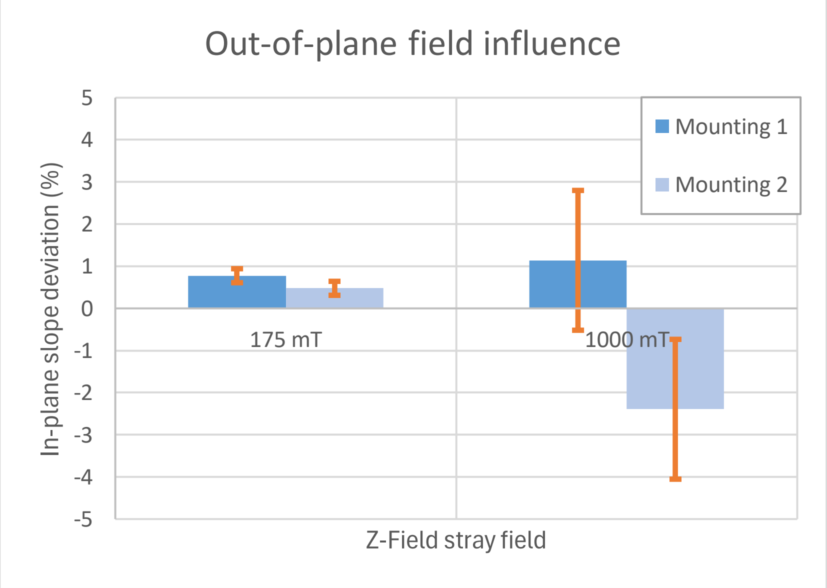

Figure 1. Demonstration of the robustness of a vortex type sensor. The plots show the normalized slope deviations for different applied out-of-plane stray fields and different mounting directions. The influences are tiny compared to the applied 1000 mT out-of-plane field.

In our study we present a brief comparison of different magnetic stacks, chip geometries and further processes, aiming to optimize and improve the MR sensor robustness against undesired influences. Commonly used stack configurations such as crossed anisotropy, vortex or interface anisotropy are compared in terms of off-axis field influences with respect to their initially intended measurement direction. The results highlight e.g. the robustness of vortex stacks against out-of-plane fields, see Fig.1 [1].

Suppression effects by the usage of multi-pinning chip designs are discussed to simple full film pinning layouts for the optimization of z-field sensing [2]. Multipurpose configurations for field guiding flux concentrators are shown, highlighting the possibility to combine the guiding effect with an additional stray field shielding. All results are put into perspective for a 3D magnetic field sensor.

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BMM350, A Monolithically Integrated TMR 3-Axis Magnetometer for Consumer Electronics Applications

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Magnetic field sensing is a key technology across automotive, industrial, and consumer domains, where increasingly stringent requirements drive the adoption of advanced magnetoresistive devices. Tunneling magnetoresistance (TMR) sensors offer high sensitivity, low noise and CMOS compatibility, making them well-suited for wheel-speed detection and steering-angle sensing in automotive systems, for high-precision current and position sensing in electrified powertrains and photovoltaic converters, and for compact 3D magnetic-field tracking in human–machine interfaces such as game controllers, smartphones, and extended reality devices.

This work presents the BMM350, a fully monolithic, wafer-level, chip-scale, three-axis TMR magnetometer developed at Bosch Sensortec GmbH (BST). The device integrates TMR stacks through back-end interconnects directly above a mixed-signal CMOS process, enabling a compact and fully monolithic architecture. A high-throughput, lot-level wafer-batch fabrication step is employed to define two mutually orthogonal pinned reference-layer orientations within the TMR stacks, enabling decoupled in-plane sensing of the x- and y-components of the magnetic field with high linearity and minimal cross-axis interference.

For out-of-plane (z-axis) measurement, the sensor includes integrated soft-magnetic flux-guide structures that efficiently redirect perpendicular magnetic flux into the in-plane TMR elements. This approach enables true three-axis field detection without increasing the overall die height, preserving compatibility with thin package requirements and eliminating the need for discrete magnetic components.

Monolithic CMOS integration further provides access to several beneficial on-chip functions. An embedded temperature sensor enables accurate thermal compensation of the output over the full specified temperature range. A magnetic reset mechanism allows controlled reinitialization of the sensor's magnetic configuration, significantly improving resilience against strong external magnetic disturbances. Multiple operating modes allow optimization of noise, bandwidth, and power consumption, enabling the sensor to be tuned for a wide range of application-specific constraints.

The resulting device combines high magnetic sensitivity, small footprint and height, and compatibility with high-volume semiconductor manufacturing. Its architecture demonstrates a scalable pathway for integrating multi-axis TMR sensing with advanced CMOS functionality for next-generation consumer, automotive, and industrial magnetic-sensing applications.

Acknowledgements
The authors sincerely appreciate the invaluable contributions of the Bosch Sensortec TMR Team to this work.

Development of Shape-Memory Functionality in Ni-Fe-Ga Microwires

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Miniaturized actuators are increasingly demanded in robotics, optics, biomedical devices, and precision engineering, where compact size, high reliability, and substantial mechanical output are essential. Shape-memory alloy–based microwires represent a particularly attractive platform for microscale actuation due to their large recoverable strains, high actuation stresses, tunable transformation temperatures, and excellent fatigue resistance. These materials can exhibit recoverable strains up to 12%, transformation temperatures adjustable from –170 °C to 400 °C, durability exceeding 9×10^6 cycles, and generated stresses above 100 MPa. Moreover, the Taylor–Ulitovski method provides a scalable fabrication route, enabling kilometer-scale production from minimal amounts of alloy.

In this work, we focus on engineering the shape-memory characteristics of Ni-Fe-Ga microwires through systematic control of composition, rapid solidification conditions, and post-processing treatments. By identifying and tailoring the key parameters governing microstructure evolution, atomic ordering, and internal stress states, we establish direct correlations between processing conditions and martensitic transformation behavior, functional strain response, and mechanical stability. Representative case studies demonstrate how optimized fabrication strategies enable enhanced transformation temperatures, improved reversibility, and stable actuation performance. These results provide a comprehensive framework for the deliberate design and optimization of Ni-Fe-Ga microwires for high-performance microscale actuation applications.

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Part 3

Contributed oral presentations

Design optimization of magnetic tunnel junctions-based sensors for picotesla detection

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Magnetic tunnel junctions (MTJs) have emerged as promising candidates for spintronic-based magnetometers thanks to their high sensitivity to magnetic fields, small footprint and low power consumption. Thanks to the tunnel magnetoresistance effect, their response to external magnetic fields is translated into a change in the resistance state that is measured with a bias voltage. Our project aims at developing an ultra-sensitive MTJ-based magnetometer tailored for nanosatellite (CubeSat) missions [1], with a detectivity of 1 pT/ √Hz at 10 Hz. This limit for field detection is given by the ratio between the noise of the sensor and its sensitivity, therefore our work aims at the simultaneous optimisation of these two paramaters.

In order to raise the sensitivity, the device integrates magnetic flux concentrators (MFCs), which allowed enhancing sensitivity from 3.6 %/mT to 1585 %/mT (magnetic gain of 440) [2]. Such results overcome previous magnetic-flux gains in the range of 10-100 [3]. We have also shown a significant enhancement in sensitivity by using a thick ultrasoft sensitive layer of FeCoBTa below the MgO barrier in a so-called inverted stack design. Sensitivities up to 18 %/mT have been reported using such architectures, which, combined with an MFC, reach up to 2400 %/mT.

As a second area for detectivity optimisation, the 1/f magnetic noise needs to be reduced in the low-frequency domain. A well-established strategy to reduce this type of noise is to increase the effective magnetic volume of the sensing area, achievable by inserting multiple MTJs in the MFC gap. We will present our model that includes the trade-off between the MFC gap width and length, to maintain a high magnetic gain, and the volume of magnetic layer, to improve noise. It allows to identify a sweet spot for an optimal design [4]. With this design and further MFC optimisations, we estimated an improvement of detectivity by a decade, leading to the expected detectivities around ~ 10 pT/ √Hz at 10 Hz. These advancements will pave the way towards a detectivity of 1 pT/ √Hz at 10 Hz, which could be achieved by novel noise modulation techniques.

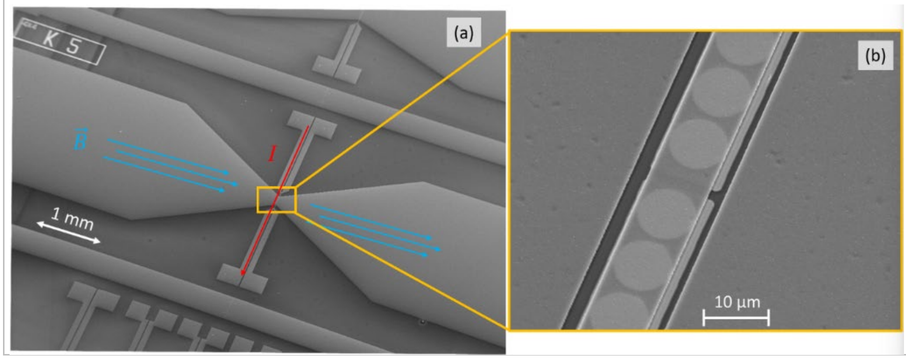

Fig. 1 (a) Scanning Electron Microscopy picture of the chip with MFCs. (b) Zoom on the MTJs below the top electrode in the MFC gap. The junctions are arranged in series-parallel blocks.

Acknowledgements
The authors thank C. Fermon for fruitful discussions. This work is supported by the French National Research Agency in part through the "France 2030" program PEPR SPIN under Project ADAGE (ANR-22-EXSP-0006), by the CNES R&T program and the ANR-22-CE42-0020 project MAROT and was partly supported by the French RENATECH network.

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Very long-term magnetic stability: On the path to identify the output very slow drift observed in PHMR sensor.

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This study investigates the long-term stability of Planar Hall MagnetoResistance (PHMR) sensors, whose DC precision is limited by a slow output drift. To exclude the external magnetic or thermal fluctuations, measurements were conducted in our shielded room under monitored and controlled conditions, with a magnetometer and a thermometer, as references.

The studied PHMR sensor is designed as a Wheatstone bridge [1]. So that we have built a similar bridge with passive resistors and used it as a phantom in our measurements for separating the drift from the signal-conditioning electronics and the one from the sensing element. Furthermore, the absence of a remanent response after the application of a magnetic step excludes magnetization effects as the dominant mechanism, here. Whereas the reference bridge exhibits fluctuations linearly correlated with temperature, the PHMR sensor output shows a temperature dependence to which a distinct and observed time-dependent drift is superimposed. The removal of these thermal effects revealed a strictly linear residual drift with a yet-to-be-understood phenomenon. However, existing sensor models [2] can be extended. It yields the output voltage as a function of time for the measurement system, at magnetic field operating point ($B = B_0$), as follows

$$V_S(t) = A\left[S_T\left(B(t) + b_n(t)\right) + k \times \Delta T(t) + a \times t + V_{offset}\right] + e_n(t) + R \times i_n(t)\,.$$

where $A, S_T, B(t), b_n, e_n(t), i_n(t), k, \Delta T, a, V_{offset}, R$ are the chain gain, the magnetic sensor sensitivity [V/T] evaluated at the magnetic operating point, the applied magnetic field, the equivalent input magnetic noise derived from the spectral density [2], $b_n(f)$, the amplifier voltage and current noise sources, the temperature sensor sensitivity [V/K], the temperature change with respect to the initial temperature $\left(\Delta T(t) = T(t) - T(0)\right)$, a linear drift coefficient [V/s], a DC offset voltage and the PHMR Wheatstone bridge resistance. At this stage, several experiments suggest that the linear drift may be related to the differential bias voltage of the PHMR Wheatstone bridge and internal magnetic effect. Further investigations will focus on quantifying, clearly, this phenomenon.

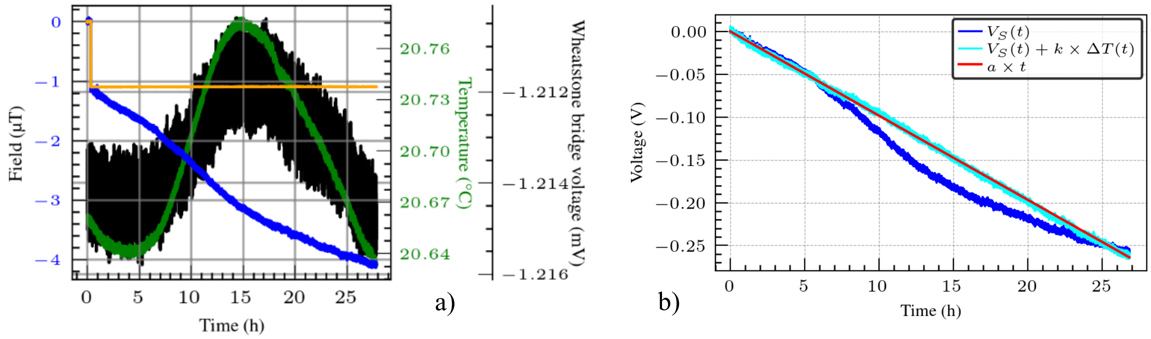

Fig. 1: a) After applying a magnetic field step of around 1 [μT], simultaneous observations, of the sensed magnetic field (in Tesla units) by the PHMR sensor (blue curve) and by the fluxgate (orange curve), of the temperature (in °C unit) measurement (green curve), and of the Wheatstone bridge output (in V units) as a phantom (black curve). b) Linear drift of the PHMR after temperature compensation (cyan curve) for $k = 0.28\ [V/K]$ and corresponding fitted linear drift coefficient $a = -9.8\ 10^{-3} [V/s]$ (red curve).

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Exploring optical methods for reprogramming spintronic sensors

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Magnetoresistive (MR) sensors are widely used in magnetic sensing applications requiring high sensitivity, low production cost and a small spatial footprint. These sensors can detect only one component of the three-dimensional magnetic vector field. We attempt to make MR sensors multiaxial by using light to reprogram individual sensing elements on-demand [1]. Light is a promising candidate for reprogramming because it can easily be shaped and focused onto microscopical features. It can also be passed through waveguides on chips, opening possibilities for bridging spintronic sensors with photonic integration. Moreover, light can be compressed into ultrashort pulses which are known to very efficiently drive various magneto-optic effects.

One of these effects is all-optical helicity-independent switching, occurring in ferrimagnetic thin films containing rare-earth elements like gadolinium. In such systems, a single femtosecond laser shot realizes a deterministic 180° reversal of magnetization. We implement this toggle mechanism in existing MR sensor architectures such that their reference axis can be reprogrammed using light.

We show that laser pulses can be used to toggle the pinning direction of an antiferromagnet between up and down orientation [2]. Crucially, the effect works under field-free conditions, preserves unidirectionality at zero field and is repeatable for successive pulses. This makes toggling the reference axis of an MR sensor feasible (Fig. 1a). We developed a model that exposes the relevant parameters and material properties that govern the pinning reversal [3], allowing us to pinpoint tunable knobs and materials for achieving optimized integration into MR sensing devices.

We then expanded further to sensing anisotropic magnetoresistance in gadolinium-based ferrimagnets. We fabricated a stack of permalloy, cobalt and gadolinium for optimized magnetoresistance and optical switching performance. A maximum anisotropic magnetoresistance of 0.6% is reached, while the threshold fluence for optical switching is around 10 mJ/cm^2. As a demonstration, we used two pads connected in series with orthogonal in-plane anisotropies and focused the laser on one of the pads, allowing us to toggle between *x*- and *y*-sensitivity in a single sensing device (Fig. 1b). In the future, we envision true single element multiaxial sensing by designing geometries with engineered anisotropy landscape.

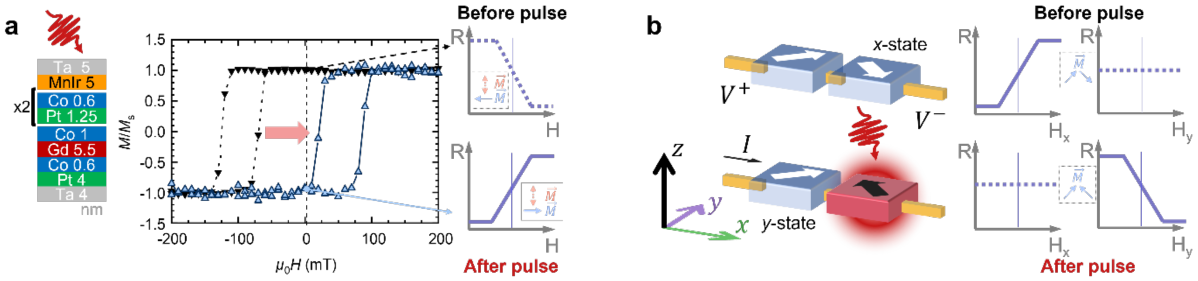

Fig. 1 a The stack used for demonstrating all-optical pinning reversal in a reference layer. The black hysteresis curve is measured as-grown, while the blue curve is measured after firing a single laser pulse. **b** Design of a sensing device that can be toggled between *x*- and *y*-sensitivity by a single laser pulse. The *R-H* curves in **a** and **b** show schematically how the sensor output is affected in each case.

Acknowledgements

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AI – Driven Modeling of Modulated Magnetoelectric Sensors

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Modulated magnetoelectric (ME) sensors can detect low-frequency magnetic fields with small amplitudes. Their performance depends on a high-dimensional parameter space in which the nonlinear interaction of magnetic, electric, and mechanical properties is connected with the readout electronics and multiple operating conditions. This complexity makes key tasks challenging, such as designing sensors for specific applications, conducting systematic performance analysis, and identifying ideal operation conditions.

In this work, we make an initial step toward managing this complexity by proposing AI-based surrogate models that systematize operating point selection and characterization workflows. We train three artificial neural networks (ANNs) on measurement data from a ΔE-effect-based modulated ME sensor. By using key operating parameters like excitation amplitude, excitation frequency, and magnetic bias field, the ANNs predict admittance (magnitude and phase), noise spectral density (NSD), and signal output. The resulting models accurately reproduce the measured response. They achieve high accuracy with sub-percent errors for admittance magnitude and phase, percent-level error for NSD, and a 90th-percentile absolute relative error of ≈ 5% for the signal model.

A data-efficiency analysis, where we systematically reduce the amount of data which is used for training, shows that admittance predictions stabilize already at 5% training data corresponding to 14 curve-equivalents with a coefficient of determination of 0.99 and nRMSE of below 0.2%. The signal model is highly unstable at 5% training data (2 samples), but becomes stable from 50% (28 samples) onward with a coefficient of determination of approximately 0.97 and nRMSE of 16%. It further improves to 9% nRMSE at 100% of the available training data (54 samples). In contrast, NSD prediction remains data-limited up to 75% training data and reaches good agreement only at 100% training data corresponding to 61 curve equivalents with a coefficient of determination of 0.99 and nRMSE value of about 5%.

Finally, we present three different optimization use cases based on the proposed AI surrogates. Each reflects a different level of practical relevance. First, a global optimization task aims to identify the global minimum of the limit of detection (LOD) across the entire parameter space. Secondly, we consider a constrained single-objective optimization problem, in which the magnetic bias field and excitation amplitude are restricted by the dynamic range of the electronics, while the objective remains to minimize the LOD. Thirdly, we consider constrained multi-objective scenario, where the noise floor is dominated by external environment noise, and the expected range of the target signal is already known. In this case, optimization considers LOD, identifies feasible operating regions by enforcing bounds on magnetic bias field and excitation voltage while requiring the signal output to exceed a predefined threshold.

Taken together, these results indicate that AI surrogates are a first step towards a digital-twin approach for ME sensors that allow rapid operating-point selection and systematic characterization. In the future, such models could support application-driven design as well as array and setup optimization under competing requirements like LOD, response time, size, power, and provide a foundation for virtual testing and inverse problem solving, such as localization and magnetic field reconstruction.

Acknowledgements

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Simulation and Optimization of a Dual Halbach Permanent-Magnet Field Source

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Permanent magnets are a stable source of static magnetic fields, independent of electrical power. Optimization of the distribution of this field has led to the emergence of the Halbach array, invented by Klaus Halbach in the 1980s to improve the performance of particle accelerators [1]. By carefully orienting the magnetization vectors, Halbach arrays allow the magnetic field to be amplified on one side and reduced on the other, a phenomenon known as "unilateral flux" [2]. On the active side, the magnetic field is constructively added, reaching values up to approximately twice as high as in simple arrays. On the inactive side, the field lines partially cancel each other out, reducing flux leakage and interference. The effect is achieved by rotating the magnetization vector of each segment by a constant angle (e.g., 90° or 45°). This unique feature makes it possible to use Halbach magnets as a variable magnetic field source, adjustable by mechanical movement or structural reconfiguration. By changing the relative position to a target object or changing the orientation of the assembly, the intensity of the field perceived by the target can be adjusted [3].

In this study, numerical simulations were performed for analyzing the magnetic field distribution of an electromagnetic field source based on a dual Halbach array. Unlike coil-based implementations, which focus on high-power linear actuation, energy harvesting, or magnetic detection, the present approach aims to propose a controllable field source for experimental and industrial applications. Simulations performed in COMSOL Multiphysics allow the comparison of different configurations and the optimization of design parameters to obtain an intense and uniform field in the area of interest. The simulation results showed that the proposed dual Halbach structure is promising for achieving a motor-controlled variable magnetic field source, but it also presents practical challenges. The proposed configuration is susceptible to undesirable field inhomogeneities in magnetic characterization systems, mostly due to the difficulty of manufacturing and precisely aligning the 16 magnetic segments. In addition, in order to function as a calibrated magnetic field source, especially considering that most magnetic sensors exhibit specific anisotropy and are susceptible to directional fields, it is necessary to integrate a magnetic feedback sensor that will adjust the rotation of the servomotors in real time and, implicitly, the position of the magnets, in order to adjust the rotation of the magnets as close as possible to the area where the magnetic test sample will be placed.

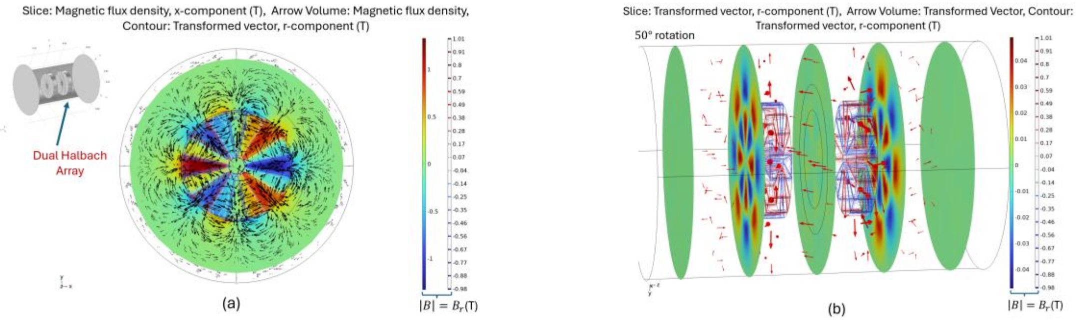

Fig. 1. (a) Dual Halbach magnet configuration and magnetic field lines distribution of one Halbach Magnet; (b) Magnetic flux distribution on the dual Halbach structure for a 50° rotation angle.

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Non-Destructive Analysis of Magnetic Layer Properties of Encoders using Simulation-Based Hysteresis Modeling

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Magnetic linear and rotary encoders have become indispensable in various technical applications due to their robustness, cost-efficiency, and long lifetimes [1]. However, their performance can be further improved by optimizing the fabrication process of magnetic pole wheels, the writing of the magnetic zone pattern, as well as the sensor performance [2]. To achieve improvements, it is crucial to investigate the resulting magnetic properties of the thin magnetic layer, such as remanence, anisotropy, and coercivity. We propose a non-destructive method that analyzes these properties directly on fabricated wheels using a simulation-based approach.

Our method involves defining a specific pattern with varying sequences of alternating and parallelly magnetized zones, which is then reproduced by a magnetization simulation model based on analytical field calculation [3]. The underlying hysteresis model [4] simulates both outer and inner hysteresis loops, allowing us to extract key parameters such as remanence and coercivity (see Fig. 1).

Our results demonstrate that our approach accurately reproduces the relevant magnetic properties of the magnetic layer, including the writing-relevant hysteresis loop. Additionally, it enables the evaluation of anisotropy and out-of-plane magnetization. Comparison with hysteresis measurements on a Vibrating Sample Magnetometer (VSM) shows excellent agreement, validating our approach.

This work provides a valuable tool for quality control and process optimization in the fabrication of magnetic pole wheels, ultimately contributing to the improvement of magnetic encoder performance.

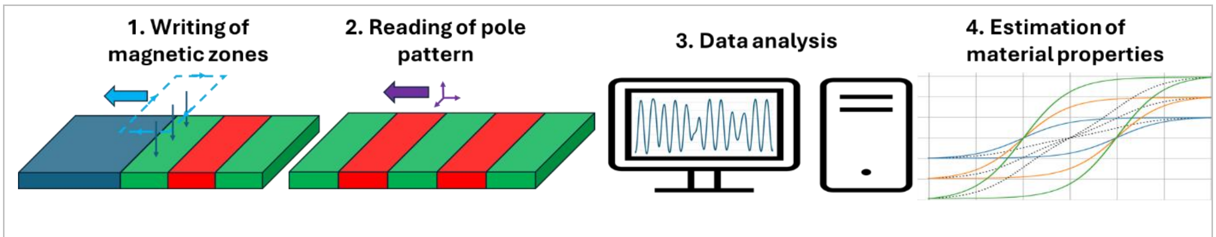

Fig. 1 Procedure of the proposed approach for testing the magnetic properties of pole wheels.

Acknowledgements
This work has been jointly supported by Infineon Technologies Austria AG, ELSOMA GmbH, Nanomag GmbH and by Silicon Austria Labs (SAL), owned by the Republic of Austria, the Styrian Business Promotion Agency (SFG), the federal state of Carinthia, the Upper Austrian Research (UAR), and the Austrian Association for the Electric and Electronics Industry (FEEI).

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Magnetic MEMS for reconfigurable magnonic devices

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The integration of micromagnets in piezo-MEMS has been proposed as a viable route to implement a low-power integrated strategy for reconfiguring the magnetic field landscape in spintronic/magnonic devices.[1] In the last year we have developed a wafer-scale technology platform allowing to fabricate soft and hard magnets, respectively Py and SmCo, on state-of-the-art piezo MEMS like membranes and cantilevers. The relative displacement of said micromagnets with respect to a spintronic/magnonic device allows to tune the stray field used for biasing it, thus reconfiguring in real time the device functionalities.[2]

In this talk I'll report on some implementations of the above concept in the case of magnonics. Combining magnonics and microelectromechanical systems (MEMS) is the strategy of the European project M&MEMS to build up a new technology platform for tunable RF components. The additional degree of freedom offered by the possibility of controlling, in real time, the distance between magnonic devices and other magnetic elements mounted on the movable part of MEMS, opens new routes towards the realization of integrated and tunable devices for RF signal processing.

In the first part of this talk I'll report on the first demonstrations of the M&MEMS concept: tunable phase shifters working up to 10 GHz fully integrated on Silicon with frequency band up to 10 GHz.

In the second part I'll introduce some more recent results dealing with the deployment of our approach for the realization of innovative sensing and computing architectures.

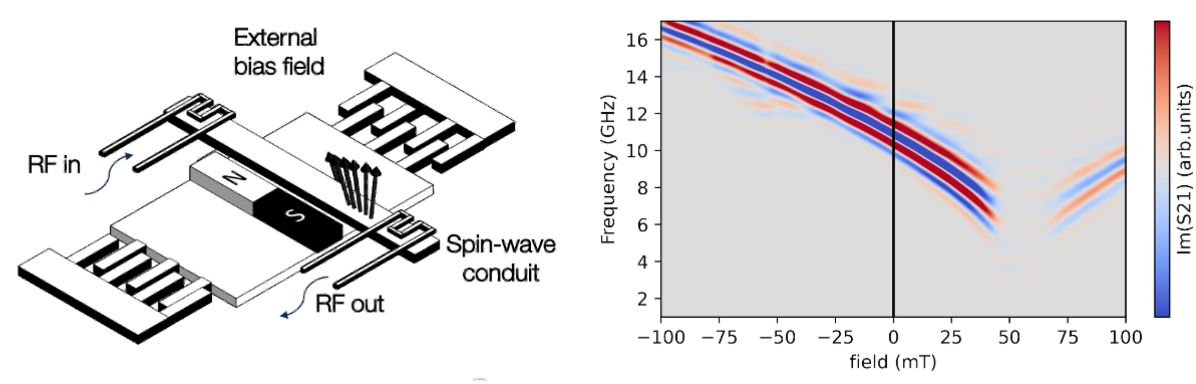

Fig. 1 Concept of the magnetic-MEMS for reconfiguring a magnonic device and demonstration of the standalone operation of a phase shifter at zero bias field thanks to integrated SmCo magnets.

Acknowledgements

We acknowledge funds from the European Union via the Horizon Europe project “MandMEMS”, grant 101070536, and the program NextGenerationEU, PNRR MUR – M4C2 – Investimento 3.1, project IR_0000015– “NFFA–DI,” CUP B53C22004310006.

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Exchange-Bias SAW Sensors for Zero-Bias Field Operation

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The compound magnetoelectric effect, which combines piezoelectric and magnetostrictive materials, is utilized in surface acoustic wave (SAW) sensors to detect magnetic fields. Interdigital transducers are configured in a delay line on piezoelectric bulk ST-cut quartz substrates that excite shear-horizontal Love waves. The magnetostrictive thin film employs the ΔE-effect, whereby the elastic modulus changes under an external magnetic field. These changes alter SAW velocity, resulting in a measurable phase shift [1]. A single-domain magnetic configuration is accomplished by two exchange-biased FeCoSiB layers [2]. Tailoring the magnetic anisotropy orientation relative to acoustic wave propagation creates an internal magnetic bias, enabling a pronounced sensor response to AC magnetic fields at zero external DC magnetic bias field. A comparison is made between SAW sensors with pinned anisotropy axes of the FeCoSiB layers that are either canted in parallel or arranged in a scissor-like configuration with opposite canting angles.

Electrical and magnetic characterization demonstrates high phase sensitivities of up to 1000 °/mT and limits of detection down to the sub 100 $pT/Hz^{1/2}$ range at low frequencies. Without an external magnetic bias field, sensitivities of up to 500 °/mT are achieved for both magnetic layer concepts. In addition, angle-resolved measurements reveal a well-defined sinusoidal directional response, confirming the vectorial sensing capability of the SAW sensors.

To demonstrate the applicability of this sensor in biomagnetic diagnostics, the zero-biased SAW sensor is employed for unshielded detection of magnetic nanoparticles via AC susceptibility measurements. The magnetically induced phase response of the SAW enables contact-free detection of Fe_2O_3 nanoparticle suspensions, with the out-of-phase susceptibility component scaling linearly with particle concentration in agreement with the Debye model of Brownian relaxation. AC susceptibility measurements particularly benefit from the high bandwidth of the SAW sensor, as the relaxation frequency of the nanoparticles can be as high as 50 kHz. In addition, the SAW sensors offer a high dynamic range and are not magnetically saturated by the excitation field up to 100 µT.

Overall, the presented results establish exchange-biased, single-domain SAW magnetic field sensors as a versatile and highly sensitive platform that shows zero-bias operation, low noise and vector sensing capabilities. These sensor characteristics are exploited in the AC susceptibility measurement of magnetic nanoparticles.

Acknowledgements

The authors would like to thank the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) which funded this work through the CRC 1261 “Magnetoelectric Sensors: From Composite Materials to Biomagnetic Diagnostic”. Additionally, gratitude is extended to Jana Meyer-Strenzke and Henrik Wolfram for their contributions to sensor fabrication and characterization.

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Real-time monitoring of viscosity and density with a magnetoelastic sensor

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A magnetic biosensor based on the magnetoelastic resonance of an amorphous microwire ($Fe_{73}Si_{11}B_{13}Nb_3$) as the active element is presented, designed for real-time, contactless monitoring of changes in the surrounding medium. The device integrates a spectral characterization platform with a self-oscillating circuit that operates directly at the microwire resonance frequency, enabling continuous measurements under flow conditions.

The sensing principle relies on resonance frequency shifts induced by variations in mass, density, or viscosity of the environment. The influence of microwire length, diameter, and oxidation state was systematically analyzed to optimize performance and ensure reproducibility. In oscillating regime, the system achieved a high-quality factor ($Q > 17000$), providing high frequency resolution and enhanced sensitivity to small variations [1].

The sensor was validated using water–glycerol solutions with different concentrations, successfully distinguishing changes below 1.5% and establishing a quantitative correlation between frequency shift and medium parameters [2]. These results demonstrate the potential of magnetoelastic microwires for miniaturized biosensors aimed at early diagnosis and continuous biomedical monitoring.

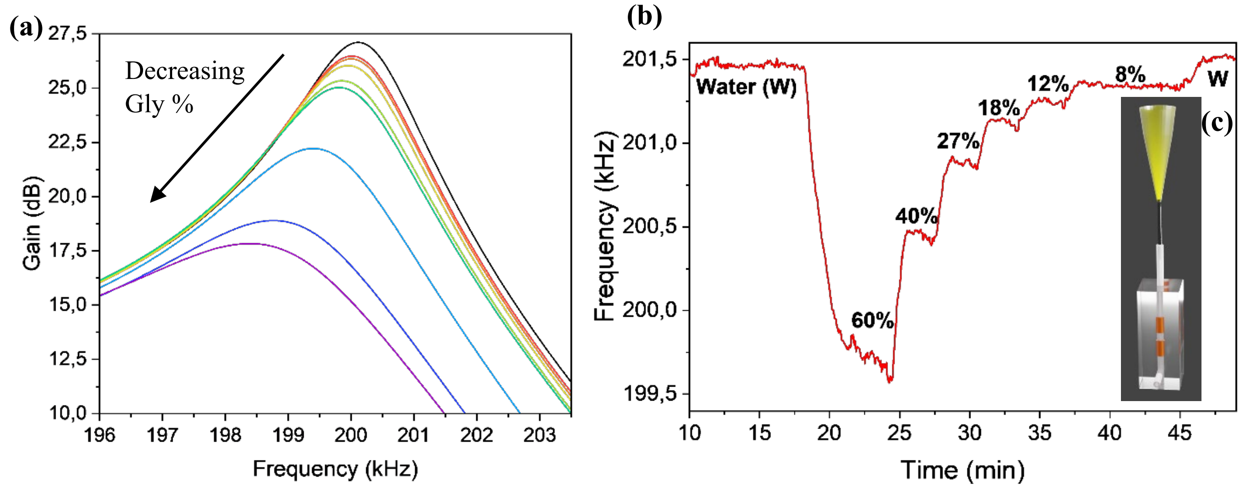

Fig. 1 (a) Magnified view of the peak shifts for different solutions. **(b)** Real-time continuous-flow measurements of different water-glycerol solutions. **(c)** Continuous flow platform for sensing.

Acknowledgements
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Tunable Microwave Scattering Signatures of 3D Sensing Platforms Based on Ordered Magnetic Microwire Assemblies

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This work explores novel configurations of sensing array platforms composed of Co-based amorphous ferromagnetic microwires (MWs). These materials are of particular interest as they combine wireless Giant Magnetoimpedance (GMI) properties with inherent magnetostrictive behavior, enabling the high-sensitivity modulation of microwave scattering effects through low-strength DC or AC magnetic fields [1].

Amorphous MWs are ultrasoft ferromagnetic materials (coercivity ≈ 0.2 Oe) characterized by circumferential magnetic anisotropy. This unique magnetic structure facilitates a high surface impedance sensitivity when exposed to external stimuli, which is the physical basis for their wireless sensing capabilities [2].

Microwave scattering experiments were conducted by varying the length and number of MWs arranged in parallel to form linear arrays. Based on these results, several array configurations were developed, achieving significant S_{21} transmission coefficients reaching approximately −50 dB. The influence of DC and AC magnetic fields on the S_{21} parameter was analyzed in the frequency and time domains, respectively. Furthermore, the sensing capability of the MW arrays to detect mechanical strain was experimentally demonstrated, confirming their potential for multifunctional, wireless sensing applications.

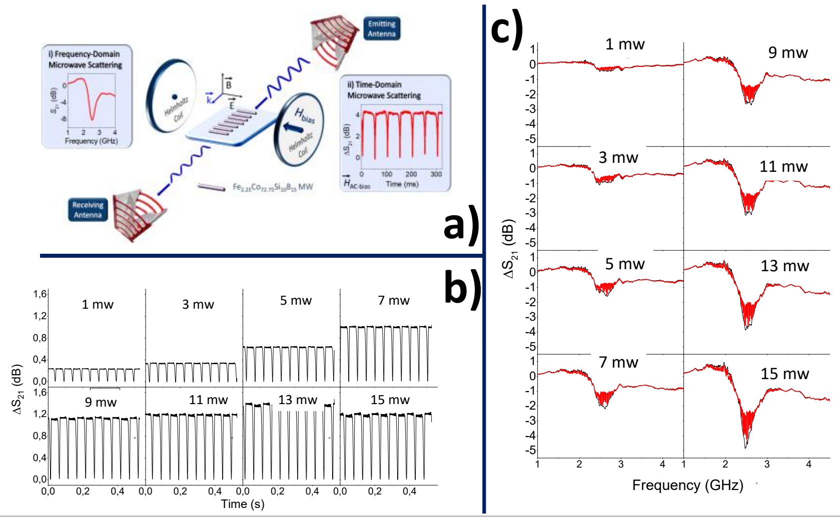

Fig. 1 a) Setup: Schematic of the microwave transmission system and Helmholtz coils (H_{bias}). b) Time-Domain: ΔS_{21} evolution for an increasing number of microwires c) Frequency-Domain: ΔS_{21} spectra showing resonance scaling with the microwire count.

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Spintronics sensor for neuronal activity detection

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Magnetic signal detection enables remote sensing, access to vectorial information and separation of signal sources. For these reasons, several approaches have explored the use of magnetic sensors to record signals generated in living cells and organisms, as an alternative to electrical recordings, which require direct contact to the tissue and are limited to scalar information (i.e. a potential measured with respect to a reference,) potentially restricting source discrimination

In neurons, the electrical activity of single cells - known as action potentials - is locally detected using electrodes. The magnetic counterpart of this signal is very weak (nT range or below) but it carries information about the direction of current flow within the cell or between cells [1]. In addition, magnetic signals are not distorted by the surrounding tissue and may provide a robust approach for chronic recordings in implantable devices.

We recently demonstrated *in vivo* recordings of magnetic signals from single neurons using spintronic sensors, which offer both miniaturization and high sensitivity [1]. We are now developing a dedicated in vitro platform to investigate these signals in detail and with high accuracy, using optically accessible cells. We present how the sensors are optimized for this application and how they are integrated into the *in vitro* platform.

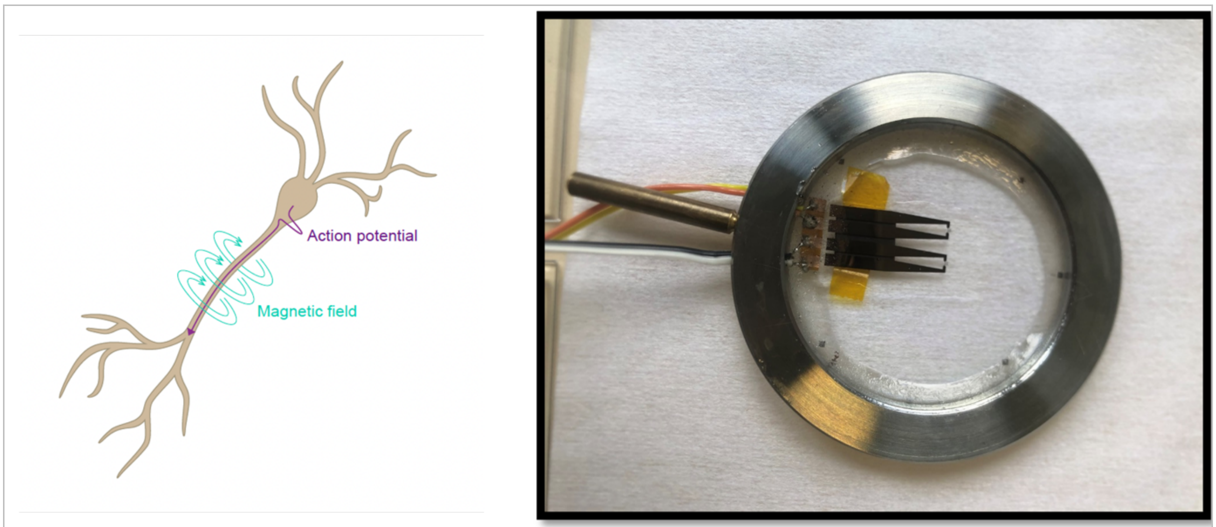

Fig. Left: Schematic of the magnetic field generated by the electrical activity in a single neuron (Action potential)-*from [2]*; Right: Picture of a spintronics sensor developed for in vitro recordings, compatible with a microscope, allowing an optical access to the cells

Acknowledgements
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Programmable Magneto-Active Melt Electrowritten Fibers for Skeletal Muscle Engineering

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Skeletal muscle diseases—including muscular dystrophies and muscle wasting in chronic disease—affect millions of people worldwide, leading to progressive loss of strength and mobility. Treating these conditions remains challenging because skeletal muscle relies on a highly ordered, anisotropic architecture that enables its primary function: generating force through coordinated, uniaxial contractions. Reproducing this structural and functional anisotropy *in vitro* is essential for meaningful disease modeling, drug screening, and regenerative applications. However, current *in vitro* muscle models fall short because they lack 3D supportive matrices that : 1) provide anisotropic mechanical cues to guide aligned neo-tissue formation; and 2) enable contactless, cyclical mechanical stimulation to promote tissue organization, maturation, and function. To address these challenges, of direct relevance to biomedical magnetic actuation, we develop magnetoactive 3D fiber matrices with defined microarchitectures and magnetic anisotropy to promote anisotropic tissue organization and enable contactless mechanical stimulation of skeletal muscle cells.

A polycrystalline NdFeB powder (MQFP™, Magnequench) was melt-mixed at 80°C with Polycaprolactone (PCL) at 20% w/w (FPCL20), and characterized magnetically via Vibrating Sample Magnetometer (VSM, Microsense) and rheologically via small amplitude oscillatory shear (SAOS) at 90°C for Melt Electro Writing (MEW) processability, against FPCL0 as a positive control. Sinusoidal and straight fibers were fabricated using an in-house MEW system and magnetized by applying a 2000 mT field through a homogeneous electromagnet. Vertical support lines were printed across sinusoidal fibers forming scaffolds with defined unit cells. Depending on the geometry, fibers were aligned and/or stretched according to their actuation mechanism, then magnetized for 60 seconds. An in-house 3D magnet actuated the magnetized MEW fibers by applying a homogeneous magnetic field along the longitudinal axis for sinusoidal fibers and perpendicular to the fiber axis for straight fibers. Lastly, C2C12 myoblasts were cultured in 2D wells and 3D MEW fibers until differentiation and analyzed via Prestoblue, LIVE/DEAD, and immunostaining for cytocompatibility and skeletal muscle differentiation markers.

VSM measurements of FPCL20 were performed to investigate the magnetic response of MEW fibers, yielding an average saturation magnetization of $(1.07 \pm 0.05) \times 10^{-6}$ A·m² and an effective residual magnetic flux density ($\boldsymbol{B}_{r,\mathrm{eff}}$) of 32.0 ± 2.8 mT. Magnetized FPCL20 sinusoidal scaffolds displayed an engineering strain of 37.4 ± 12% under unloaded conditions, showing promise for physiologically loaded conditions. SAOS measurements indicated FPCL20 remained within a processability range suitable for MEW. Cytocompatibility analysis revealed no significant difference in cell viability between FPCL0 and FPCL20 fibers, with both groups forming organized myotubes along the microgeometry, while the 2D group displayed disorganized myotubes.

FPCL20 MEW sinusoidal fibers guided skeletal muscle myotube organization without significant cytotoxicity, achieving 37.4% ± 12% engineering strain, ideal for *in vitro* cyclical stimulation. Building on this, we next intend to biologically characterize the differentiation of immortalized human myoblast under contactless mechanical stimulation aiming at improving tissue maturation and function, and ultimately advancing magnetoactive fiber matrices as actuators for biomedical applications.

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Magnetoelectric Laminates Based on PVDF and Fe–Si–B Amorphous Ribbons for Sensing and Cellular Stimulation

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Magnetoelectric laminate composites based on polyvinylidene fluoride (PVDF) films and amorphous $Fe_{79}Si_9B_{12}$ ribbons were developed for magnetic field sensing, electric current detection, and magnetically induced cellular stimulation. The devices exploit strain-mediated coupling between the magnetostrictive response of the amorphous ribbons and the piezoelectric properties of PVDF. Laminates were fabricated using pre-polarized PVDF films with a thickness of 52 µm and amorphous ribbons produced by rapid quenching, exhibiting magnetic softness and saturation magnetostriction up to +32 ppm. Bi-layer and symmetric tri-layer configurations were assembled using adhesive bonding followed by thermal curing, resulting in mechanically compliant magnetoelectric structures suitable for sensing and bioelectronic applications.

The magnetoelectric response of the laminates was evaluated through measurements of the magnetoelectric voltage coefficient. The symmetric tri-layer configuration exhibited a peak magnetoelectric coefficient exceeding 21.8 $V\cdot cm^{-1}\cdot Oe^{-1}$, indicating efficient strain transfer and strong magnetoelastic coupling. When used as magnetic field sensors, the devices operate under AC magnetic excitation and exploit the nonlinear magnetostrictive response of the amorphous ribbons. The presence of an external DC magnetic field modifies the deformation dynamics of the laminate, producing a phase shift between the excitation signal and the PVDF output voltage that enables discrimination of the polarity of the external magnetic field.

For electric current sensing, the magnetoelectric laminate was integrated into a closed magnetic circuit using a U-shaped ferrite core and an excitation coil. The excitation frequency was tuned to the magnetoelastic resonance of the magnetic ribbons to maximize sensitivity. A conductor carrying the current to be measured passes through the magnetic circuit, generating a magnetic field that shifts the transfer characteristic of the sensing element. By monitoring the phase-sensitive output voltage and applying a DC offset current, a linear relationship between the measured current and the sensor response can be obtained, enabling contactless DC current detection.

In addition to sensing applications, the magnetoelectric laminates were investigated as platforms for magnetically induced cellular stimulation. Magnetostrictive deformation of the magnetic ribbons generates cyclic strain in the PVDF layer and conductive electrodes, producing localized electric potentials, mechanical vibrations, and strain-dependent electrical effects in the surrounding medium. Mesenchymal stem cells cultured on the device surface experience combined mechanical and electrical stimulation that activates mechano-transduction pathways and bioelectric signaling, including calcium influx through voltage-gated channels. These stimuli promote osteogenic differentiation and upregulation of osteogenic markers such as osteocalcin, highlighting the potential of magnetoelectric laminates as multifunctional platforms for sensing and bioelectronic stimulation.

Acknowledgements
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A universal approach for field shaping of wafer integrated PowderMEMS® micromagnets for highly miniaturized back-biased CMOS Hall sensors

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PowderMEMS® micromagnets are miniaturized magnetic structures fabricated at wafer level using a proprietary low-temperature CMOS-compatible powder-based microfabrication process. They are formed from densely packed magnetic powders that are precisely dry-filled into microcavities and solidified into three-dimensional microstructures with well-defined geometries and positioning. This approach enables high volumetric filling factors and tailored magnetic properties within sub-millimeter footprints. The resulting micromagnets can be seamlessly integrated into MEMS and semiconductor process flows, facilitating advanced magnetic microsystems.

In this work the wafer-level manufacture of highly miniaturized back-biased Hall sensors is presented. CMOS wafers with HallInOne® Hall sensors are modified by integrating NdFeB micromagnets into the Si-bulk beneath the CMOS-layer using the PowderMEMS® process: first, the magnet geometries are patterned by standard lithography on the backside of the wafer. The patterns are then transferred into the bulk-Si by a deep silicon etch (DSiE) process. The resulting microcavities are filled with dry NdFeB powder and the powder is solidified by atomic layer deposition of aluminum oxide (Al_2O_3). Finally, the magnets are magnetized on wafer level [1].

Depending on the intended application, specific shaping of the bias field is desired. This can be achieved by modification of the magnet pattern [2]. However, changing the geometry of the mask opening will in turn lead to cavities of varying depth due to DSiE lag. Consequently, each design change of the micromagnets would require labor-intensive tuning of the DSiE process until the desired etching depth is reached. Furthermore, multi-design wafers (MDW) that incorporate a multitude of different magnet geometries would be impossible.

To overcome these limitations, a universal grid pattern (UGP) approach that uses predefined unit cells has been developed (**Fig. 1**). Each unit cell has the same width and pitch, enabling a uniform etch depth. For shaping of the bias field, the unit cells are rearranged as desired to achieve the intended field geometry. Especially the omission of cells that are close to the actual hall plates can be used to locally decrease the field and increase the available dynamic range of the sensor (**Fig. 2**). The UGP approach can also be combined with other sensing technologies such as e.g. XMR.

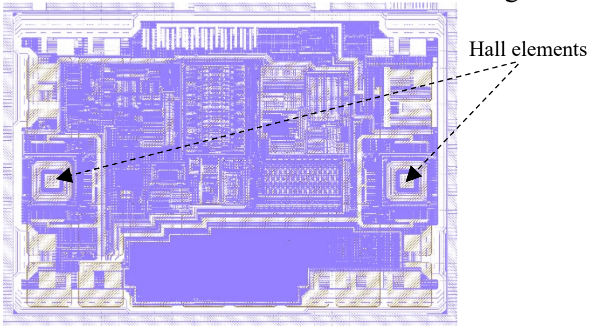

Fig. 1: Layout of the top metal of a HallInOne® CMOS Hall sensor with the PowderMEMS® UGP micromagnet underneath.

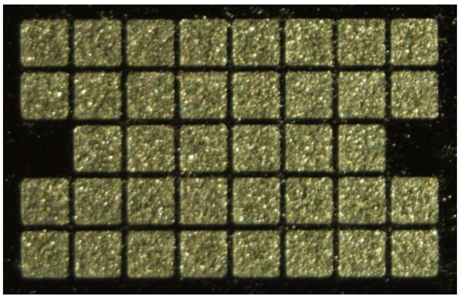

Fig. 2: Micrograph of a PowderMEMS® UGP micromagnet. Cells located underneath the Hall elements have been selectively omitted to increase sensor dynamic range.

Acknowledgements
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Fabrication of sub-mm NdFeB micromagnets via laser-micromachining suitable for application in magnetic MEMS devices

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Magnetic microelectromechanical systems (MEMS) require the integration of high-quality high-energy-product micro-structured magnets with thickness and lateral dimensions ranging from tens to hundreds of micrometers to enable the generation of strong forces within compact volumes [1]. The manufacture of such micromagnets is, however, inherently challenging and currently represents a major bottleneck for magnetic MEMS industrial uptake. A gap can be currently witnessed in magnet manufacturing technologies between bottom-up microfabrication routes (which result in good magnetic properties and accurate shapes, but are usually slow, expensive and limited to magnet thicknesses up to few tens of µm only) and top-down approaches typically based on mechanical or electrical-discharge machining of sintered bulk magnets (which are able to achieve feature sizes of few hundreds of µm but induce surface degradation due to stress or heating that ultimately leads to a loss of remanence and coercivity) [2].

Here, we report on the fabrication of micromagnets with sub-mm thickness and lateral features via ultrashort pulsed laser-micromachining of 300-µm-thick NdFeB sintered foils. The use of extremely short laser pulses limits the occurrence of laser-induced surface damage, thereby resulting in micromagnets with remanence and coercivity values close to the nominal properties of sintered bulk magnets (Figure 1). The suitability of these micro-structured permanent magnets for MEMS applications is demonstrated by integrating them into a proof-of-concept MEMS device designed via semi-analytical calculations [3] and comprising, among others, planar micro-coils on a flexible polymer membrane for the generation of electromagnetic actuation forces of the order of few mN. Potential end applications include, for instance, micro-pumps and micro-speakers.

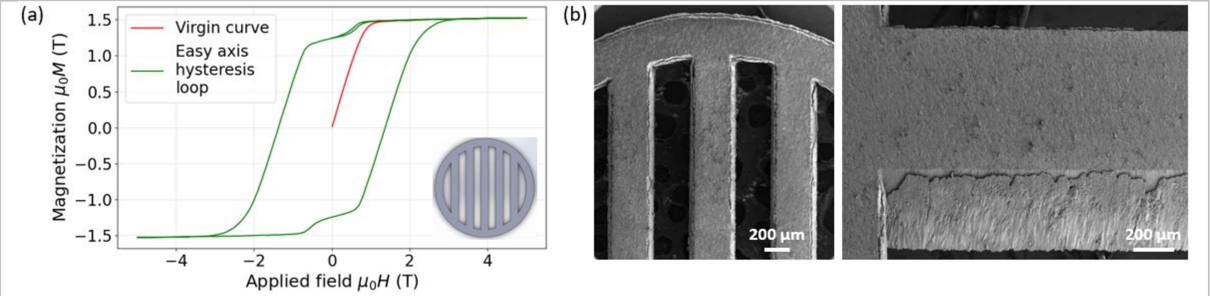

Fig. 1 (a) Hysteresis loop (including first magnetization curve) and (b) SEM micrographs (top view on the left, tilted view on the right) of a laser-micromachined NdFeB magnet sample.

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Improving Metal-Semiconductor Contact Resistance in Extraordinary Magnetoresistive Sensors

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Metal-semiconductor contacts are critical components in many electronic devices. In sensor applications, careful design and engineering of the metal-semiconductor contacts is essential for meeting device performance requirements. This is particularly true for Extraordinary Magnetoresistive (EMR) devices, where magnetoresistance is predominantly geometric in nature [1-2]. EMR devices respond to an applied magnetic field by redistributing charge carriers into a higher-resistive current path. Owing to their ease of fabrication, simple governing physics, and absence of active magnetic noise, EMR devices hold significant potential for room-temperature magnetometry [1].

In this numerical study, we investigated different contacting strategies, namely top-contacted and side-contacted configurations in EMR devices, to understand how the area of the contact region influences current redistribution and magnetic field response. We explore in detail the dependence of device size and transfer length of charge carriers on the contact resistance. This analysis provides key insights into improving metal–semiconductor contact resistance and the overall device performance. Our results show that for device sizes larger than 20 µm, the magnetic field response is higher in top-contacted EMR devices compared to side-contacted devices. For a contact resistivity of 10^{-4} Ω·cm^2, the difference in response is approximately two orders of magnitude.

Our results emphasize the critical role of contact engineering in optimizing EMR device performance and provide practical design guidelines for reducing the impact of contact resistivity in EMR devices. Experimental validation is currently underway to support the numerical findings.

Acknowledgements
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BIRD: A Current-readout CMOS chip with a 1µT Offset (3σ) using the Spinning-Voltage technique for internal Si and external GaN Hall-plates

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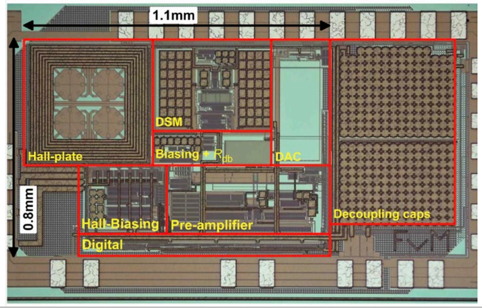

Fig. 1 Die Micrograph of the BIRD chip.

Magnetic field sensors are essential components in a wide range of applications, from electronic compasses to current sensors for power monitoring. The latter are particularly demanding, as they require high-accuracy sensing of both static (DC) and dynamic (AC) magnetic fields. CMOS Hall-effect sensors are often preferred for these tasks because they are cost-effective and do not require post-backend processing. However, their DC accuracy is limited by high offsets originating from the Hall-plates. While traditional spinning-current techniques can remove offsets from a linear (resistive) Hall-plate, residual offsets caused by the Junction Field Effect (JFE) remain a major bottleneck since the Hall-plate resistance is now modulated by the biasing voltage or current, causing a residual offset after applying the spinning technique.

This recently published work introduces the "BIRD" chip (Fig. 1) [1], which employs a spinning-voltage technique to address these limitations. In this dual topology, the Hall plate is biased with a constant voltage instead of current, and the Hall signal is read out as a short-circuit current. This approach is intrinsically more robust against voltage-dependent non-linearities, such as the JFE and velocity saturation, which are leading causes of residual offset in standard current-biased sensors. To maximize performance, an octagonal Hall-plate geometry is utilized to optimize the signal-to-noise ratio relative to power consumption. In addition to the on-chip Hall-plate, an external 4-contact Hall-plate can be connected to the BIRD chip. Fig. 2 shows the residual offset for 9 GaN Hall-plates fabricated at the Stanford Nanofabrication Facility (SNF), with the active area similar to the Hall-plates in [2]. At low biasing voltages, the residual offset is 1.4uT (3 sigma), similar to previous measurements with current-spinning [2].

The readout circuitry utilizes negative feedback to force precise biasing voltages across the Hall plate terminals. Kelvin connections are integrated within the feedback loop to minimize the impact of switch on-resistance mismatch. Additionally, (system-level) chopping techniques are employed to eliminate 1/f noise and residual switching offsets. The chip was manufactured in a standard 0.18µm CMOS process (Fig. 1). Experimental measurements show that the proposed current-readout sensor achieves an residual offset of 1µT (3σ) with the internal Si Hall-plate(Fig. 3), which is the lowest residual offset reported for integrated Hall-sensors.

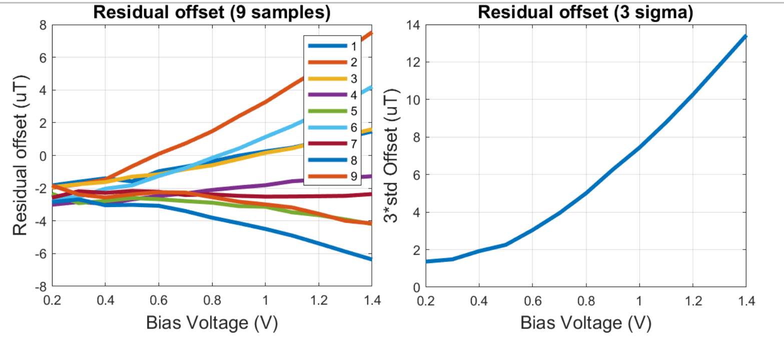

Fig. 2 Measured residual offset 9 GaN Hall-plate sensors co-packaged with the BIRD chip.

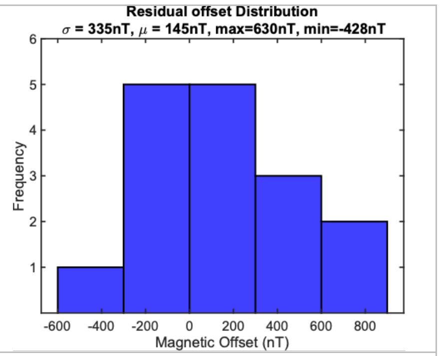

Fig. 3 Measured residual offset of the BIRD chip (internal Hall plate) after 8-phase spinning.

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Multifunctional High-Resolution Flexible Elliptical Planar Hall Effect Sensors for Magnetometry and Strain Sensing

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Magnetic sensors underpin technologies ranging from navigation and industrial automation to medical diagnostics and consumer electronics. Within the magnetoresistive family, planar Hall effect (PHE) sensors stand out for their straightforward architecture and their ability to reach ultra-low equivalent magnetic noise (EMN) in the $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ regime. In rigid elliptical PHE (EPHE) devices, we previously achieved EMN down to 24 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ at 50 Hz, and 5 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ at 10 Hz when integrated with magnetic flux concentrators - demonstrating that PHE-based sensing can compete with substantially more complex magnetometers.

A central challenge is translating this performance into flexible platforms, where bending, strain, and thermal constraints often degrade resolution. We address this by leveraging the intrinsic single-domain-like response of EPHE sensors and by treating strain not only as a disturbance, but as an additional controllable degree of freedom. Flexible EPHE sensors on polymer substrates retain exceptionally low noise, reaching EMN values of ~200 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ at 10 Hz in the flat state and ~300 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ under bending - already representing a marked leap beyond other flexible magnetic-field sensors.

Beyond magnetometry, we show that bending-induced magnetoelastic anisotropy produces a reproducible, strain-dependent modification of the effective in-plane anisotropy and therefore of sensitivity and noise. This enables multifunctional operation, in which the same EPHE element acts as both a high-resolution magnetometer and a strain sensor, with measurable response down to few-$\mu\varepsilon$ (microstrain).

Finally, we introduce a next-generation flexible EPHE platform on ultrathin (~50 μm) elastic silicon, designed to overcome polymer-limited excitation current and thermal management. Comparative performance under identical bending conditions reveals how substrate choice reshapes the attainable resolution–strain envelope, opening a path toward scalable, high-resolution, multifunctional flexible magnetics.

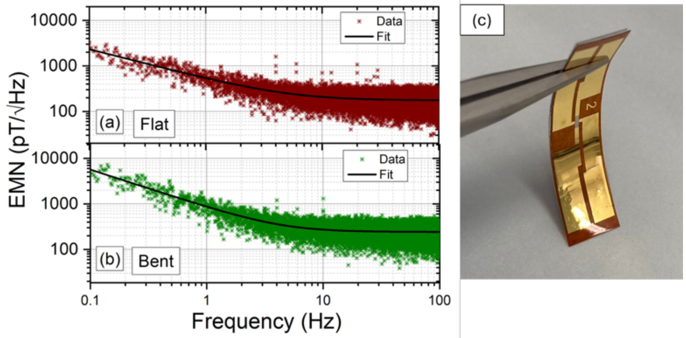

Fig. 1 EMN of flexible elliptical PHE sensors vs. frequency in (a) flat and (b) bent states. (c) A photo of a flexible elliptical PHE sensor.

Macrospin toy model program as a help for magnetic magnetoresistive sensor stack prediction

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Giant or Tunnel Magnetoresistance (GMR-TMR) magnetic sensors are widely used in applications ranging from automotive systems to non-destructive testing (NDT) and biological detection, owing to their high detectivity, strong integrability, and tunable magnetic response. However, each application imposes specific performance requirements: wide linearity range for NDC, thermal and magnetic field stability for automotive environments, and ultra-high detectivity for biological sensing [1].

Optimizing sensor performance is particularly challenging due to the large number of adjustable parameters, including material selection, layer thicknesses, interlayer coupling, magnetic anisotropy, and transport properties. Exhaustive experimental exploration through systematic variation of materials and thicknesses is therefore difficult.

In this work, we present a toy but efficient macrospin-based modeling tool designed to guide the development of G-TMR sensors. After introducing the typical G-TMR stack architecture and its magnetic behavior, we will describe the principles of the macrospin based Stoner-Wohlfarth model and its implementation in a user-friendly software environment.

We demonstrate how this tool helps to the characterization and determination of materials and stack parameters. As a case study, we illustrate the optimization of a GMR stack to meet targeted performance. Finally, we will discuss the strengths and inherent limitations of this simplified macrospin approach, highlighting its role as a practical pre-design and optimization tool helping experimental development and analysis.

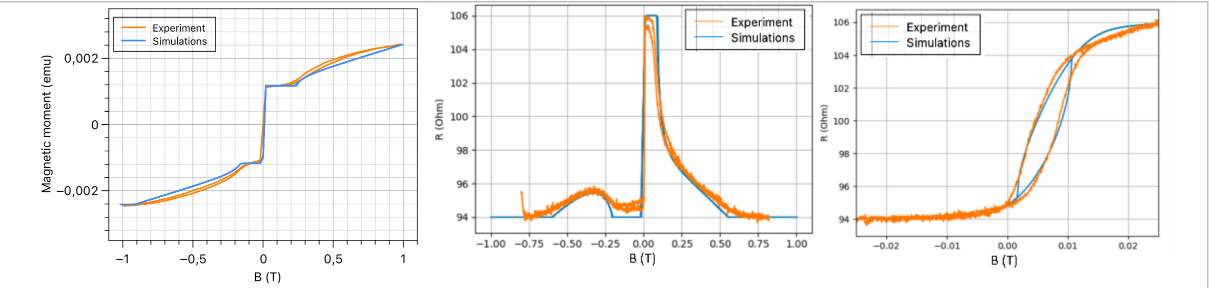

Fig. 1 Comparison of magnetic moment and resistance measurement versus field (complete full stack major loop and free layer minor loop) with its simulation for a typical GMR stack.

Acknowledgements
- ANR funding through grant n°ANR-17-CE19-0021-01, ANR-22-CE42-0013-02 and PEPR SPIN –ADAGE ANR-22-EXSP-0006

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Sensitivity Enhancement of Vicinal $La_{2/3}Sr_{1/3}MnO_3$ Anisotropic Magnetoresistance Sensors using Engineered Flux Concentrators

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We fabricated anisotropic magnetoresistance sensors based on epitaxial $La_{2/3}Sr_{1/3}MnO_3$ (LSMO) thin-films deposited by PLD. The films were patterned into Wheatstone bridge (WB), and a well-defined magnetic easy axis was induced at room temperature using 4° vicinal $SrTiO_3$ (STO) substrates via step-induced uniaxial anisotropy [1]. Magnetotransport and low-frequency noise measurements were performed to determine sensor sensitivity and detectivity. Detectivity values as low as 1.4 $nT.Hz^{-1/2}$ at 1 Hz and 240 $pT.Hz^{-1/2}$ at 1 kHz at voltage bias (Vb) of 20V were achieved, rivaling state-of-the-art GMR and TMR sensors [1] To further enhance performance, we propose to add magnetic flux concentrators (MFCs) to LSMO WB. We used finite element methode simulations to design the MFC geometries providing local field amplification (fig.1-b). Then, thick $Ni_{80}Fe_{20}$ (6–7 µm) MFCs were electrodeposited [2]. Preliminary results show a fourfold reduction of the effective anisotropy field in the largest devices (fig.1-a). As a result, identical sensitivity (V/T) can be achieved at Vb=1.5V instead of 5V, leading to substantially reduced power consumption through magnetic field amplification by the MFC. Smaller sensors with longer MFCs are currently being fabricated, targeting sensitivity gains in the 10 to 100 range. Further, thinner (~1 µm) $(Ta/NiFe)_n$ or $(Ta/CoFeB)_n$ multilayer MFCs were sputtered. Finally, Optical Beam Induced Resistance Change imaging was performed to investigate the current density distribution within the WB arms, thus leading to optimised WB operating conditions (inset of Fig1-c). This work demonstrates that engineered MFCs can substantially enhance the sensitivity of LSMO-based AMR sensors, opening a path toward ultra-low-detectivity oxide-based sensors.

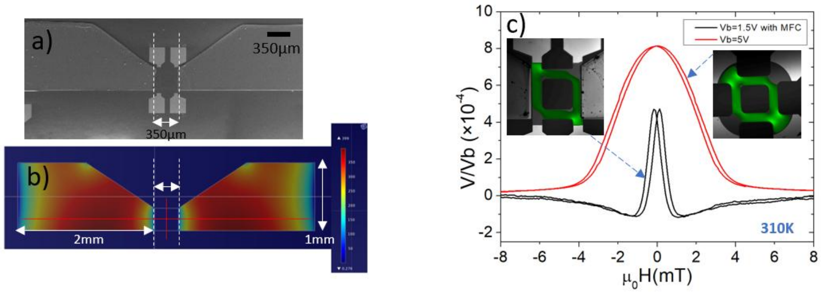

Fig. (a) View of a 66µm×200µm LSMO AMR WB with MFC; (b) Comsol simulation of the field amplification; (c) Normalized V/Vb sensitivity measurement with and without MFC.

Acknowledgements
This work is supported by France 2030 government investment plan managed by the French National Research Agency under grant reference PEPR SPIN –ADAGE ANR-22-EXSP-0006

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Geometry comparison of offset, sensitivity, and noise of AlGaN/GaN Hall-effect sensors in GaN-on-SOI technology

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Gallium nitride (GaN) Hall-effect plates are of interest for magnetic sensing in harsh environments due to the wide bandgap and robustness of GaN [1]. Previous work has demonstrated low offset and noise in GaN 2DEG Hall plates and has highlighted the role of geometry influence in sensor offset and voltage-related (S_V) and current-related (S_I) sensitivity [2, 3]. However, these systematic comparisons remain limited to academic-grade fabrication. In order to realize commercial devices, these geometries need to be studied in a more industrial-oriented process. This work presents early characterization of 3 different geometries in a GaN on silicon-on-insulator (SOI) process [4].

Devices were measured in a 2 mT Helmholtz coil and biased up to 1 mA. Across all 9 devices, S_I was measured to be between from 63–86 V/A/T, while S_V between 0.050–0.071 V/V/T, similar results to that of previous work [2,3]. Offset after current spinning, seen in Fig. 2, is strongly dependent on geometry and bias current: at 1 mA, offsets range from 1-3 µT to approximately 20–23 µT, and trend quadratically. Noise spectra were also measured for all devices and exhibit a clear 1/f contribution at low frequency. Corner frequencies measured at 1-2 V bias range from 10-300 kHz[1].

These results confirm that different Hall-plate geometries show similar performance tradeoffs seen in literature[2-3]. Geometry 2 (G2), an equal-sided octagon, has the highest S_V [3]. Geometry 3 (G3), an octagon with narrower contacts, has higher S_I than G2 due to its shorter contacts [3]. Geometry 1 (G1) has the highest resistance, so it also has highest S_I. This shows the shortcomings of S_I as a figure of merit, since G3 is designed for the highest SNR scaled with input current [3]. As seen in Fig. 2, G1 exhibits lower offset at high bias due to non-ideal effects (such as heating) are far from the active region, and it exhibits low offset (<3 µT) even in high bias conditions, further confirming its potential for high-precision sensing [2]. These results not only provide a consistent experimental basis for evaluating these geometries to support informed device design, but also show the chip-to-chip variation due to processing spread in the industrial GaN technology. Regardless, this work is a crucial step towards the realization of GaN Hall devices for applications in power sensing as these devices have been realized in a commercially available power device GaN technology.

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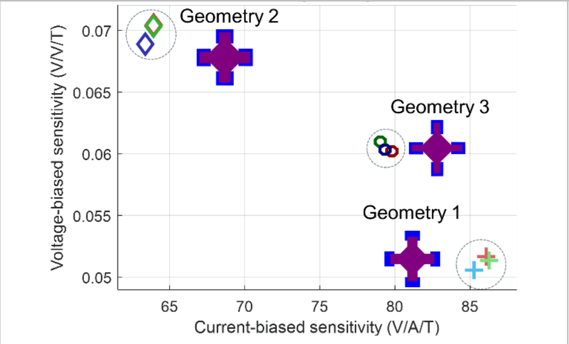

Fig. 1 Voltage vs. current-related sensitivity the three geometries on 3 chips. Marker color corresponds legend in Fig. 2.

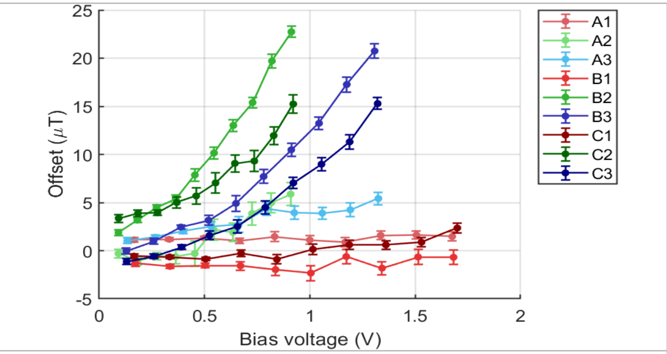

Fig. 2 Offset of each sensor as a function of bias voltage. Each chip (A-C), and each geometry(1-3) corresponds to sketches in Fig. 1.

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Porous polymer sponge and magnetic nanoparticles: a magneto-elastic energy harvester

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Industry 5.0 and Smart City projects aim to create sustainable and technologically advanced smart factories and services that respect the planet's production limits and citizens' health [1]. This is leading to an increase in the use of sensors and devices. This ambitious revolution suffers from an increase in energy consumption, which must be addressed by using renewable energy sources along with the development of smart devices capable of recovering wasted energy (i.e. energy harvesters).

This study aims at supporting the energy transition by developing an innovative energy harvester based on composite materials exploiting the magnetoelastic effect capable of recovering energy from ubiquitous mechanical vibrations. A porous soft sponge was fabricated by the low-cost sacrificial pattern technique, using sugar or salt crystals as sacrificial material and polydimethylsiloxane (PDMS) as polymer matrix. The latter was loaded with magnetically hard magnetic nanoparticles (MNPs) such as NdFeB and hexagonal Ba-ferrite. An optical image of the magnetic polymer sponge is shown in Figure 1 (left). The sponge is characterized by a homogeneous porosity throughout its volume. The brown colour is given by the homogeneously dispersion of MNPs. The morphological details of the porous structure are analysed using SEM images (Figure 1 right). The pores appear regular in shape with sizes of hundreds of micrometres. The porosity of the magneto-polymer sponge was finely optimized to control mechanical properties and to improve its deformability under mechanical vibrations. At the same time, the composition and concentration of MNPs were tuned to maximise the output signal of the device (coercivity approx. 5.25 kOe and 2.71 kOe respectively for NdFeB and Ba-ferrite MNPs). Controlled mechanical vibrations were applied to the harvester by means of a custom agitator, which operates in the frequency range 5 – 40 Hz and amplitude range 0.5 – 5 mm. Under mechanical vibration, the MNPs in the harvester, which were aligned in a strong magnetic field during the preparation of the sponge, move following the compression of the flexible sponge. The magnetic moment of the moving MNPs is converted into electrical energy by electromagnetic induction in a pick-up coil and then stored into a capacitor.

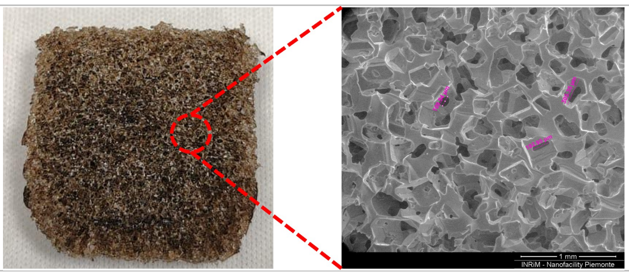

Fig. 1 Left: optical image of magnetic polymer sponge. Right: SEM image of pores.

Acknowledgements
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Harmonic Hall Voltage Analysis of Current-Induced Torques for Magnetic Sensor Design

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Spintronic sensors are used in automotive and robotics systems, navigation, and healthcare applications [1]. They offer high sensitivity, miniaturization and are compatible with conventional integrated circuit fabrication. Commonly used spintronic sensors based on giant or tunnel magnetoresistance possess a fixed linear operating range once fabricated, which limits their use in scenarios requiring real-time adjustable field sensitivity to prevent response saturation of the sensing layer [2]. Recently, anomalous Hall effect magnetic sensors have shown tunable sensitivity and linear range enabled by spin–orbit torques (SOT) [3]. This opens possibilities to explore SOT and current injection as a way for controlling the sensing layer magnetization orientation in multilayered spintronic sensors [4].

SOT-based tunability has not yet been established as a design method for spintronic sensors. Bridging this gap requires quantitative determination of the damping-like (DL) and field-like (FL) torque components acting on the ferromagnetic electrode. Through controlled multilayer and interface engineering compatible with spintronic thin-film technology, the ratio and efficiencies of these torques can be tuned.

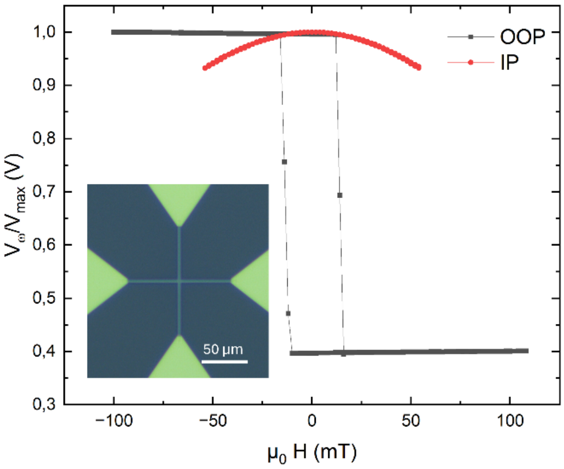

Figure 1 Patterned Hall-cross device (inset) and normalized first-harmonic Hall voltage measured versus applied field for two field orientations: $\mu_0 H_z$, out-of-plane and $\mu_0 H_x$, in-plane. The sensing current is applied along the x-direction of the Hall cross.

In this work, we use patterned Ta(t)/CoFeB(t)/MgO Hall-cross devices (Fig 1.) as a characterization platform to quantify the current induced modulation of the magnetization in the CoFeB layers. The modulation is quantified using first- and second-harmonic Hall measurements, and a macrospin model is employed to extract the effective fields associated with the DL and FL torques. We address key dependencies on heavy-metal thickness and effective perpendicular magnetic anisotropy, and we evaluate how Joule-heating-driven thermal gradients and device dimensions (shape anisotropy) influence the extracted parameters. With this methodology we aim to compare between different stacks and then define the best materials combination for integration in a spintronic sensor multilayer system. The extracted torque parameters will be used to select stacks for integration into magnetoresistive sensor geometries, aiming to build a framework to assess the ultimate current-tunable sensitivity and linear ranges using SOTs.

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Magnetoelastic Ribbons: Optimization for Mass Sensing and Application to Hydrogel Gelation Monitoring

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Magnetoelastic resonators have gained increasing attention because of their high versatility and sensitivity in detecting a wide range of physical and biological parameters. They are especially attractive due to their low cost and the possibility of wireless detection[1]. Over time, several factors have been optimized to enhance their performance, such as material composition, geometry[2], and crystallization processes[3]. However, these aspects have generally been investigated separately rather than in an integrated manner.

More recently, we combined the optimization of these parameters together with ribbon thickness and compared the performance of the resulting samples with that of conventionally used resonators. The optimized devices exhibited more than twice the sensitivity of traditional samples, highlighting their strong potential for applications involving the detection of small mass changes.

In addition, we are currently applying these ribbons to monitor viscoelastic processes, particularly during hydrogel formation. Hydrogels are three-dimensional polymer networks capable of absorbing large amounts of water while maintaining their structural integrity, making them widely used in biomedical and materials science applications. One of the key parameters in hydrogel formation is the gelation time. This parameter is commonly estimated using the tube inversion method, which is subjective, time-consuming, and often imprecise. By using magnetoelastic sensors, we were able to determine the gelation time of polyacrylamide under different conditions. The results demonstrate that magnetoelastic sensing provides a fast, simple, and accurate approach for monitoring gelation processes.

Acknowledgements

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Langevin-Based SPIO Magnetometer for Remote DC Magnetic Field Sensing

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We report the development and experimental validation of a Langevin-based magnetometer that utilizes the nonlinear magnetization response of superparamagnetic iron oxide (SPIO) nanoparticles for remote sensing of weak static magnetic fields. Unlike conventional magnetometers that require wired or directly positioned sensors, such as a fluxgate magnetometer, this approach enables non-contact field sensing by embedding or injecting SPIO nanoparticles as nanoscale probes and analyzing their harmonic response under AC excitation.

The operating principle is based on the SPIO's nonlinear MH characteristic given by the Langevin function under AC excitation, which generates odd harmonics in the induced signal. Such magnetization response is widely used in magnetic particle imaging (MPI) [1] and magnetic particle relaxometry (MPS) for biomedical imaging and particle characterization [2]. In the presence of an additional DC magnetic field, symmetry breaking produces even harmonics. The second harmonic amplitude is linearly proportional to the external DC field, providing a direct calibration mechanism.

Experiments were performed using an MPS apparatus comprising a solenoidal excitation coil and a co-linear gradiometer receive coil. An additional co-linear Helmholtz coil was used to apply a controllable DC offset field. An SPIO sample (50 µl) of Synomag-D (MicroMod, Germany) nanoparticles was placed inside the coils and excited at 4 kHz with 3.9 mT/μ_0 AC magnetic field. The DC field was varied over ±500 µT to generate calibration curves in the linear regime of the second-harmonic response, as shown in Fig.1. Using field cancellation, the vertical component of the local Earth's magnetic field was measured as 34.39 ± 0.03 µT, consistent with independent Gaussmeter measurements.

Our SPIO-based magnetometer demonstrates a compact, remotely addressable sensing concept with potential applications in embedded diagnostics, biomedical environments, and distributed magnetic field monitoring.

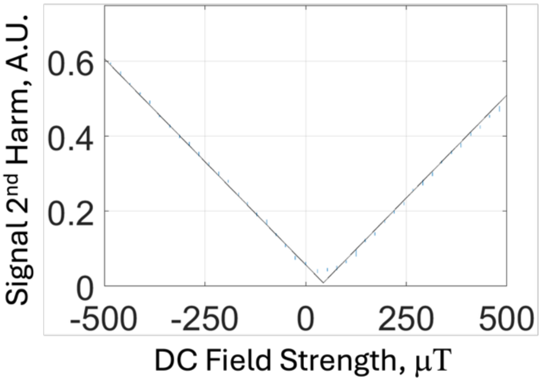

Fig. 1 DC magnetic field calibration curve showing linear fit to the experimental data of the second-harmonic response.

Acknowledgements
This work is supported in part by NIH under Award R15EB028535.

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Multiphysics Model of a Spin Hall Magnetoresistance Magnetic Field sensor

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This study [1] presents a multiphysics modeling framework and experimental validation for a next-generation magnetic field sensor based on Spin Hall Magnetoresistance (SMR) in a Wheatstone bridge configuration. SMR sensors utilize simple heavy-metal/ferromagnetic (HM/FM) bilayers, offering high sensitivity and low power consumption [2]. The model simulates the interplay between SMR, Anisotropic Magnetoresistance and Spin-Orbit Torque (SOT). A key innovation is a Stoner-Wohlfarth approach that considers a statistical ensemble of single-domain particles described by "truncated astroids", thereby accounting for the role of domain walls present in the magnetic material. This allows for modelling generic devices, like larger scale Hall bars. The SOT induced by the spin Hall current is described through the Landau-Lifshitz-Gilbert (LLG) equation considering the field-like and damping-like torque terms arising in the spin drift diffusion model. The validation of the model was performed experimentally on bilayers of HM/$Fe_{60}Co_{20}B_{20}$ with HM=Pt,Ta, patterned into Hall bars and simple Wheatstone bridges, through longitudinal magnetoresistance (MR) measurements and magneto-optic Kerr effect imaging. The model provides guidelines for optimizing SMR sensors by accounting for the interplay of the different MR contributions and therefore facilitates the development of high-sensitivity, low-power devices for automotive and biomedical applications.

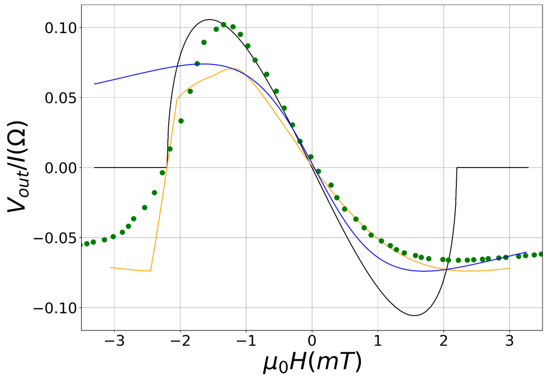

Fig. 1 Wheatstone bridge SMR sensor output (Pt/FeCoB) as a function of the applied field, at I = 5mA (green dots). Predictions from the Stoner-Wohlfarth model without (black line) and with misalignment of an angle β = 0.3 (orange line); prediction with the LLG model (blue line).

Acknowledgements
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Low-frequency noise and nano-Tesla detection limit in planar-Hall magnetoresistive (PHMR) sensors

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Planar-Hall effect (PHE) sensors have emerged as a promising class of magnetoresistive devices for detecting weak magnetic fields due to their high sensitivity, low power consumption, and compatibility with microfabrication technologies[1]. The sensing mechanism relies on the transverse voltage generated in a ferromagnetic thin film when an in-plane current interacts with an external magnetic field. In particular, planar Hall magnetoresistive (PHMR) sensors exploit this effect to achieve enhanced field resolution and a linear response within a compact device geometry[2,3]. Advances in materials engineering, thin-film deposition, and device design have significantly improved the performance of PHE sensors, enabling sub-nanotesla detection limits and stable operation over a wide dynamic range. Furthermore, optimised bridge configurations and resistance compensation techniques have been shown to suppress low-frequency noise and improve thermal stability[3-5]. These sensors offer a linear field response typically in the millitesla range and can operate efficiently at room temperature. Due to their miniature size, robustness, and cost-effective fabrication, planar Hall magnetoresistive sensors are increasingly being explored for applications in biomagnetic sensing, nondestructive testing, and magnetic communication.

Keywords:
Planar-Hall effect, Magnetic sensors, Low-frequency noise, Detection limit

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A skyrmion magnetic field sensor for ultra-sensitive out-of-plane magnetic field detection

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Magnetic field sensors are key components in spintronic technologies, where achieving high sensitivity, *i.e.* low detectivity, in miniaturized geometries remains challenging [1,2]. We report on an ultrasensitive out-of-plane magnetic field sensor based on Ta/FeCoB/TaOx trilayers, hosting ferromagnetic stripe domains and skyrmions that we image with magneto-optical Kerr effect microscopy (Fig. 1). In samples with perpendicular magnetic anisotropy, the low domain wall energy facilitates skyrmion nucleation and domain wall propagation due to the amorphous character of the layers. Exceptional low saturation fields of ~0.25 mT result in in high sensitivity to external out-of-plane magnetic fields. When patterned into symmetric Hall bar devices, the trilayers display a linear response. A maximum sensitivity of 2.2 V/mA/T is achieved at 1 mA bias current for a 100 × 100 µm² sensor, decreasing to 1.2 V/mA/T at 6 mA (Fig. 1). Surprisingly, the noise type in this sensor evolves with increasing bias current from a dominant magnetic 1/f-like component to a dominating Random Telegraph-Noise-like behavior. Overall, the detectivity improves with increasing bias, reaching ~10 nT/√Hz at 6 mA. Ongoing work aims to establish a direct correlation between domain wall configurations and noise mechanisms, to better understand the underlying physics and further optimize the detection limits.

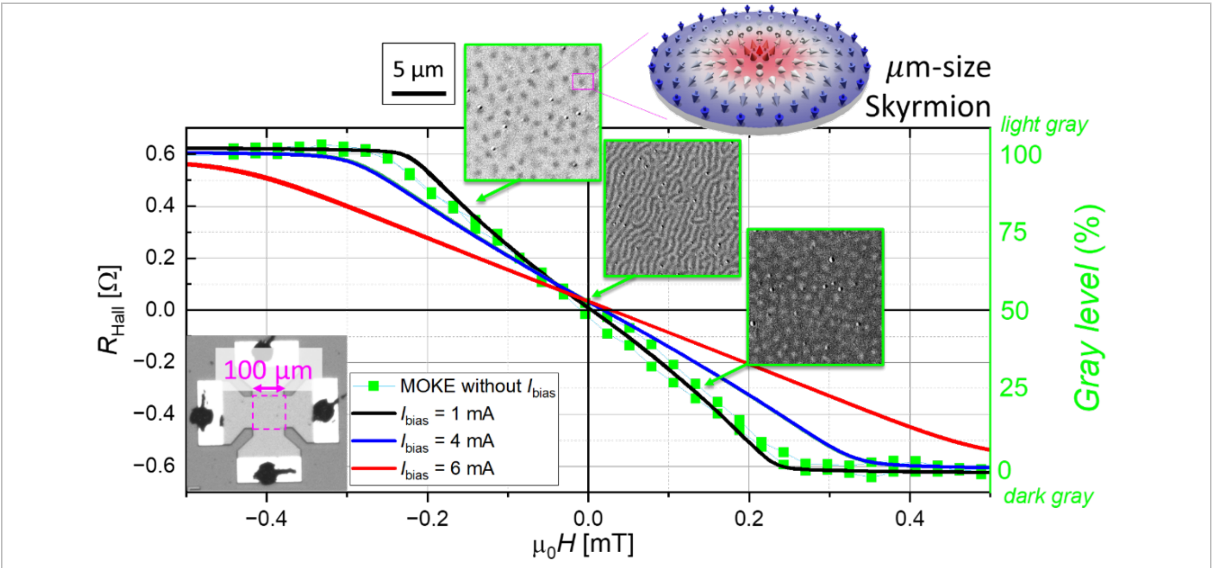

Fig. 1 MOKE loop (green) and Hall resistance (black, blue and red) as a function of out-of-plane fields for I_{bias} = 1 mA, 4 mA and 6 mA, respectively, showing the domain evolution during reversal. The electrical Hall measurements on a 100 × 100 µm² device are normalized by the bias current.

Acknowledgements
This work is supported by the French National Research Agency (ANR) through the project VERTICALE (ANR-25-CE42-3821-01), by the France 2030 government plan managed by the ANR (PEPR SPIN ADAGE (ANR-22-EXSP-0006)) and by the University Grenoble Alpes through the project CAPSKY.

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Large-Area Magnetoresistive Electronic Skin for High-Resolution Magnetic Field Mapping

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Magnetic field sensors are widely used in technologies ranging from industrial monitoring and navigation to wearable electronics and human–machine interfaces. Recent advances in eco-sustainable, flexible, and printable electronics have enabled new types of magnetic sensing devices that can be integrated into eco-sustainable, transparent, and mechanically compliant platforms [1–3]. Such technologies support the development of wearable and biointegrated systems capable of interacting with magnetic fields in everyday environments [4].

Electronic skins (e-skins) aim to extend human perception by enabling magnetoperception, i.e., the ability to sense and interact with ambient magnetic fields. A key challenge in such systems is achieving high spatial resolution over large areas without significantly increasing electronic complexity and power consumption.

Here we present a scalable magnetoresistive sensing platform based on electrical magnetoresistive tomography (EMRT), which combines the giant magnetoresistance (GMR) effect with tomographic reconstruction of resistance variations in a continuous sensing network [5]. Unlike conventional pixelated magnetic sensor arrays that require transistor-based addressing [6], our approach uses a distributed magnetoresistive mesh connected to peripheral electrodes. This architecture enables continuous magnetic field mapping over an area of 120 × 120 mm² with a spatial resolution better than 1 mm, while maintaining low circuit complexity. The system also reduces energy consumption by up to three orders of magnitude compared to transistor-based sensor matrices.

The sensing platform is implemented using transparent and mechanically compliant thin-film magnetoresistive structures, enabling flexible large-area devices suitable for wearable electronics. The concept is compatible with printable and stretchable magnetoresistive materials developed for skin-conformal sensing systems [7], which opens a path toward scalable magnetic sensors integrated directly into wearable devices.

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Anomalous Nernst effect in Co/Pt multilayers on flexible substrates

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Thermomagnetic generation through the Anomalous Nernst Effect (ANE) has been proposed as an alternative to the more classical Seebeck Effect. While the latter exhibits high thermopower efficiency, the Nernst Effect, due to its transverse nature, allows for the design of simpler generators since the thermal gradient, the magnetization direction and the generated electric field are perpendicular to each other [1] (See Fig. 1 a). We have grown magnetic multilayers of Co/Pt, with a strong perpendicular magnetic anisotropy (PMA), a high ANE and thermopower (~1 μV/K), as well as a low electrical resistivity [2]. These properties allow Co/Pt multilayers to efficiently convert temperature gradients into electric voltage via ANE.

In addition, we have demonstrated that ANE of Co/Pt multilayers can be controlled by strain engineering when they are deposited on polyimide flexible substrates. In particular, we have reported an increase by over 30% under compressive strain and a decrease under tensile strain. Fig. 1 shows (a) the hysteresis loop of the sample with $\varepsilon = -2.4\%$ and its respective (b) ANE voltage (V_{ANE}) for a thermal gradient of 20K.

All these characteristics makes ANE-based thin-film devices a promising alternative for the development of next-generation thermoelectric devices with potential applications ranging from thermal management technologies to heat flux sensors [3].

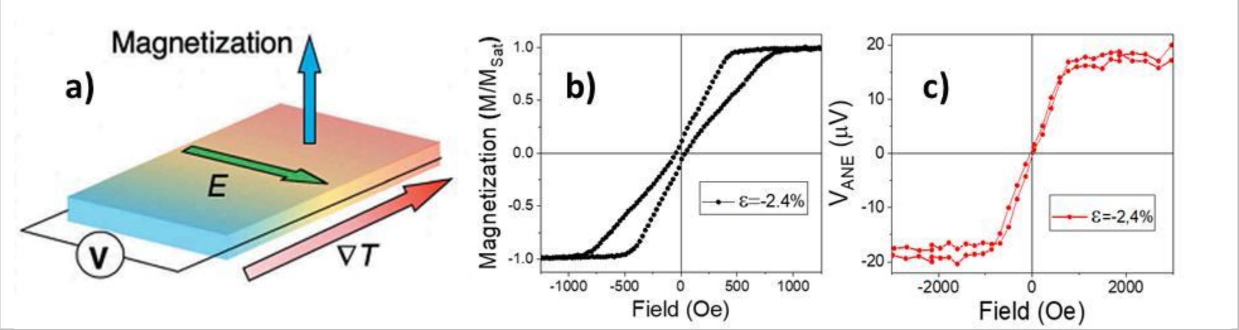

Fig. 1. Schematic images of the anomalous Nernst effect (a), the out of plane hysteresis loop (b) and V_{ANE} (c) at a gradient of 20k for a Co/Pt thin film with a strain of $\varepsilon = -2.4\%$.

Acknowledgements
We acknowlege funding by the Spanish Ministry of Innovation and Science MCIN/10.13039/501100011033, under the project PID2022-138169OB-I00. Acknowledge the Severo Ochoa Centres of Excellence program through Grant CEX2024-001445-S/ financiado por MICIU/AEI / 10.13039/501100011033.

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Micro-robot actuation in microfluidics

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Advances in microfluidics require a more robust and reliable mechanical operation to facilitate microscale tasks in a rapid with a higher level of accuracy. In this work several alternatives of micromanipulation methods were proposed with selected configurations of microrobots showcasing the engineering advantages of the microrobots by means of magnetic actuation which can pave the way for future employments of microrobots in the biomedical domain. An in-house electromagnetic system consists of magnetic coils in the horizontal setting along with the underlying magnetic coil array was employed to externally control the microrobots. The multitasking capability of the presented design was further demonstrated through distinct and promising applications including particle manipulation, micro-assembly, micromixing, and others. A very high level of mixing efficiency (over 85%) in the microscale was achieved with the presented analytical concept through the micro-robotic operation. These results opened a new chapter in terms of the microscale manipulation by means of the microrobots and further shed lights in more profound lab-chip applications down the road.

Acknowledgements

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Standardized Magneto-Optical Sensor Technology For Testing GOES

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Stray field detection in terms of domain observation of grain-oriented electrical steel (GOES) provides information about the texture quality. Standardized magneto-optical (MO) sensors and systems according to IEC TS 62607-9-2:2024 allow the fast two-dimensional detection of the stray field of the magnetic domains. This enables quality inspections of GOES under static and dynamic conditions as well as characterizations of larger areas.

INNOVENT has developed various systems for testing and observing GOES sheets under different aspects. MO imaging using CMOS-magview technology enables quick inspection of domains of GOES samples [3]. Properties of GOES such as grain size and magnetic orientation of the easy axis, edge characteristics, domain periods, rolling direction and effects by laser refinement can be investigated.

The innovative Domain Tester allows a sheet test under dynamic conditions [2] to investigate the remagnetization behavior. This system is able to detect the stray field of the domains with a frame rate of 8,000 images per second with an AC frequency of the coil-yoke system up to 400 Hz. An imaging area of 2.5 cm^2 and a lateral resolution of 30 µm enable domain reversal up to the centimeter range.

The latest development, the MOPP electrical steel sheet scanner for testing large sheet areas of GOES, has a scanning area of 1200 x 210 mm^2 with a resolution of 45 µm. Spontaneous and static domain observation can now be carried out for larger areas of investigations.

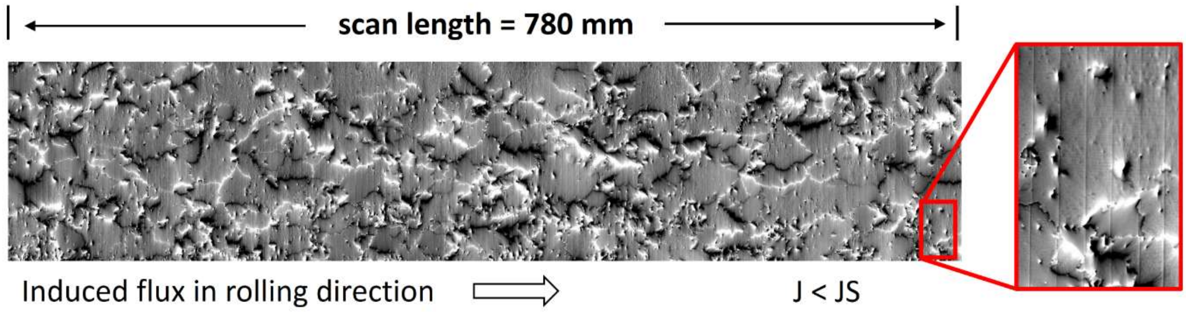

Fig. 1 Large-area testing of GOES with regard to stray field detection under induced flux. The steel sheet is magnetized and characteristics such as grain boundaries or flux spots are visible.

Acknowledgements

The developments were financially supported by INNO-KOM and EMPIR projects.

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Part 4

Poster presentations

Tuning Magnetostrictive $Fe_{70}Ga_{30}$ Thin Films for SAW-Based Magnetic Sensors through Thickness, Substrate, and Geometry

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Magnetostrictive $Fe_{70}Ga_{30}$ thin films are promising materials for strain-mediated magnetic devices because their magnetic response can be modified through magnetoelastic coupling [1,2]. This feature is particularly relevant for Surface Acoustic Wave (SAW)-based magnetic sensors, where magnetostrictive-piezoelectric layered structures can convert magnetic-field-induced elastic changes into acoustic signal modulation [3,4]. However, integration of $Fe_{70}Ga_{30}$ films in SAW platforms requires control of thickness-dependent microstructure, substrate-induced anisotropy, and lateral confinement [2,5]. Here, $Fe_{70}Ga_{30}$ thin films deposited on Si/SiO_2 and $LiNbO_3$ are investigated to clarify how these parameters affect morphology, magnetic domains, and magnetization reversal.

$Fe_{70}Ga_{30}$ films with thicknesses from 50 to 300 nm were prepared by RF sputtering. Si/SiO_2 was used as a reference substrate to evaluate the intrinsic thickness dependence, while $LiNbO_3$ was used to assess the influence of the piezoelectric substrate. Mechanical masking and laser lithography were employed to introduce lateral confinement. Surface morphology and roughness were examined by Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM), whereas Alternating Gradient Force Magnetometry (AGFM), Magnetic Force Microscopy (MFM), and Magneto-Optical Kerr Effect (MOKE) microscopy were used to investigate hysteresis, domain configurations, and reversal mechanisms.

Increasing film thickness promotes grain coarsening, roughness enhancement, and stronger domain-wall pinning, producing a clear increase in coercivity and a marked evolution of the magnetic domain structure. Although SEM observations show comparable morphology on Si/SiO_2 and $LiNbO_3$ for similar thicknesses, the magnetic response is strongly substrate dependent. In particular, $LiNbO_3$ induces direction-dependent magnetic behavior, attributed to strain-mediated magnetoelastic coupling at the piezoelectric/magnetostrictive interface. Lateral confinement further modifies reversal by changing the balance between edge nucleation, magnetostatic energy, and domain-wall propagation. Laser-patterned microstructures show that geometry mainly affects domain morphology and reversal pathways, while the switching field remains nearly unchanged at the investigated scale.

These results demonstrate that film thickness, substrate selection, and lateral geometry offer complementary routes to tune $Fe_{70}Ga_{30}$ thin-film properties. The obtained trends provide design guidelines for optimizing magnetostrictive layers in high-sensitivity SAW-based magnetic sensors.

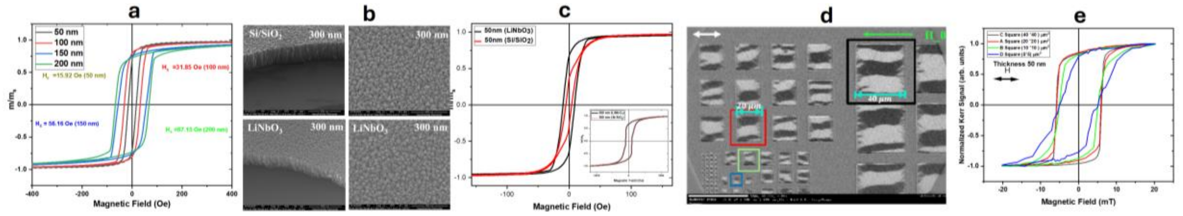

Fig. 1. $Fe_{70}Ga_{30}$ films: (a) thickness-dependent AGFM loops; (b) SEM images on different substrates; (c) substrate-dependent AGFM loops for 50 and 300 nm films; (d) laser-patterned 50 nm structures; (e) MOKE loops for different patterned geometries.

Acknowledgements

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Poster P02
1. Magnetic Sensors

Enhanced Magnetic Resolution in Elliptical Planar Hall Effect Sensors via Non-Collinear Anisotropy Engineering

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The magnetic response of elliptical planar Hall effect (EPHE) sensors to external magnetic fields is determined by their effective in-plane uniaxial magnetic anisotropy. Traditionally, EPHE devices are fabricated using a collinear scheme where the growth-induced anisotropy field ($\mathrm{H_g}$) and the shape-induced anisotropy ($\mathrm{H_s}$) are aligned along the same axis, resulting in an additive effective anisotropy field ($\mathrm{H_{eff} = H_s + H_g}$).

This work introduces a non-collinear fabrication strategy that controls the relative orientation between these anisotropy components to significantly enhance magnetic resolution. We demonstrate that a perpendicular alignment allows for partial compensation ($\mathrm{H_{eff} = H_s - H_g}$), leading to much lower effective anisotropy fields.

In particular, we show that transitioning from a parallel to a perpendicular configuration reduced $\mathrm{H_{eff}}$ from 5.4 Oe to 3.8 Oe, which lowered the equivalent magnetic noise (EMN) at 1 Hz from 50.3 to 38.3 pT/√Hz/A. These results establish non-collinear anisotropy engineering as a practical, footprint-preserving method for tuning sensitivity and achieving ultra-low noise beyond the constraints of conventional collinear fabrication.

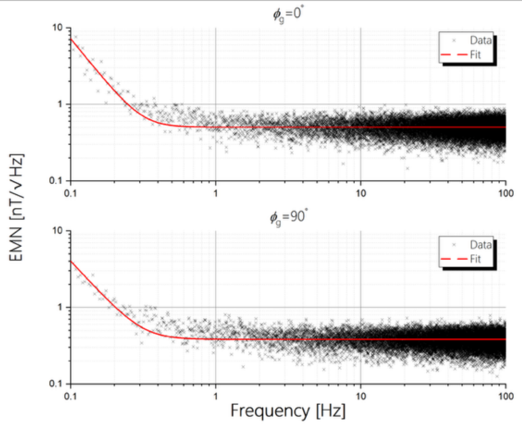

Fig. 1 EMN spectra of an EPHE sensor for two anisotropy configurations: parallel alignment (top, $H_{\mathrm{eff}} = 5.4$ Oe, EMN $= 50.3\ \mathrm{pT/\sqrt{Hz}/A}$ at 1 Hz) and perpendicular alignment (bottom, $H_{\mathrm{eff}} = 3.8$ Oe, EMN $= 38.3\ \mathrm{pT/\sqrt{Hz}/A}$ at 1 Hz). Markers: measured data; solid line: fit. The perpendicular configuration shows a lower noise floor due to the reduced effective anisotropy.

Contactless Measurement of Automobile Brake System Parameters Using Magnetic Microwires

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Current trends in the automotive industry, such as autonomous driving and increased safety, require very reliable monitoring of key components like brake systems. Accurate real-time sensing of pressure and temperature is necessary for diagnostics and vehicle stability. However, conventional sensors often require direct mechanical insertion into the brake lines, which increases the risk of leaks and wear due to vibrations and harsh environments.

Amorphous glass-coated microwires, produced by the Taylor-Ulitovsky method, offer a promising solution. Fe-based microwires with positive magnetostriction exhibit magnetic bistability, characterized by a sudden Barkhausen jump. This magnetic behavior is highly sensitive to pressure and temperature, causing a measurable shift in the critical switching field.

A contactless sensor system using two specific microwires for pressure and temperature measurement was designed. The experimental setup was constructed with genuine car components. Sensing was performed via a system of excitation and sensing coils. A variable magnetic field was generated by the excitation coil, while voltage impulses from the microwire's magnetization reversal were recorded by the sensing coil. This approach allowed the brake system to be monitored without compromising the integrity of the hydraulic lines.

A nearly linear dependence was observed for pressure measurements up to 60 bar (Fig. 1), while stable results were provided by the temperature sensor between 20°C and 65°C (Fig. 2). These findings confirm that glass-coated microwires represent a robust and safe platform for next-generation contactless automotive sensors.

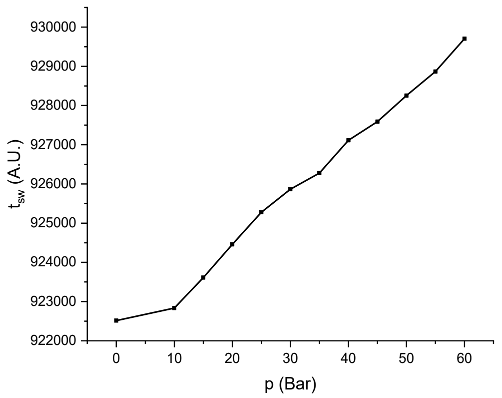

Fig. 1 Switching field dependence on the pressure of brake liquid.

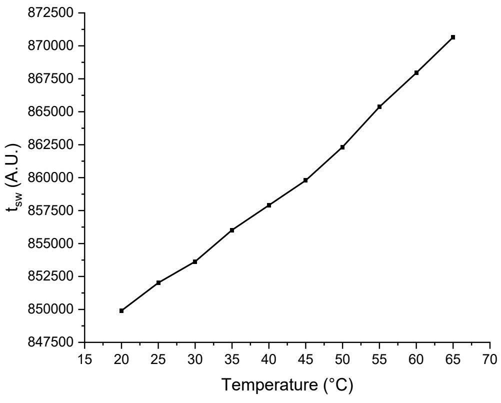

Fig. 2 Switching field dependence on the temperature of brake liquid.

Acknowledgements
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Electrodeposition and Characterization of FeNi Alloys on Copper Substrates for Fluxgate Sensor Applications

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FeNi alloys are widely recognized for their excellent soft magnetic properties, making them suitable for sensing and electromagnetic applications. In this study, FeNi alloys were synthesized by electrodeposition from aqueous solutions containing Fe(II) and Ni(II) ions. The deposition was performed using copper wire and planar copper substrates as conductive templates[1].

By The influence of key electrochemical parameters, including deposition time, current density, and electrolyte pH[2], on the composition and microstructure of the deposited FeNi layers was systematically investigated. Variations in these parameters were found to significantly affect the Fe/Ni ratio, surface morphology, and structural homogeneity of the deposits. Controlled adjustment of the electrochemical conditions enabled the formation of uniform and adherent FeNi coatings on both cylindrical and planar copper substrates[3].

Magnetic characterization of the electrodeposited materials revealed soft magnetic behavior, evidenced by a steep hysteresis loop and low coercivity. These properties are particularly desirable for magnetic sensing applications.

Beyond wire-based structures, FeNi films deposited on planar copper substrates were developed for integration into a racetrack fluxgate sensor configuration. The ability to tailor the magnetic response through electrodeposition parameters demonstrates the potential of this approach for scalable and cost-effective fabrication of soft magnetic cores for fluxgate sensing devices.

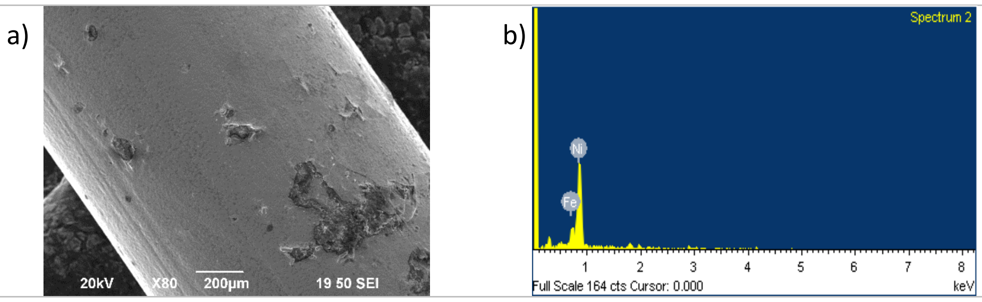

Fig. 1 a) SEM image of homogeneous FeNi coating on a Cu wire. b) EDS analysis of the surface showing the composition of the FeNi deposit

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Flexible-Fluxgate Current Sensor with Improved Geomagnetic Field Immunity

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Typical arrangements of contactless current measurement utilize flux concentrators and Hall devices, AMR arrays or fluxgates. Another solution is using flexible Rogowski coil, with the limitation of AC-only sensing. Having the Rogowski-like design for DC-current measurements would be advantageous in situations where the current conductor must not be interrupted. Some recent developments [1] focused on utilizing flexible substrate incorporating fluxgate assembled in MEMS technology. Flexible current sensor composed of (a pair of) fluxgates was also realized in flexible printed-circuit-board technology (with arrangement similar to [2]) – however the first iteration [3] suffered from excessive sensitivity to geomagnetic field. The gap between the two fluxgates (Fig.1) provides simpler mechanism for application (i.e. attachment to the measured current conductor) but also compromises offset stability when the sensor moves relative to the Earth's field. In the new implementation, this effect is largely suppressed by better signal processing. Instead of single-channel processing of one composite signal, both fluxgate outputs are processed by independent phase-sensitive detectors. The two resulting DC signals are then subtracted into final output which is proportional only to the measured current. Although the offset of each fluxgate does shift with applied geomagnetic field, the differential response effectively minimizes the parasitic geomagnetic sensitivity – see Fig.2.

Sinewave excitation current of 175 mApp @ 10 kHz) was used with 2nd harmonic detection using two separate lock-in amplifiers. In the full paper, we study also stability during open/close cycles of the Rogowski-like sensor. Preliminary sensor noise is about 1.3 mApp in 0.1-10 Hz band.

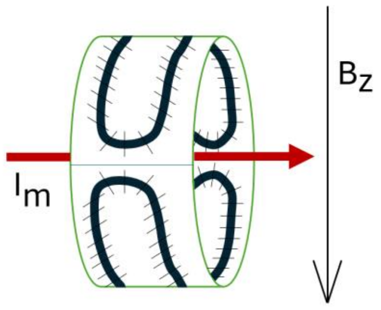

Fig. 1 Arrangement of two flexible fluxgates encompassing the current (Im). Geomagnetic field (Bz) may influence measurement. (The enclosed diameter is about 4 cm.)

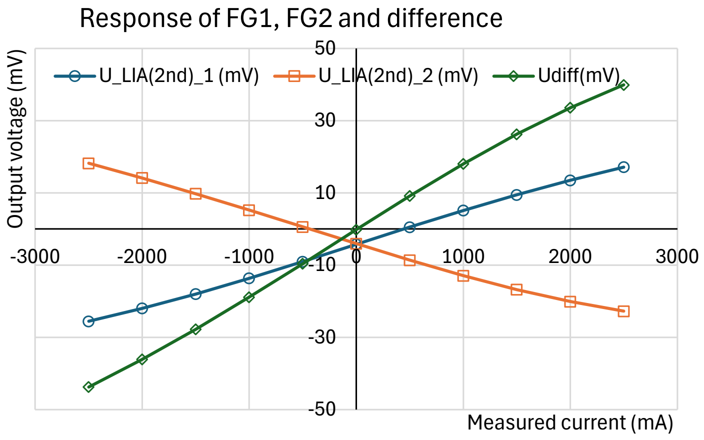

Fig. 2 Response of the current sensor (in orientation according to Fig.1). Observable geomagnetic field-induced offset of about -5mV is present in the individual responses – ○ and □), while it is suppressed in the difference (◊).

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A highly unconventional Hall sensor based on skyrmions

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Magnetic field sensors are a key application in spintronics, particularly those based on magnetoresistive effects due to their small size, low cost, and high sensitivity [1]. We report on a highly sensitive out-of-plane magnetic field sensor using Ta/FeCoB/TaOx trilayers hosting skyrmions [2]. In these samples with perpendicular magnetic anisotropy, low domain wall energy enables thermal demagnetization and facilitates skyrmion nucleation and domain wall propagation due to the amorphous character of the layers. Under external perpendicular magnetic fields, the magnetization saturates at exceptionally low values of ±0.25 mT and when patterned into 100×100 μm^2 Hall bar devices they show a linear anomalous Hall response in between.

Surprisingly, the sensitivity of this sensor is highly frequency dependent (Fig.1(a)) with a first decrease around 100 Hz and a second one for frequencies above 1 kHz. Furthermore, the sensitivity at frequencies smaller than ~300Hz decreases for bias currents above 2 mA. This can be related to an increase in temperature, but may also be related to a change in the type of domain-wall motion or its intrinsic magnetic configuration. Alongside, increasing the bias current completely modifies the noise behavior in the sensor (Fig. 1(b)), which changes from a spectrum containing a 1/f-like component (black and green curve) to a dominating Random-Telegraph-Noise-like spectrum (blue and red curve). The next surprising finding here is that above 2 mA, the noise is not at all scaling with the bias current where from we would expect a continuation of increasing 1/f-noise with the bias current. Together these findings result in an optimized detectivity at low frequencies with detection limits below 10 nT/√Hz for higher bias currents (Fig. 1(c)).

This opens the path to explore the potential of skyrmion-based devices for low out-of-plane magnetic field detection. Ongoing work focuses on correlating domain wall and skyrmion dynamics with the observed noise behavior as a function of magnetic field and bias current.

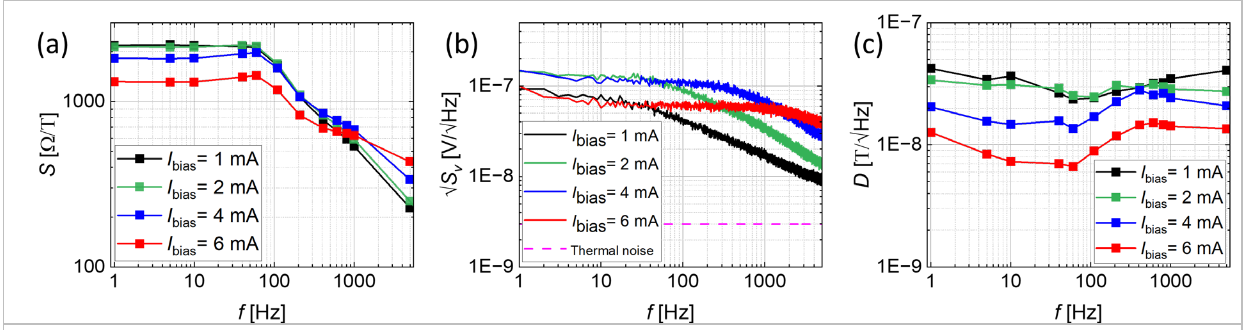

Fig. 1 Sensitivity (a), noise (b) and detectivity (c) of the skyrmion Hall sensor for different bias currents from 1 to 6 mA.

Acknowledgements

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Optimizing top-pinned magnetic tunnel junctions for novel sensing applications

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Magnetoresistive sensors are central to modern sensing technologies, offering adjustable thin-film properties and fabrication processes that allow easy integration with other technologies. Magnetic tunnel junctions (MTJs) are particularly interesting for their high tunnel magnetoresistance (TMR) ratio, giving high sensitivity to magnetic fields. Depending on the application, the MTJ stacks must be carefully engineered [1]. State-of-the-art MTJs typically use a bottom-pinned reference layer based on exchange-biased synthetic antiferromagnets (SAF) like buffer/IrMn/CoFe/Ru/CoFeB for accurate angular sensing or robust high temperature operation [2]. In emerging applications such as ultra-low field detection [3], current tunable sensitivity or photonic circuit integration, top-pinned MTJ configurations are sometimes preferred. However, this configuration introduces unique challenges including increased interfacial roughness at the reference layer, which hinders precise control of the magnetic and electrical properties.

In this work we investigate a top-pinned MTJ stack based on Ta(t_{buffer})/CoFeB/MgO(t) /CoFeB(t_{CoFeB})/Ru(t_{Ru})/CoFe(t_{CoFe})/IrMn/Ta. Using vibrating sample magnetometry (VSM) and current in plane tunneling (CIPT) we evaluate the critical saturation fields of the building blocks, the expected TMR and resistance-area product. In particular, we address the impact of t_{buffer}, t_{Ru}, t_{CoFeB} and t_{CoFe} in correlated interfacial roughness which affects the characteristic fields of both the SAF and the CoFe/IrMn bilayer. We also investigated the annealing temperature (300 °C to 400 °C) needed to achieve crystallization of the barrier without compromising the magnetic behavior of the stack and optimized the growth parameters for the MgO in our current sputtering system. Finally, the MTJ stacks will be fabricated into micro scale pillars for electrical characterization. Our optimized top pinned MTJ can then be integrated with other technological platforms.

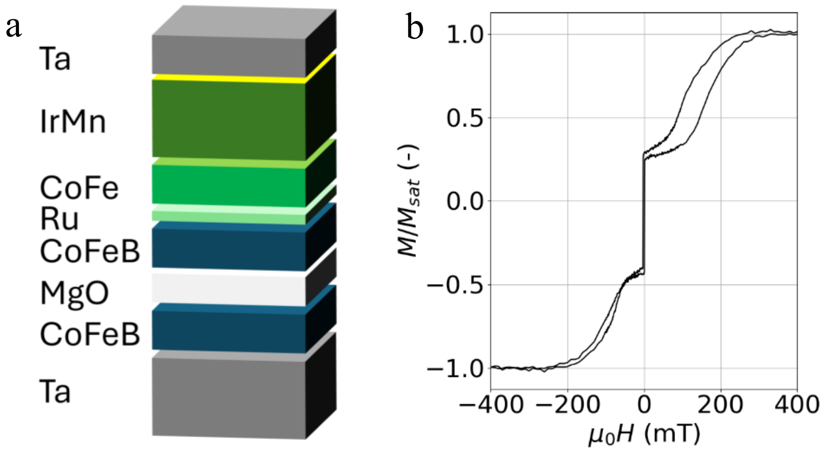

Fig. 1 a) Schematic representation of the deposited MTJ stack b) Representative M(H) loop for $t_{Ru} = 0.75$ nm

Acknowledgements: The authors thank Aurélie Solignac for support in performing CIPT measurements

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Rapid design of magnetic MEMS: micro-speaker and micro-mirror

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Magnetic microelectromechanical systems (MEMS) are employed in several application fields spanning from automotive to biomedical, space and IoT [1, 2]. Standard magnetic MEMS include permanent micromagnets and micro-coils and they can operate as sensor, actuator and energy harvesting devices. Their design usually requires powerful computational capabilities as well as long calculation times as it is usually performed via finite-element simulations. A new fast semi-analytical method [3] is applied for the design of two MEMS: a micro-speaker and a micro-mirror. The first consists of arrays of laser-cut NdFeB permanent micro-magnets that encase micro-coils mounted on a flexible membrane (Fig. 1 (a)) where the latter can be made to vibrate by supplying the micro-coils with an AC current, which ultimately generates a sound pressure output [4]. Such micro-speaker is designed for in-ear applications. The second includes an array of permanent magnets as well as micro-coils fabricated on the suspended micromirror plate around the reflective area (Fig. 1 (b)). The MEMS micromirror exploits the Lorentz force arising from the interaction of the electrical current through the micro-coils with the magnetic field generated by the permanent magnets to actuate and control the motion of the suspended region. The envisioned micro-mirror can be applied in the field of satellite and optical communications [5].

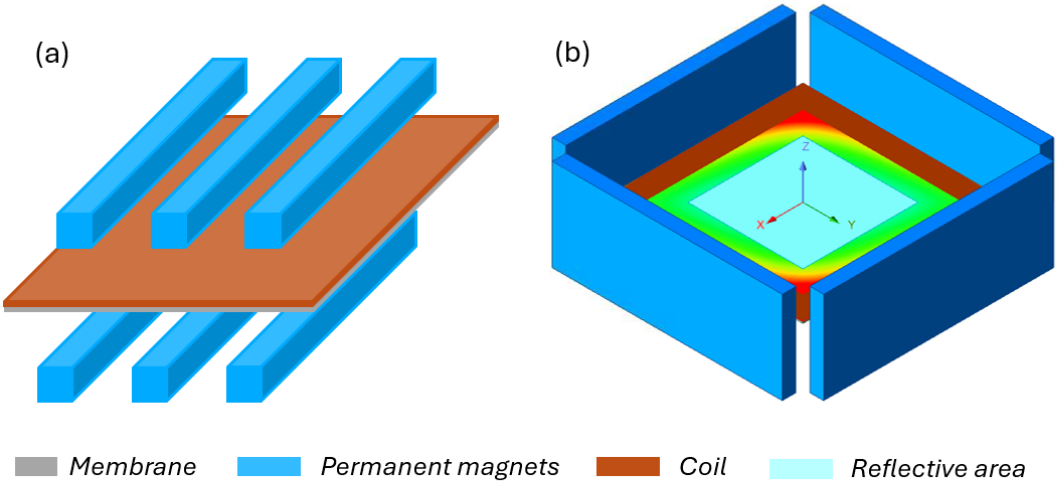

Fig. 1 (a) Sketch of the magnetic MEMS micro-speaker. (b) Sketch of the magnetic MEMS micro-mirror.

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Grain induced uniaxial magnetic anisotropy in AlScN/CoFeB thin films

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The magnetoelectric (ME) effect enables electric-field control of magnetization and magnetic-field control of strain through strain-mediated coupling between magnetostrictive and piezoelectric layers. The ME effect has gained a lot of attention due to its wide range of applications in magnetic field sensors, spintronic and RF devices [1,2]. Hence, understanding the routes to effectively couple the piezoelectric and magnetostrictive layers is crucial for the improvement of ME devices.

In this work, the influence of the surface roughness of AlScN on a 10 nm thick CoFeB layer was investigated. AlScN was chosen as the piezoelectric material, as it is compatible with standard CMOS processes. Although CoFeB has been previously studied in conjunction with other piezoelectric substrates [3], its behaviour when interfaced with AlScN is not well understood. AFM measurements revealed the presence of abnormally oriented grains (AOGs) in the AlScN layer. It has been previously shown that the roughness of the substrate can induce uniaxial anisotropy in the magnetic layer [4]. To characterize the presence of in-plane anisotropy, hysteresis loops were measured using VSM by varying azimuthal in-plane angle. The polar plots of coercivity shown in fig. 1. confirm the presence of uniaxial anisotropy in the CoFeB grown on the rougher AlScN substrates. For comparison, CoFeB grown on Si substrates with the same growth conditions showed isotropic behaviour. The role of different seed layers such as Ta and Pt was also investigated. The results presented here are the first steps for further development of high-quality magnetoelectric composites and the future direct integration of ME devices with CMOS technology.

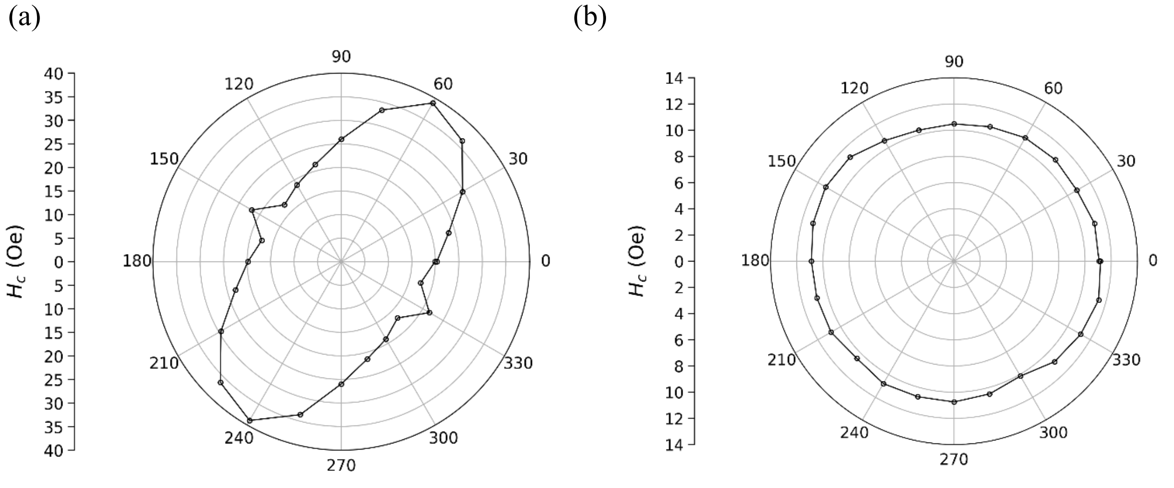

Fig. 1 Polar plots of Coercivity (H_c) for (a) AlScN/CoFeB/Ta (b) Si/CoFeB/Ta

Acknowledgements
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Giant Reversible Strain of 16% in Ni-Fe-Ga Shape Memory Microwires

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Glass-coated Ni-Fe-Ga Heusler microwires provide an excellent platform for investigating the physics of the shape memory effect in confined geometries. Compared to conventional bulk shape memory alloys, the microwire geometry provides a high surface-to-volume ratio for rapid thermal response and naturally confines transformation strain to the axial direction, making them ideal for linear micro-actuators [1]. This work focuses on the Ni-Fe-Ga system, which overcomes the stoichiometric instability caused by manganese evaporation typical in standard Ni-Mn-Ga alloys during rapid solidification.

$Ni_{50}Fe_{27}Ga_{23}$ microwires were successfully fabricated utilizing the Taylor-Ulitovsky method. The transport signature of the structural phase transition under current heating was investigated. By passing a DC current directly through the metallic core after glass removal, the transformation between the high-temperature cubic austenite and the low-temperature tetragonal martensite was effectively detected via a characteristic non-linear resistance step.

To quantify the shape memory capability, Dynamic Mechanical Analysis (DMA) was performed. Upon heating from -100 °C under a constant tensile stress of 40 MPa, the microwire exhibited an exceptional giant reversible strain of approximately 16% (Fig. 1). This profound macroscopic deformation is attributed to a combination of transformation-related lattice strain and pronounced stress-assisted variant reorientation (detwinning) in the martensitic state, facilitated by the strongly oriented crystallographic structure along the wire axis.

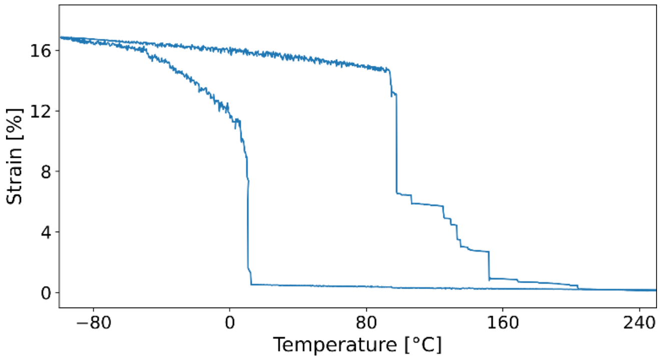

Fig. 1 Temperature dependence of strain for a $Ni_{50}Fe_{27}Ga_{23}$ microwire measured via DMA, exhibiting ~16% reversible strain.

To probe the internal magnetic anisotropy, Ferromagnetic Resonance (FMR) measurements at a fixed microwave frequency of 36 GHz were conducted in the martensitic state [2]. The resulting spectra revealed two distinct resonance features, which may correspond to the respective easy and hard axes of magnetization within the multivariant martensite.

Acknowledgements

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Linear Variable Inductive Transducer Position Sensor with EE Shape Armature

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Position transducers and sensors are essential components of electromechanical devices and industrial machinery for automation, control, and maintenance. Demand for position sensors is increasing as the electrification of transportation systems and fast robotic development is on the rise. Linear variable differential transformer (LVDT) position sensors with a cylindrical structure are the most widely used transducers for position measurements in industrial applications because of their robust, cost-effective design and adequate accuracy. To achieve a wide linearity range, standard LVDT position sensors require long toroidal coils or long armatures, which make them bulky for long-distance measurements and limit their application due to weight constraints. Flat-type magnetic position sensors offer greater flexibility in reducing the active volume while maintaining high sensitivity compared to standard LVDT position sensors with cylindrical structure [1]-[2].

A new position sensor is presented in this paper based on a linear variable inductive transducer (LVIT) structure. It has two coils, compared to the three coils in LVDT position sensors, as shown in Fig. 1, and an EE-shaped or shell-type armature. The coils' voltage difference is a function of armature position. The optimization of the coils' shape is made to decrease the nonlinearity error and extend the linearity range. The nonlinearity error is below 0.8% over a ±80 mm movement range in the optimized model (Fig. 1 b)), compared to the initial design, which had over 2.5% nonlinearity error (Fig. 1 a)). The short armature and simple coil structure are the main advantages of the proposed position sensor. The detailed design optimization and measurements will be presented to further reduce the nonlinearity error.

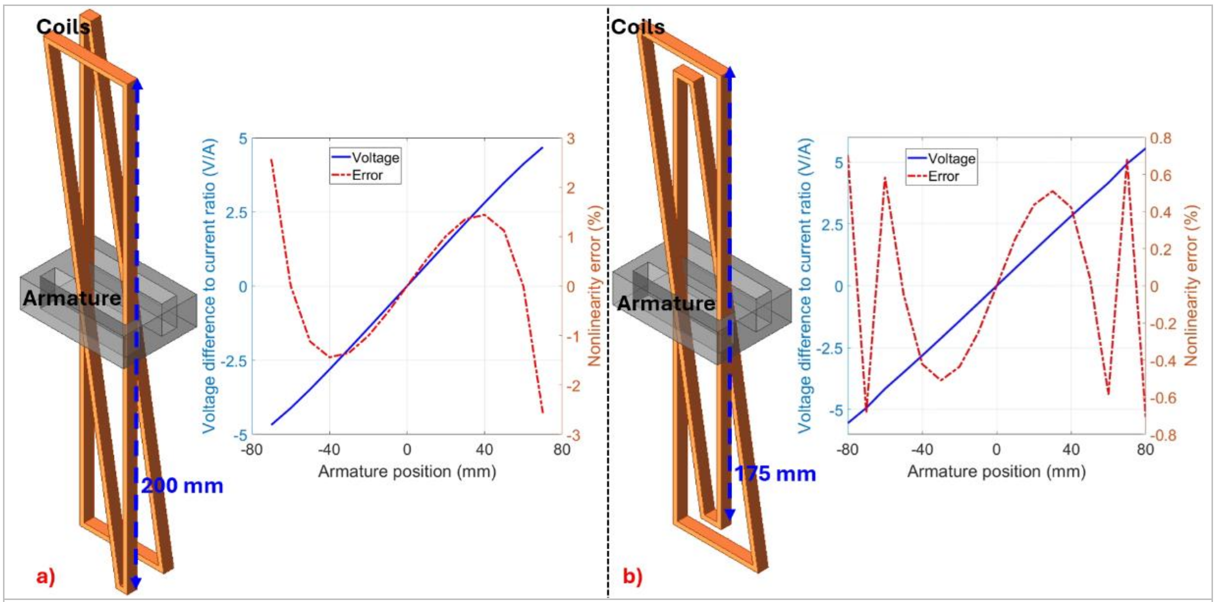

Fig. 1 The voltage difference to current ratio and nonlinearity error versus armature position, a) Initial design and b) Optimized design – Ferrite armature core

Acknowledgements
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Poster P12
2. Magnetic Actuators & MEMS

Introducing PYRAMID: Inverted Pyramid 3-axis Hall-effect magnetic sensor with offset cancellation

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Hall-effect sensors remain the dominant technology in the magnetic sensor market. Traditional CMOS-compatible three-axis Hall sensors are based on a combination of planar Hall devices and vertical Hall devices; however, vertical Hall devices typically exhibit a trade-off between offset and sensitivity / signal-to-noise-ratio [1]. Alternative three-dimensional concepts include the hexagonal prism architecture [2] and Hall sensors with integrated magnetic concentrators [3], but these approaches suffer from limited CMOS compatibility, larger footprints, or reduced dynamic range.

Here, we present our recently published [4-5] alternative three-axis silicon magnetic sensor based on an inverted pyramid geometry (Fig. 1), manufactured using standard MEMS processing techniques and CMOS technology. The sensor demonstrates high in-plane and out-of-plane current sensitivities (64.1–198 $\text{V A}^{-1}\text{ T}^{-1}$) and low crosstalk (< 4.7%) [4]. In addition, it can be proved that a dynamic offset cancellation technique called current spinning is applicable, reducing the raw offset by one to three orders of magnitude. The achieved residual offset at 1 V lies in the range of 0.2–4 mT [4-5], which is higher than that of silicon-based planar Hall devices but comparable to five-contact vertical Hall devices [2]. Noise spectral density measurements showed thermal noise floors of around 0.5 $\mu\text{T}/\sqrt{\text{Hz}}$ and corner frequencies below 40 kHz at 1.31 V [5]. This result implies that the device can be current-spun with current CMOS nodes, without introducing additional residual offset contributions from the readout circuitry.

We also present here early results of our forward-looking approach to improve the device's sensitivity. Given that the Hall voltage is directly related to carrier mobility, it is of interest to make the active layer of the inverted pyramid out of a high-mobility, single-crystal semiconductor. N-type gallium arsenide (GaAs) is chosen for its 5X higher electron mobility than silicon and compatible crystal structure and lattice. We are investigating the use of metal-organic vapor phase epitaxy (MOVPE) to deposit GaAs in the pyramid cavity. Fig. 2 includes a ~5 µm-thick GaAs film grown selectively inside the silicon pyramid template.

Overall, this inverted-pyramidal Hall-effect sensor represents a promising and structurally simpler alternative to state-of-the-art three-axis magnetic sensors. With further optimization, it may enable low-cost advanced applications such as position tracking and three-axis current monitoring. Finally, the structure can be used as an epitaxy platform to include a high-electron mobility material.

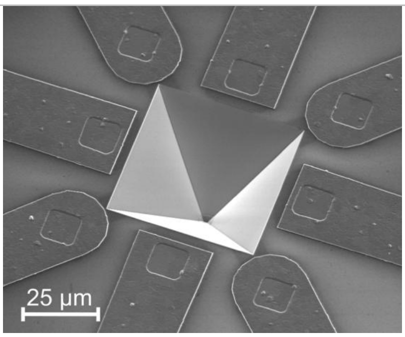

Fig. 1 Scanning Electron Microscope image of the 3-axis PYRAMID Hall-effect sensor [6]

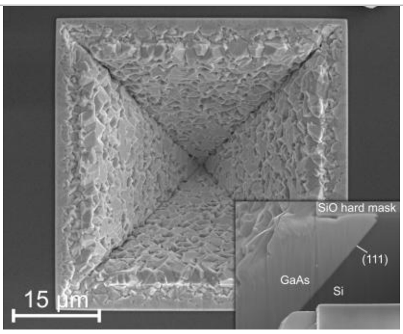

Fig. 2 SEM image of GaAs grown by MOVPE in the PYRAMID structure. Inset: corner cross-section cut by FIB.

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Development of a High-Sensitivity Planar Hall Magnetoresistance Sensor for Non-Invasive Vascular Monitoring

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Magnetic sensors based on the planar Hall magnetoresistance (PHMR) effect have emerged as a promising approach for non-invasive detection of physiological signals from the human vascular system. In this study, we developed and optimized a PHMR sensor using a MgO/NiCo/Cu/IrMn/MgO multilayer stack specifically for monitoring blood flow dynamics.

During material optimization, we compared MgO and Ta as capping and buffer layers. The results showed that MgO significantly outperformed Ta, leading to a clear improvement in sensor output. We also replaced the conventional NiFe layer with NiCo, which provided higher sensitivity. In addition, post-deposition annealing was performed at various temperatures to enhance interlayer coupling and improve the crystalline quality of the multilayer structure.

To enable practical measurement, an external permanent magnet was integrated with the sensor. Using COMSOL Multiphysics simulations, we analyzed the magnetic field distribution and tested different shielding configurations. This approach allowed us to flexibly adjust the magnet–sensor arrangement according to each sensor's offset while maintaining the operating field around 40 Oe.

We further modified the sensor geometry to improve skin contact, resulting in a 25% increase in effective contact area compared to the previous design. Following optimization, the sensitivity increased by 36%, reaching around 5.6 V/T (equivalent to 0.56 mV/Oe at 1 mA), while the measurement range remained about 40 Oe. This sensitivity is significantly higher than sensitivities of conventional cross-type PHMR sensors reported in recent literature (~0.05–0.2 V/T). [1]

The optimized sensor was tested on the radial artery of laboratory volunteers. Signal preprocessing and time–frequency analysis were applied to extract meaningful physiological information from the blood flow waveforms, with further refinement of the signal processing planned for future work.

The developed PHMR sensor demonstrates improved sensitivity and better body contact, highlighting its strong potential for wearable devices in continuous cardiovascular monitoring.

Acknowledgements

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Fabrication of Flexible Giant magnetoresistance (GMR) sensors for recording of neural signals

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Spintronic sensors have emerged as promising candidates for magnetic field sensing in healthcare, wearable electronics, human–machine interfaces, and communication systems. In neuroscience, the detection and stimulation of neural activity are essential for the diagnosis and treatment of neurological disorders. Current neural recording techniques include electroencephalography (EEG), electrocorticography (ECoG), and magnetoencephalography (MEG). Among these, MEG offers significant advantages over EEG because magnetic signals are reference-free and are not distorted by the varying conductivity of biological tissues. However, conventional MEG systems rely on ultra-sensitive superconducting sensors that require cryogenic cooling with liquid helium and bulky instrumentation, limiting their applicability for local in vivo recordings.

Spintronic giant magnetoresistance (GMR) sensors in spin-valve configuration provide an attractive alternative, offering high magnetic sensitivity at physiological temperatures while enabling miniaturization to micrometer dimensions[1]. Recent advances have demonstrated the feasibility of in vivo neuronal magnetic recordings using GMR-based magnetrodes[2]. For effective neural recording, sensors must detect extremely weak magnetic fields with high temporal and spatial resolution while maintaining low noise performance, particularly at low frequencies below 100 Hz.

Integrating GMR sensors onto flexible substrates presents additional advantages for neural interfaces, including reduced tissue damage, minimized glial scar formation, and improved conformity to the curved surfaces of cortical tissue. Flexible magnetrodes therefore hold strong potential for next-generation brain–computer interfaces and chronic neural implants. Nevertheless, significant challenges remain in maintaining the magnetic sensitivity and low-noise characteristics of GMR devices when transferred from conventional rigid silicon substrates to flexible materials.

This work explores fabrication strategies for flexible GMR-based magnetic neural probes with improved encapsulation and biocompatibility. The influence of sensor design, multilayer stack optimization, and microfabrication processes on polymer substrates is investigated. The presented research contributes toward the development of next-generation magnetic neural probes capable of bridging the gap between conventional electrophysiology and large-scale magnetoencephalography by enabling localized magnetic recordings directly within neural tissue.

Acknowledgements

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Microdisks as magnetic labels for GMR biosensors

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In recent years, portable biosensing platforms based on electrical and magnetoresistive (MR) technologies have emerged as powerful alternatives to conventional diagnostic methods. Among them, giant magnetoresistance (GMR) devices stand out as highly sensitive platforms for portable biomarker detection. The operating principle of GMR sensing relies on detecting the stray magnetic field generated by magnetically labeled samples at the sensor surface under an applied external magnetic field. This approach enables low detection limits and minimal background interference, owing to the absence of intrinsic magnetism in biological media.

Magnetic labels typically consist of superparamagnetic nanoparticles (SPNPs) based on metal oxides. However, top-down fabrication strategies now allow the creation of nanometer- and micrometer-scale patterned structures with precise geometrical control and narrow size dispersion. Here, we propose vortex-state NiFe microdisks (MNDs) as alternative magnetic labels. Arrays of 2 µm diameter disks were fabricated by direct laser lithography, followed by electron beam evaporation in a high-vacuum chamber. This approach enables the use of pure magnetic materials, resulting in labels with a magnetic moment significantly higher than that of conventional SPNPs. The vortex state was confirmed by vibrating-sample magnetometry, showing the characteristic zero remanence.

The GMR detection of vortex-state NiFe microdisks exhibits high output and faster signal saturation compared to conventional SPNPs. As shown in Fig. 1, the sensor voltage rapidly drops within few minutes upon microdisk detection, compared to 20–30 minutes for commercial SPNPs, and fully recovers to the baseline after their removal, demonstrating the reversible and fast response of the system. Preliminary experiments using GMR detection of MNDs investigated the detection of thrombin, a key enzyme in blood coagulation, via aptamer immobilization, highlighting the potential of these sensors for biomedical applications.

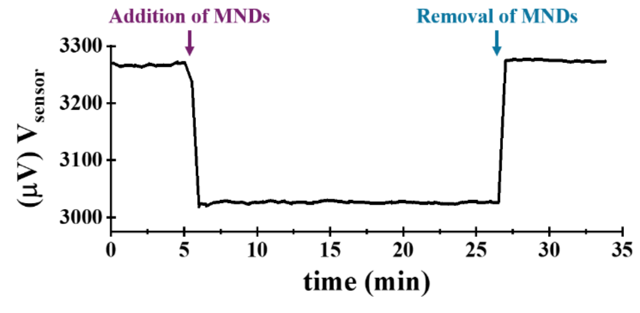

Fig. 1 Sensor voltage response upon addition and subsequent removal of MNDs.

Acknowledgements
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Towards quantitative magnetic LFAs: comparison of inductive and GMR detection

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Lateral flow assays (LFAs) are increasingly adopted for rapid point-of-care testing, and their adaptation with magnetic nanoparticles (MNPs) as labels enables quantitative readout rather than purely qualitative interpretation. Realising this potential requires sensors that are inexpensive, portable, and precise enough to detect and quantify small quantities of magnetic material.

In this work two such detection techniques are compared. The first is an inductive method, in which MNPs are detected through a shift in the resonant frequency of a planar-coil LC oscillator operated at MHz range. It therefore probes their AC susceptibility, resolving the magnetic relaxation of the superparamagnetic particles. The flux-based transduction integrates the magnetic response over a sensing volume and offers a broad dynamic range that accommodates large variations in sensed mass. The second is a giant magnetoresistance (GMR) method, operated below 1 Hz under an applied bias field, in which the stray field of the MNPs is sensed locally. Thus magnetic moment of MNP under an applied bias field is sensed locally. Therefore, GMR offers higher sensitivity for small or localised quantities but is more dependent on sample geometry and proximity, and its narrower detection range requires re-tuning when the sensed mass varies significantly.

MNPs are sensed in different mm-sized sample configurations : liquid suspension, humid in nitrocellulose, dried in nitrocellulose. This study contrasts two particle types: 10 nm superparamagnetic and 70 nm ferrimagnetic nanoparticles, which differ critically in remanence. Particle mobility shapes the response of both sensors, but through distinct mechanisms. For the inductive method, the AC susceptibility reflects the interplay of Néel and Brownian relaxation; rather than acting as independent channels selected by particle size, the two contribute jointly, and their balance is reshaped by clustering and aggregation, which alter the effective hydrodynamic volume of the particles. For GMR, mobility of MNP affects whether they can completely align with the bias field, whose orientation is itself a parameter of study. We discuss these trade-offs and provide guidance on jointly selecting a particle label and detection scheme for a given LFA application.

From Quantum Sensing to teaching Quantum with NV Centers

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Nitrogen-Vacancy (NV) centers in diamond have emerged as a leading quantum technology platform, owing to their long coherence times, optically addressable spin states, and high sensitivity to external perturbations.

In this poster, we highlight two application areas of NV centers.

First, a single NV center in a diamond scanning tip functions as a nanoscale quantum sensor enabling measurements of magnetic field, current density distribution, and near-field optical or sub-surface signals. Our commercial scanning NV system, Quantum Scanning Microscope combines single NV center technology with atomic force microscopy and confocal optical readout to study magnetic phenomena with high spatial resolution in a fast and user-friendly way. This system enables studies of materials such as antiferromagnets, and multiferroics, as well as magnetic textures like spin waves, and skyrmions. Recently, we have extended the capabilities of our system to facilitate measurements at cryogenic temperatures, allowing the study of various superconducting phases and two-dimensional magnetic materials.

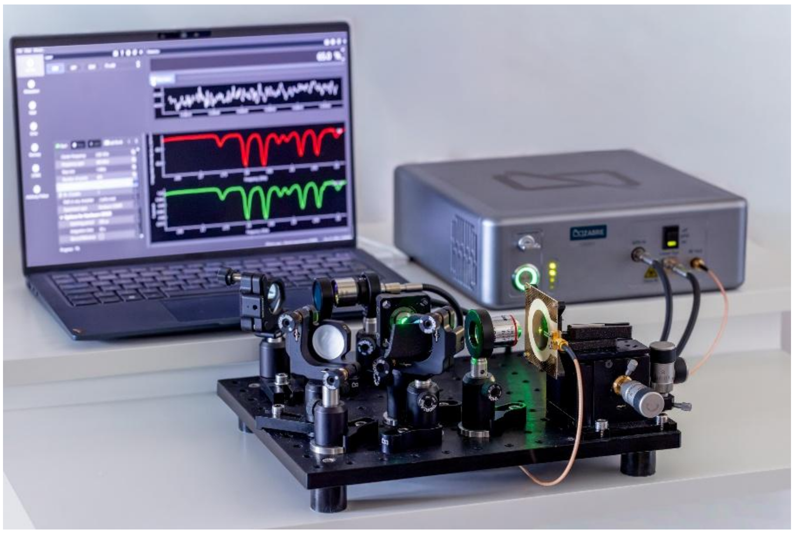

Fig. 1 Quantum Edukit.

Second, because NV centers in diamond operate under ambient conditions, they provide an ideal platform to demonstrate a wide variety of quantum phenomena. We have developed an educational kit based on NV centers, Quantum Edukit to teach quantum mechanics in a hands-on and interactive manner. The kit is depicted in Fig. 1, and it enables exploration of principles such as level quantization, quantum superposition, light-matter interaction and quantum optical effects in real time. Sample experiments include observation of the Zeeman effect, Rabi oscillations, Ramsey interferometry, and spin echo. On an experimental level, students gain hands-on experience in building optical setups, optimizing the performance of quantum systems, and acquiring practical skills used in quantum research labs.

These applications illustrate the versatility of NV centers, enabling both nanoscale sensing and interactive education in quantum mechanics.

Enabling Compact Magnetic Bias Sources for Next-Generation Sensors and Quantum Processors Through Thermally Stable PowderMEMS® Micromagnets

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Integrated permanent magnets play a critical role in next-generation microsystems spanning from conventional automotive sensing to emerging quantum technologies. In back-bias sensing architectures, permanent magnets are employed alongside magnetic field sensors to detect soft magnetic targets such as rotating encoder wheels. This configuration is widely deployed in automotive systems where high volumes demand cost-effective and miniaturized solutions. Ferrite-based microwave components, including tunable filters, circulators and phase shifters, also rely on external magnetic bias fields for frequency tuning and non-reciprocal signal control. Beyond these classical applications, precisely positioned local magnetic fields are essential for quantum computing and quantum sensing: manipulation of ions in ion traps and operation of quantum processors and magnetometers based on nitrogen-vacancy centers depend on precisely defined static magnetic fields or field gradients. Replacing discrete magnets with monolithically integrated alternatives offers significant advantages in miniaturization, manufacturing cost reduction and scalability.

The PowderMEMS® microfabrication platform developed at Fraunhofer ISIT enables wafer-level integration of permanent magnets with a thickness of several hundred micrometers directly into silicon substrates [1]. Owing to its low processing temperatures, this technique is fully compatible with pre-processed microelectronic circuitry. Recent demonstrations have confirmed the viability of this approach in multiple application domains. A fully integrated back-bias Hall sensor system incorporating NdFeB micromagnets was realized and successfully used to detect motion of rotating gear wheels, representing a typical automotive use case [2]. Also, an AMR sensor was equipped with substrate-integrated magnets for in-plane biasing [3]. Regarding quantum technology, PowderMEMS® micromagnets were integrated into silicon interposers, enabling Zeeman splitting of nitrogen-vacancy centers in diamond [4].

Both automotive and quantum applications demand reliable magnetic and mechanical performance across a wide range of temperatures. Automotive environments require operation up to 423 K, whereas cryogenic quantum systems operate at temperatures as low as 5 K. This study systematically evaluates the magnetic characteristics and structural integrity of NdFeB PowderMEMS® micromagnets throughout the full temperature window from 5 K to 423 K. NdFeB magnets integrated on 200 mm silicon wafers were subjected to repeated thermal cycling via immersion in liquid nitrogen with 20 cycles of 5 minutes each. Post-cycling inspection revealed no structural degradation. Magnetic hysteresis measurements performed using vibrating sample magnetometry between 5 K and 423 K confirmed stable ferromagnetic behavior. Extended thermal aging at 423 K for 1500 hours resulted in remanence degradation below 5%. These findings demonstrate the exceptional thermal resilience of PowderMEMS® integrated micromagnets, validating their suitability for industrial microsystem applications and cryogenic quantum technology platforms.

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A traceable system for the calibration of optically pumped magnetometers

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Optically pumped magnetometers (OPMs) represent a potential metrological sensor for the low magnetic field range [1,2]. OPMs employ the magnetic resonance of alkali atoms such as Rb, Cs and K. Miniaturized OPMs using ^{87}Rb have been recently developed using silicon microfabrication techniques [3]. Such devices, with small sensing volumes (sub-mm size) and sensitivities in the range of a few pT/Hz$^{1/2}$, are attractive for the sensing of small magnetic field variations in different context such as space exploration and biological sensing [4,5]. However, the metrological possibilities of miniaturized OPMs have not been investigated in detail yet. From the metrological point of view, any experiment which is traceable to the fundamental constants corresponds to an appropriate realization of the measurement unit. For the magnetic field, indirect methods are commonly used. The traceability is achieved either through electric current (by a known coil system) or through frequency (by using the gyromagnetic constant of a well-known substance, such as the water proton) [6]. In this paper we present a setup developed for the characterization of OPMs in a traceable vector magnetic field. The setup is composed by: i) a triaxial Helmholtz coil system providing a maximum magnetic field of 100 μT with homogeneity of 10^{-5} in a region of linear size of 100 mm; ii) a computer controlled system able to adjust the magnetic field at a desired value within 1 nT of fluctuations, and iii) a proton precession magnetometer (with sensing size of 100 mm) able to detect traceable values of the magnetic field with resolution of 0.1 nT. The results obtained will be helpful to assess the performances of a traceable magnetic field sensor of sub-mm size in the low magnetic field range (< 100 μT) which is currently not available.

Acknowledgements

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Alignment and calibration of magnetometer suite using geomagnetic storms

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Arrays of magnetic sensors are used in the TEM (Time domain electromagnetics) magnetic method of geophysical surveys for mineral exploration, including vectorial magnetometers e.g. fluxgates and SQUIDs [1]. For successful data analysis, sensors need to be aligned to a common coordinate frame.

During deployment the engineer's choice would be to align calibrated sensors horizontally and rotate the Y component to local geomagnetic East (h=0 nT). However, the procedure is tedious and unreliable for sensors with large offset uncertainty/drift. The flux-locked-loop SQUID [2] exhibits low noise but is a relative instrument - its offset is arbitrary, thus fine alignment using geomagnetic East is impossible; it is also difficult to rotate the sensors in the dewar or the dewar itself. Another low-noise vectorial sensor is the fundamental-mode orthogonal fluxgate [3], with a large offset up to 100's of nT and a temperature coefficient of several nT/K – eastward alignment would result in several degrees of uncertainty. During a high solar activity period it is possible to use geomagnetic storms for numerical alignment to correct initial arbitrary attitude and imperfect calibration. Our preliminary results [4] showed numerical alignment of SQUID data using the geomagnetic storm of 10-12 May 2024.

In this contribution we present the procedure and results of alignment and fine calibration of a suite of three co-located magnetometers using data from five geomagnetic storms within 18 months, and we analyze the stability of the numerical alignment. The following devices were used in this study: a second-harmonic race-track fluxgate (CTU-Vario), a fundamental-mode orthogonal fluxgate (FMOF) and a dual-axis, high-temperature SQUID (StarCryo/FZ Jülich). Data from the on-site HER Observatory fluxgate magnetometer (FGM-2, DTU Space) in geodetic frame (XYZ) served as a reference.

We propose our method for fine in-field calibration and orientation of sensor arrays during high solar activity period. Fig.1a shows alignment residuals when the May '24 storm matrix was applied to the January '26 storm – below ±5 nT for all sensors. Fig. 1b shows sensor declination calculated from the May '24 matrix for all storms - the SQUID was 6° off; seasonal changes are due to temperature drift.

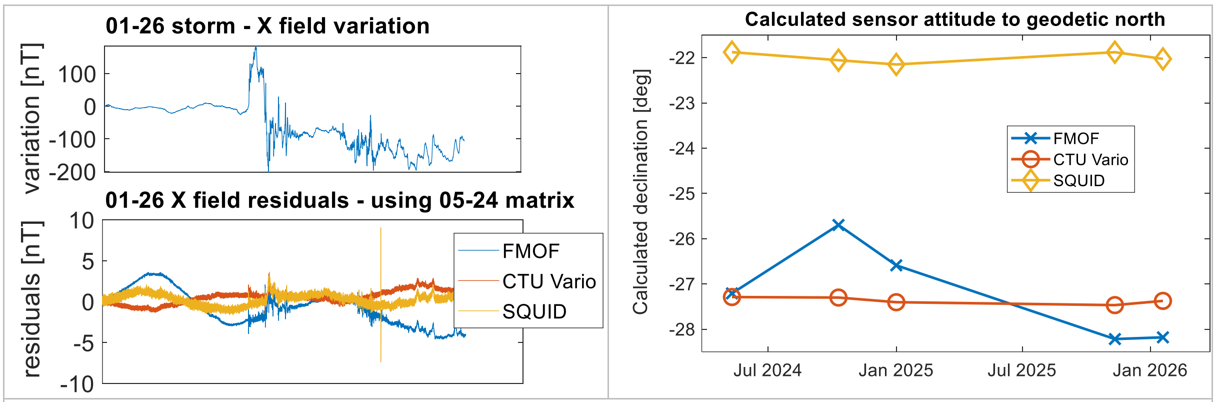

Fig. 1 (a) residuals – Jan '26 storm with May '24 matrix **(b)** attitude to geodetic north - declination

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Decoherence Spectroscopy of Spin Waves in van der Waals Antiferromagnets

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The advent of two-dimensional magnetic van der Waals (vdW) materials have expanded the boundaries of nano-magnetism and led to novel ideas for information transfer in the field of spintronics [1]. By probing the intrinsic layer-dependent magnetic phases, it is possible to gain insight into the spin structure and dynamics [2]. We are interested in CrSBr, a layered anti-ferromagnet with intralayer ferromagnetic (FM) and interlayer anti-ferromagnetic (AFM) coupling [3]. Using our cryogenic scanning Nitrogen-vacancy (NV) magnetometer [4] we demonstrate a novel method of lateral exchange bias (LEB) to control the Neél vector, which is the primary order parameter in antiferromagnets. Using this technique, we are able to engineer different orientations of the Neél vector to controllably write domain walls (DWs) in the AFM bilayer [5] as demonstrated in Fig-1.

Furthermore, by using NV-based decoherence spectroscopy, we show the presence of spin waves localized at the domain wall. In particular, we observe that the NV spin exhibits increased decoherence as it approaches the DW. Our measurements provide direct insight to the dynamical degrees of freedom associated to the DW motion, and ultimately towards controlled driving of the DW motion in two-dimensional antiferromagnets.

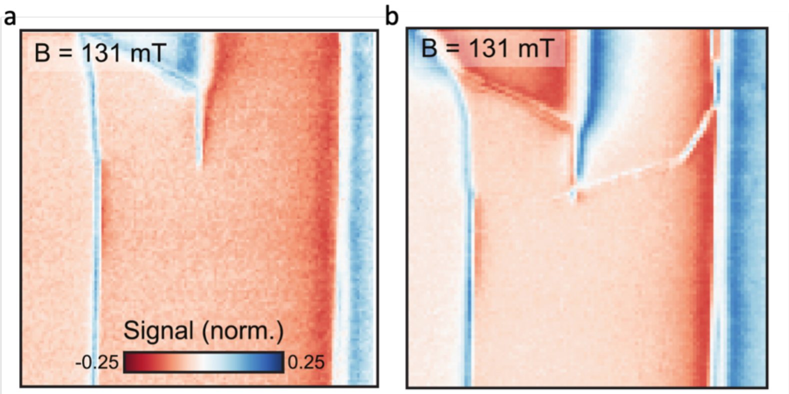

Fig. 1 By reversing the direction of magnetization in the control layer (3-Layer) with respect to the pinning layer (7-layer), we can imprint antiferromagnetic domain walls into the bilayer. **a.** No Domain Wall (DW) since the control and pinning layer are oriented in the same direction. **b.** Control and pinning layer are oriented in opposite directions, leading to the appearance of a DW via lateral exchange bias (LEB).

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Amorphous Bistable Microwire Sensor for Uniaxial Oscillations with Ultra-Low-Power Electronics

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Amorphous bistable glass-coated microwires exhibit fast magnetization switching between two stable states (M^+, M^-) driven by domain-wall propagation along the wire axis. Owing to their positive magnetostriction, the switching field is strongly modulated by axial mechanical stress, enabling highly sensitive magnetoelastic sensing. This property makes bistable microwires attractive for detecting dynamic mechanical phenomena such as vibration and oscillatory motion [1].

This paper presents the use of a bistable $Fe_{76}Si_9B_{10}P_5$ microwire as a magnetic sensor for uniaxial mechanical oscillations derived from the principle of a linear position sensor with resolution down to 10 µm. Mechanical vibration applied along the wire axis produces a periodic modulation of the switching field, which is evaluated through time-domain detection of domain-wall propagation events. This approach enables direct measurement of oscillatory motion over a wide frequency range from units of hertz up to the kilohertz range, depending on excitation conditions and signal processing that may be configured by controlling microcontroller.

The experimental setup uses a bistable microwire with a 26 µm metallic core and 61 µm total diameter, excited by a 20 mm long bifilar coil (245 turns, 1 mm diameter) [2]. The bifilar configuration enables unipolar excitation and simplifies the sensor electronics. Signal generation and time-resolved evaluation of switching events are implemented using an STM32G474RE mixed-signal microcontroller optimized for high-precision analog timing measurements.

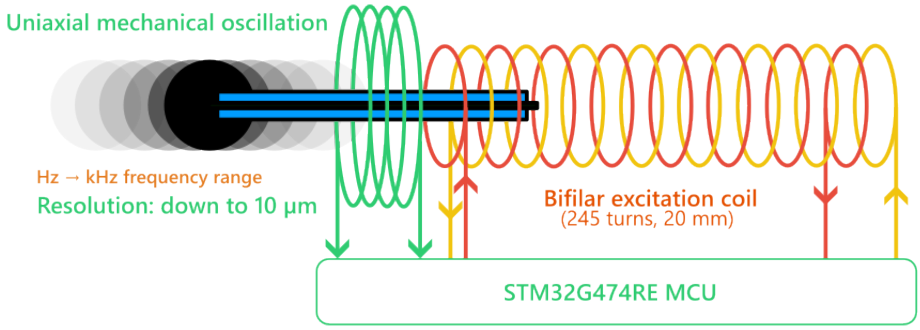

Fig. 1 Uniaxial mechanical oscillations measurement based on a bistable microwire with a bifilar excitation coil

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Offset Optimization of Orthogonal Fluxgate with Multiple Microwires

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Orthogonal fluxgates based on magnetic microwires operating in the fundamental mode often exhibit large magnetic offset and offset drift. The suppression techniques introduce additional sources of noise, creating the need for sensors with low inherent offset. Such magnetometers often employ an array of magnetic microwires connected in series, where the total magnetometer offset is given by the sum of individual offsets, which cannot be reliably measured in advance as the process of magnetic microwire soldering affects the offset due to heat and stress. Subsequent manual rotation of individual microwires to compensate for these offsets is also not practical for the same reasons.

We present a simple method for optimizing the total magnetometer offset by introducing a contact matrix that allows interconnections of individual microwires to be changed, as the offset sign can be flipped by the change of the excitation current DC bias polarity [1]. While the final implementation will use solder bridges at each end of the holder, electronic analog switches are used to speed up the optimization process. The four microwires connected in series without additional return paths allow 24 permutations that alter each microwire direction and order in the array. Since the connection order does not affect the total offset, there are only six unique direction states. The addition of return paths and extra switches allows direction states with all four wires in one direction and intermediate three-and-one variants. This further expands the optimization space but increases the switch matrix complexity.

The total magnetometer offset is measured for different direction states and the whole problem can be solved as a system of linear equations with $o_{total} = s_1o_1+s_2o_2+s_3o_3+s_4o_4+o_5$. The figure below shows an example of a microwire array with a total offset of –60 nT in the worst-case configuration and possible optimization down to +3 nT. The extra benefit is the offset value of each individual microwire in the given array, which can be used to track single defective microwires that would spoil the whole array otherwise. Furthermore, this method can be used to reduce overall magnetometer offset drift in multi-microwire array magnetometers, which is further studied in our contribution.

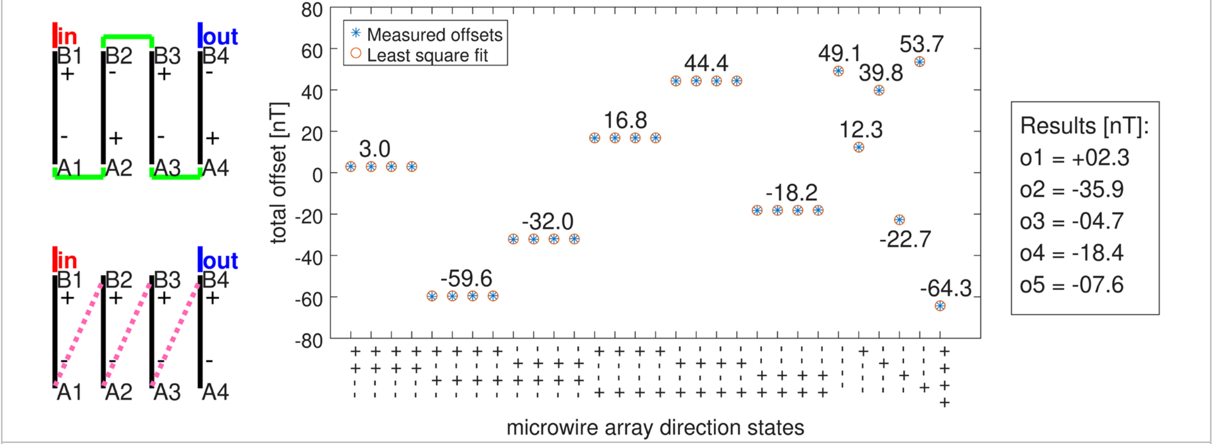

Fig. 1 Simplified microwires interconnection diagram (solid color switches can swap positions; dotted is fixed switch) and the example measurement results with sorted direction states.

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Time-Domain Fluxgate-Based Active Magnetic Field Cancellation in a Braunbek Coil System

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In this work the design and preliminary evaluation of a field cancellation technique based on the reading of a time-domain fluxgate magnetometer is presented. The sensor uses a periodically excited soft magnetic core and extracts the external field information from the asymmetries in the saturation timing of the pick-up coil signal [1]. This signal is converted into a digital waveform via a hysteretic comparator that allows for robust pulse duration determination. The output of the sensor is then fed into a closed loop system which employs Braunbek coils to actively cancel the magnetic field across one axis [2]. This study also examines the effects of different treatments of the fluxgate sensor's core and different fluxgate topologies on active field compensation outcomes. The proposed technique can be used for magnetic field compensation inside the uniform field area of the given coil system, potentially serving as a laboratory primary standard.

Acknowledgements

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Disclaimer: Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

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Investigation of the 3D Spatial Response of Planar Hall Magnetoresistance Sensors

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The analysis of the spatial response of a vector magnetic sensor using gradient, for example, is a key aspect for applications involving the detection and localization of magnetic sources. Theoretically, the measurements performed with this type of sensor introduce an angular dependence of the magnetic field following a $cos(\theta)$ law with respect to its sensitivity axis. In this context, we have investigated the spatial response of Planar Hall MagnetoResistance (PHMR) sensors.

To characterize this response, a homogeneous, spherical, and rotating magnetic field was applied to the PHMR sensors. In parallel, the magnetic field induced by the setup was measured using a triaxial magnetometer, a Fluxgate (Fig. 1a - *Red sphere*). The far-field pattern (*or homogenous magnetic field response*) associated with the fluxgate measurement exhibits a quasi-ideal spherical shape.
The PHMR sensor was then aligned with the *Z*-axis of the spherical field, allowing the observation of its normalized spatial response (Fig. 1a – *Double Green sphere*). The shape of this response confirms the vector nature of the PHMR sensor.

Comparing the measured response with the ideal response makes it possible to evaluate the system's limitations by visualizing the intrinsic accuracy of the setup, which can be interpreted as a measurement error (Fig. 1b). This representation of the error, which can be characterized as common mode, opens new metrological perspectives for the spatial characterization of vector magnetic sensors and spatial filtering.

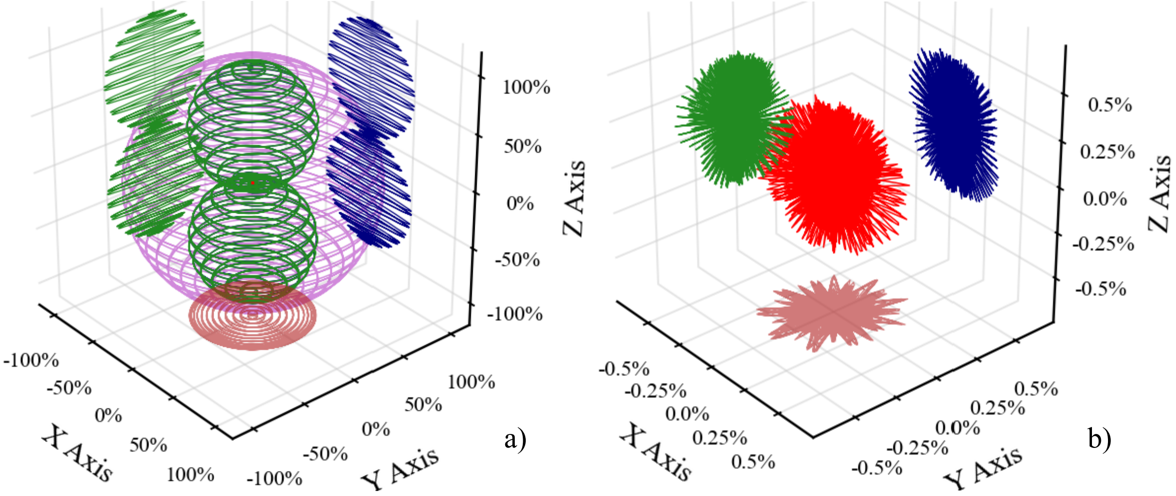

Fig. 1: a) Applied rotating spherical magnetic field measured by a reference fluxgate (light purple), measured PHMR spatial response (green) with projections onto the principal planes (blue, green, firebrick) and resulting measurement error (red). **b)** Zoomed view of the measurement error, with projection onto the principal planes (*XY*, *XZ*, and *YZ*).

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Finite element modeling of magnetoactive polymer composites for the flux control of microfluidic systems

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Magnetoactive polymer composites have received significant attention in the last years due to their rapid and reversible response to external magnetic fields. By incorporating magnetic nanoparticles into an elastomeric matrix, they can exhibit unique properties under the application of static or alternating magnetic fields. One of the particularly interesting applications proposed is the integration of the composites in microfluidic systems, aimed at the development of magnetically actuated valves and peristaltic pumps [1].

In this work we develop a finite element model of a thermoplastic polyurethane (TPU) composite strip with different concentrations of cobalt ferrite ($CoFe_2O_4$) magnetic nanoparticles, based on the samples used in [1], and simulate its mechanical response to the presence of a magnet. The model, based on Comsol Multiphysics, includes all the relevant parameters of the physical system, such as the mechanical behavior of the sample, as well as the geometry and magnetic characteristics of both the magnet and the composite strip, allowing to study the elastic deformation experienced by the sample.

The output of the finite element simulations (Fig. 1, left) is compared to the experimental results obtained on the real sample (Fig. 1, right). Moreover, the flexibility provided by the model will allow us to explore and propose alternative physical configurations that can optimize the mechanical response of the composite.

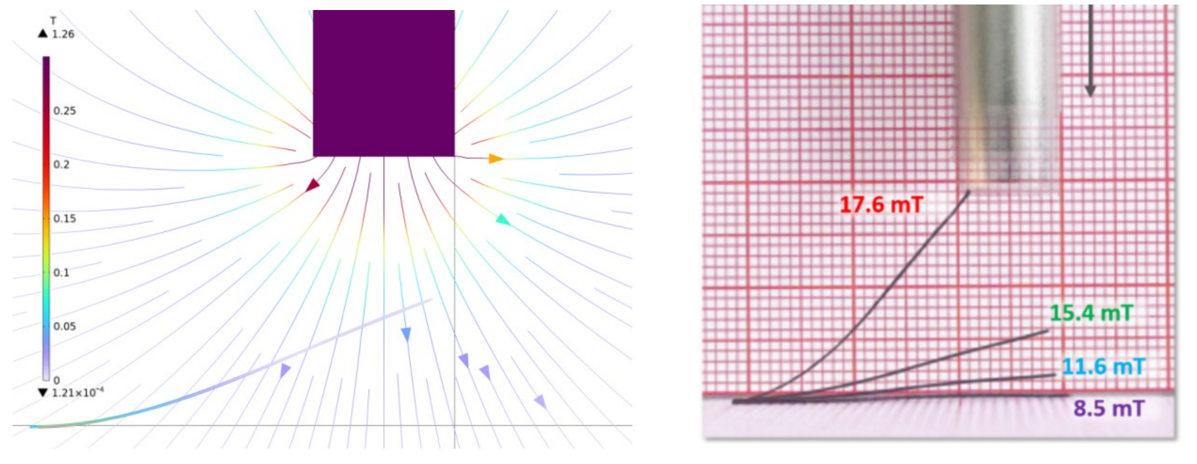

Fig. 1: Elastic deformation of the composite strip in the presence of a magnet bar: finite element simulations (left) and experimental results (right).

Acknowledgements
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Poster P27
9. Modeling & Simulation

Study on Demagnetization of Complex Structures for Space Applications

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Demagnetization of satellite components, entire spacecraft, and other space hardware is often necessary. Failure to perform demagnetization can lead to navigation issues or degrade the scientific performance of a mission. The current standard ESA procedure for demagnetization is described in the ECSS-E-ST-20-07C document (which generally addresses electromagnetic compatibility), specifically in Section 5.4.5 DC Magnetic Field Emission, Magnetic Moment. The deperming procedure consists of applying an alternating magnetic field (2.5–5 Hz) with a peak amplitude of approximately ±5 mT. The field amplitude is increased to this value at a rate of 2% and subsequently decreased at a rate of 1%, and the process is performed sequentially for all three axes.

The goal of the current ESA-funded research is to investigate whether modifications to this procedure could improve the residual magnetic moment of the EUT (Equipment Under Test), preferably while using the existing ESA deperming laboratory equipment. Experience from other fields—such as paleomagnetism (demagnetization of rock samples) [1], military applications (demagnetization of large structures), and other sources (e.g., NASA)—will first be reviewed and tested on small-scale samples, and later validated using demonstrators such as CubeSat-class spacecraft.

Currently, we are experimenting with the demagnetization of small samples (e.g., a D-SUB9 connector) and comparing the effects of a procedure similar to the current ESA method with an alternative approach in which the sample undergoes continuous rotation (simultaneously about all three axes) while entering and leaving a solenoid coil. The non-magnetic mechanism used to rotate the sample is shown in Fig. 1. It forms part of a system for measuring the magnetic moment of small samples using fluxgate sensors. These sensors were removed during the demagnetization procedure to allow the rotating head to fit inside the available solenoid coil (117 mm inner diameter). The magnetic moment of a standard D-SUB9 connector after magnetization in an electromagnet was m_m=1.94 mA/m^2 along its long axis (Y in Fig. 1). After demagnetization (50 mTp-p), the residual magnetic moments were 0.29 mA/m^2 for the standard method and 0.1 mA/m^2 for the rotating-sample method. Further work will investigate the influence of the demagnetizing field magnitude, frequency, and overall configuration for more complex samples, using both experiments and simulations.

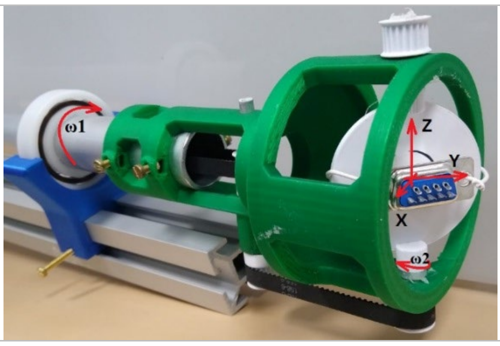

Fig. 1 Non-magnetic platform for 3D rotation of a sample.

Acknowledgements
Further research presented in this abstract will be supported by European Space Agency (ESA) project "Advanced Demagnetisation Methods".

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Micromagnetic study of buffer layer effect in SOT-enabled single-element magnetic sensors

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Magnetic field sensors are key in automotive, industrial, robotics, and biomedical applications. In positioning or mapping, determining the three components of the magnetic field can yield relevant additional information and improve the measurement accuracy[1]. Current strategies for three-dimensional magnetic sensors rely on discrete assembly, local laser annealing, or multiple thin-film depositions [2], which present limitations in terms of cross-sensitivity and spatial offset, as different elements are used for measurements along different field directions. Spin-orbit torque (SOT)-enabled magnetic field sensors have emerged as an alternative for measuring the magnetic field vector in a single element [3]. This sensing element consists of a heavy metal (HM)/ ferromagnet (FM) / MgO multilayer with perpendicular magnetic anisotropy patterned into a Hall cross shape [3]. Under a critical current (J_c) the change of the out-of-plane component of the magnetization is linear with the applied magnetic field ($m_z(H)$). This linear behavior is observed for both H perpendicular to the plane and parallel to the applied current. Using a combination of the anomalous Hall effect resistance measurements under positive and negative current, the magnitude of the different H components can be extracted [4].

In this work, we implement a micromagnetic modeling framework to address the impact of using different HM in the linear range (ΔH) of $m_z(H)$. Changing HM also alters the interfacial magnetic anisotropy (K_i) and the spin-Hall angle (θ_{SH}). K_i arises from the FM/MgO interface but also from the crystallographic mismatch at the HM/FM interface and the better ability of some HMs to absorb B, hence increasing the amount of Fe/O hybridization [5]. This systematic study addresses the impact of θ_{SH} and K_i in ΔH towards delivering the optimal range for J_c.We will also address the evolution of the domain structures to deliver the best material configurations for devices with larger ΔH. These results are another step towards delivering competitive SOT based sensors.

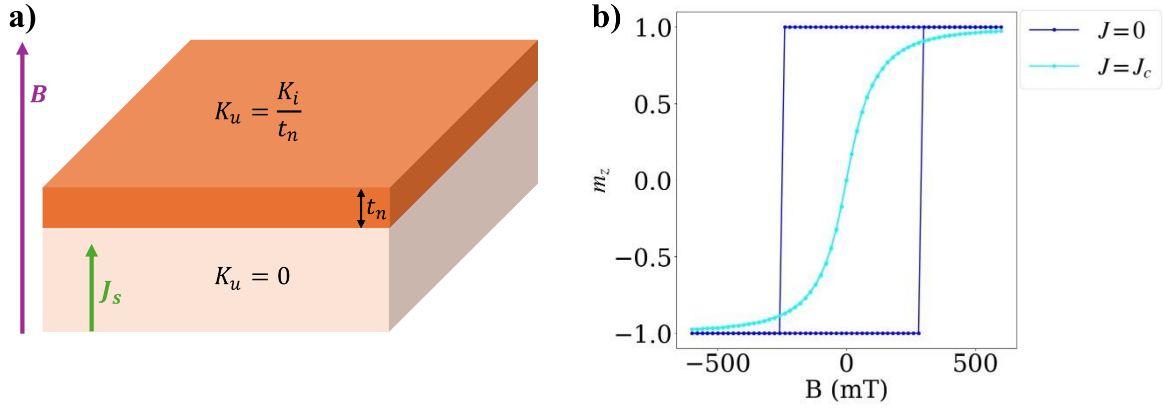

Fig. 1 - **a)** Schematic of the simulation case with implementation of K_i and **b)** Simulated $m_z(B)$ with linearization via current.

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Stack-Driven Switching Field Engineering in Bottom-Pinned Perpendicular Magnetic Tunnel Junctions

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Perpendicular magnetic tunnel junctions (pMTJs) are highly attractive for magnetic field sensor applications due to their large tunnelling magnetoresistance (TMR), scalability, and thermal stability. For reliable sensor operation, a well-controlled separation between the effective switching thresholds of the free and reference layers is required to define a stable operating window, minimise offset fields, and ensure robust response characteristics. In bottom-pinned stacks, however, magnetostatic fringe fields originating from synthetic antiferromagnetic (SAF) reference layers can act as an effective bias field on the free layer, modifying its energy landscape and inducing asymmetric switching behaviour [1]. Furthermore, insufficient SAF exchange coupling may lead to unintended reference-layer reversal below the free-layer coercivity, thereby compromising device stability and accuracy [2]. These effects highlight the importance of precise reference stack engineering for sensor optimisation.

In this work, we investigate switching field control in bottom-pinned CoFeB/MgO pMTJ stacks by systematically tuning the SAF reference layer design and spacer coupling. The multilayer stacks were deposited using the high-precision industrial sputtering cluster tool, Singulus Rotaris, enabling sub-nanometre thickness control and excellent interface reproducibility—key parameters for reliable SAF balancing and minimised stray-field bias.

Magnetometry measurements demonstrate that tailored SAF coupling enhances reference layer stability and allows controlled adjustment of the free-layer switching field while preserving high perpendicular magnetic anisotropy and large TMR ratios. The improved switching field margin directly translates into reduced offset fields and enhanced operational robustness, both critical for high-sensitivity and low-noise magnetic sensing.

These results highlight how precise multilayer deposition and targeted stack engineering provide a pathway toward highly stable and tunable pMTJ-based magnetic sensors suitable for advanced detection applications.

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Effect of RAM Mixing Duration on Transport and Magnetic Properties of Fe-Al Soft Magnetic Compacted Powder Cores

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Soft magnetic materials are essential in a wide range of technologies, including motors, sensors, actuators, inductors, power transformers, and microelectronics [1]. While traditional laminated steels provide low hysteresis losses and high permeability, their use is typically limited to two-dimensional magnetic flux paths. In contrast, soft magnetic powder cores fabricated via powder metallurgy enable complex three-dimensional magnetic designs, offering potential for miniaturization, efficiency enhancement, and novel electrical machine topologies [2]. Moreover, powder metallurgy allows net-shape production, reducing machining requirements, material waste, labor, and energy consumption compared to layered electromagnetic steels [3]. To fully utilize these advantages, optimization of the magnetic properties in the compacts is required. These properties depend on multiple factors, including the composition and nature of the starting powders, mechanical mixing and milling parameters, compaction pressure, and annealing conditions [4].

In this study, Fe + 3 wt.% Al powders were mixed in a resonant acoustic mixing (RAM) mixer for durations ranging from 15 min to 48 h in order to study the influence of mixing time on particle interaction and structural development. The mixed powders were subsequently compacted under a pressure of 2 GPa into cylindrical tablet-shaped samples with a diameter of 10 mm.

Temperature-dependent electrical resistivity (up to 750°C) and thermal diffusivity (up to 775°C) were measured to evaluate transport properties and to provide indirect insight into structural evolution during heating.

Based on the observed temperature dependencies, hypotheses regarding material's structural and compositional changes were proposed. These assumptions were verified using scanning electron microscopy (SEM) and SEM-EDX analysis performed on powder and compacted samples, allowing direct observation of particle morphology and elemental distribution.

Guided by the resistivity and diffusivity results, additional heat treatments were carried out in Ar atmosphere at 600 °C, 650 °C, and 700 °C. The influence of annealing on magnetic behavior was subsequently evaluated. Ring-shaped samples with a rectangular cross-section were prepared for magnetic characterization. Measurements of complex relative permeability allowed determination of the permeability cut-off frequency, while coercivity measurements showed that the RAM mixing process does not significantly affect the magnetic softness of compacts across the investigated mixing durations.

This study provides a comprehensive experimental framework linking processing parameters with structure–property relationships in RAM mixed Fe–Al systems and contributes to the optimization of soft magnetic materials prepared via powder metallurgy routes.

Acknowledgements

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Composition-Driven Enhancement of Magnetostriction and Thermal Stability in $Co_2FeAl_xSi_{1-x}$ Heusler Alloys

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Enhancing the magnetostriction and thermal stability of magnetostrictive materials is essential for magnetic sensor and actuator applications. Co-based Heusler alloys offer a unique platform due to their high Curie temperatures and tunable electronic structures[1, 2]. In this work, we investigate the composition-dependent magnetoelastic response of $Co_2FeAl_xSi_{1-x}$ (x = 0-1) alloys by combining first-principles calculations and magnetostrictive measurements.

With increasing Al content, the crystal structure gradually transforms from the ordered $L2_1$ phase to B2 disorder. Intermediate compositions (x ≈ 0.25-0.5) exhibit an $L2_1$/B2 mixed state accompanied by reduced cubic symmetry and local lattice distortion. This moderate disorder leads to a pronounced enhancement of the saturation magnetostriction, reaching ~30 ppm at room temperature[3].

Electronic structure calculations reveal that Al/Si substitution continuously shifts the Fermi level within the minority-spin pseudogap. When the Fermi level is located near the center of the pseudogap (x ≈ 0.5), both the spin polarization and the calculated magnetostriction coefficient (λ_{001}) reach their maxima.

Temperature-dependent measurements (80-300 K) show that the magnetostriction follows the Bloch $T^{3/2}$ law[4], indicating that spin-wave excitation dominates the thermal decay behavior. The intermediate compositions exhibit the smallest decay coefficient, demonstrating enhanced magnetoelastic stability associated with improved electronic robustness.

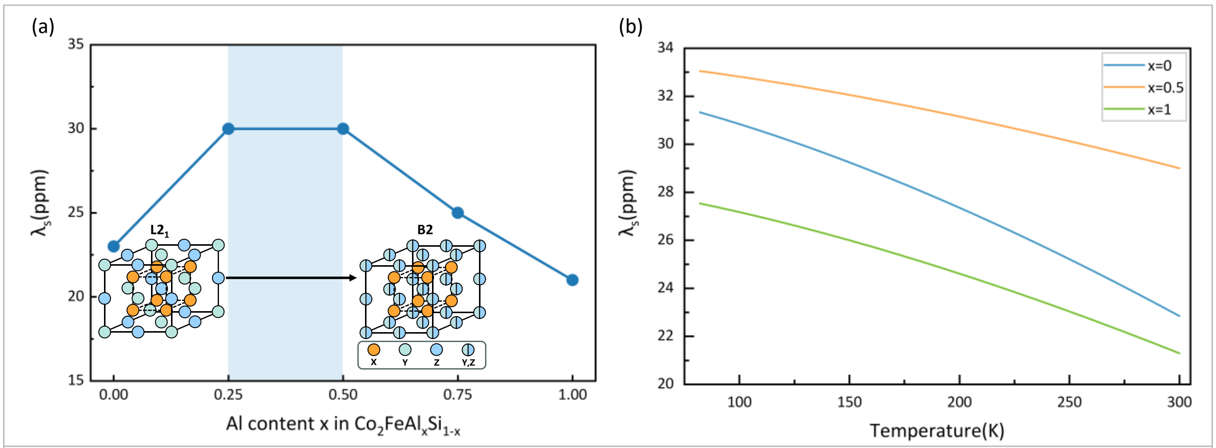

Fig. 1 (a) Room-temperature saturation magnetostriction λ_s versus x, showing a maximum (~30 ppm) in the intermediate compositions. (b) Temperature dependence of λ_s (80-300 K) with Bloch $T^{3/2}$ fitting.

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Reversible Tuning of Magnetic Anisotropy in Stress-Annealed FINEMET Wires for Multi-Mode Sensors

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Nanocrystalline FINEMET alloys are renowned for their superior soft magnetic properties, typically achieved through stress-free annealing [1]. However, specific sensing applications require tailored anisotropy rather than maximum permeability. While stress annealing is a known method to induce such anisotropy, the reversibility of this induced state in FINEMET nanocrystalline wires has not been fully explored.

Here, we investigate the reversibility of magnetic anisotropy induced by stress annealing in Fe-based nanocrystalline FINEMET wires (nominal composition $Fe_{73.5}Cu_{1}Nb_{3}Si_{13.5}B_{9}$) with a diameter of 118 μm. We demonstrate that stress annealing at 550°C for 1 hour under a tensile stress of about 27 MPa (produced by a 30 g mass) induces a significant transverse anisotropy, as evidenced by the linear hysteresis loop with low remanence and coercivity shown in Fig. 1 below (green curve).

The main result is that this induced anisotropy is completely reversible. Subsequent stress-free thermal relaxation at the same temperatures fully restores the ultra-soft magnetic behavior characteristic of the standard nanocrystalline state (square loop), as illustrated by the cyan curve in Fig. 1.

Such reversible tunability offers a route for developing resettable or multi-mode magnetic sensors using FINEMET wires, allowing them to switch between a highly linear sensor mode and a high-sensitivity switch mode. This capability enables the development of advanced sensors that can be recalibrated or repurposed in-situ, offering significant advantages for precision devices.

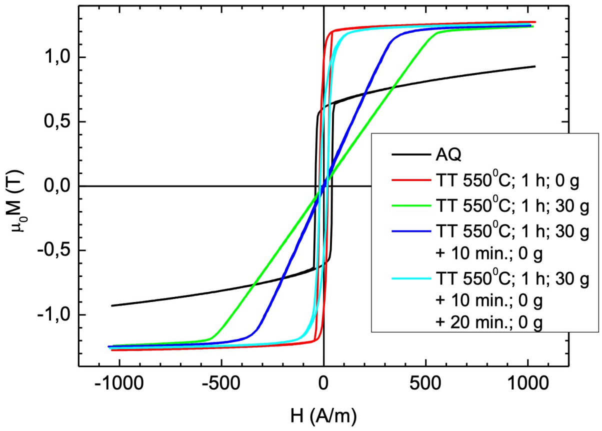

Fig. 1 Magnetic hysteresis of as-quenched amorphous FINEMET wire with 118 μm in diameter (AQ-black), as well as after conventional annealing (red) and stress annealing (green) at 550°C for 1 h. Subsequent stress-free relaxation annealing has been performed on the stress annealed sample (blue and cyan curves, respectively).

Acknowledgements

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Integration of Magnetic Nanofibers with Permalloy Thin Films and Sensing Applications

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Controlling the anisotropy of magnetic thin films is one of the key factors in the microfabrication of magnetic sensors with suitable properties for desired applications. Surface and interface anisotropy occurs at the free surface or at the junction between two materials, like ferromagnetic/antiferromagnetic layers. In [1], were integrated magnetically assembled iron oxide nanoparticle coatings with pseudo-spin-valve thin films to enhance spintronic device performance due to magnetic interactions between the nanoparticles and the underlying film.

In this study we used polymer nanofibers, doped with Fe_2O_3/NiO nanoparticles, deposited by electrospinning [2] on thin Permalloy disks, with a diameter of 1 mm and a thickness of 20 nm. For this geometry there is no uniaxial anisotropy axis which is beneficial to demonstrate the effect of magnetic interaction between magnetic nanofibers and Permalloy thin film. The polymer was a mix of Chitosan (CS) and Polyvinyl alcohol (PVA). The magnetic nanoparticles, with a mean diameter of 50 nm, were added in a concentration of 1 mg/mL. For electrospinning was used the E-FIBER EF100 machine. A magnetic field of 200 Oe was applied during the deposition to obtain aligned nanofibers on the Permalloy disks. Through SEM measurements we found well aligned nanofibers with lengths ranging from 10 to 20 µm and a mean diameter of about 197 nm.

The effect of interaction between magnetic nanofibers and Permalloy thin film was evaluated through anisotropic magnetoresistance (AMR) effect measurements using a planar Hall effect (PHE) setup, as shown in Fig. 1(a). Figures 1(a) and 1(b) present the field dependencies of the measured signal with *H* applied parallel and perpendicular to the main direction of the nanofibers, which is assumed to be an induced easy axis of magnetization. The study also examines other magnetic field orientations. Finally, we demonstrate magnetic field sensing applications using a differential PHE sensor setup.

This study demonstrates that magnetic nanofibers can effectively control the detection characteristics of magnetic sensors by inducing a well-defined anisotropy axis within their layers.

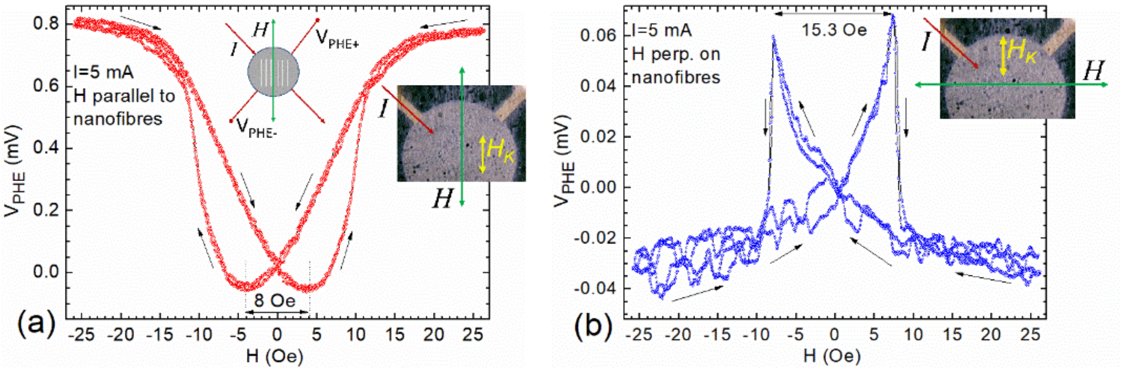

Fig. 1. The field dependencies of the measured signal when (a) H is applied parallel and (b) perpendicular to the main direction of the nanofibers; the insets show the measurement setup.

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Real-Time Magnetic Field Sensing Using Planar Hall Magnetoresistance (PHMR) Sensor Integrated on a Robotic Arm

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Magnetic thin-film sensors offer a promising approach for high-sensitivity and real-time field detection in dynamic environments. In this work, a planar Hall magnetoresistance (PHMR) sensor [1] is integrated onto a robotic arm to measure three-axis magnetic field components (X_1, Y_1, Z_1) during motion.

The sensor exhibits stable signals under static conditions and clear variations when the robotic arm moves. As shown in Fig. 1, the Z_1 component displays a strong transient response, while X_1 and Y_1 show moderate changes, indicating directional sensitivity. Notably, the measurements are performed without any external magnetic source, demonstrating the ability of the PHMR sensor to capture motion-induced variations in the ambient magnetic field.

The observed performance is attributed to the optimized thin-film structure, where interface engineering and thickness tuning play a critical role in enhancing sensitivity and minimizing noise. Additionally, the integration of low-noise signal conditioning electronics ensures reliable data acquisition under real-time operating conditions. These results highlight the potential of PHMR-based sensors for compact, high-performance magnetic sensing in dynamic systems.

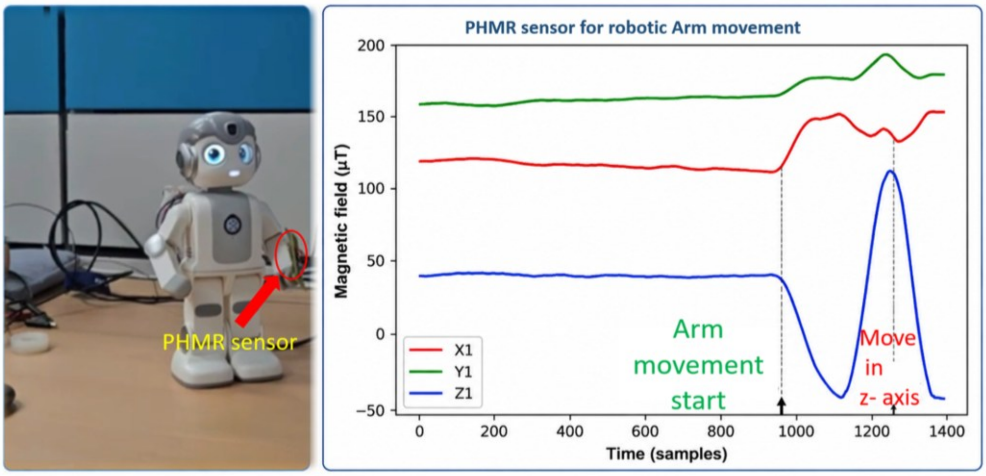

Fig. 1. Magnetic signal measured by PHMR sensor attached to the robotic arm, showing variation in X_1, Y_1, and Z_1 componentes during arm motion.

Acknowledgements
This work was supported by the R&D program of the Ministry of Trade, Industry & Energy, Korea (RS-2023-00236809).

Reference

[1] B. Lim *et al.*, *APL Mater.* 10 (2022) 051108.

Application of Magnetic Microwires for Stress Sensing in Conveyor Belt Adhesive Joints

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This study investigates the application of magnetic microwires as sensors for monitoring mechanical stress within the adhesive joints of conveyor belts. The primary motivation for this research is to optimize the service intervals of conveyor belts, thereby preventing costly repairs. In this experiment, a magnetic microwire was embedded directly into an adhesive joint (see Fig. 1). The test specimen was subsequently subjected to axial tensile loading up to an elongation of 5 mm. During the loading process, the switching time of the Barkhausen jump within the microwire was recorded.

The results demonstrate the feasibility of stress sensing in conveyor belt adhesive joints. In the graphs shown in Fig. 2, an increasing value of arb. units, representing the domain wall switching time, can be observed. This value increases alongside the load applied to the microwire and subsequently decreases proportionally. Furthermore, a certain degree of hysteresis can be observed in the resulting graphs, which is attributed to the imperfect clamping of the sample in the measuring system. Due to the miniature dimensions of the microwire and its capability for localized measurement, it is possible to detect the formation of cracks or other defects in its vicinity that could compromise the structural integrity of the bonded joint.

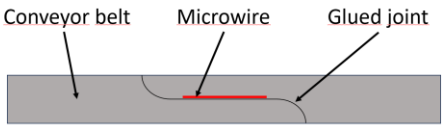

Fig. 1 Placement of the magnetic microwire sensor within the glued joint.

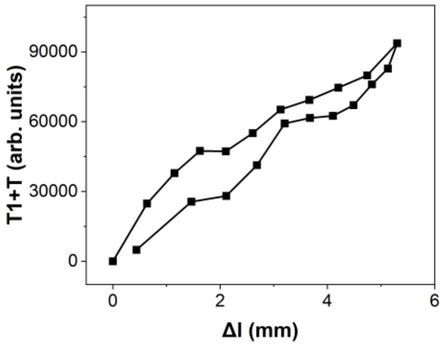

Fig. 2 Switching time of the Barkhausen jump as a function of elongation.

Acknowledgements
This work is a part of these projects APVV - 21-0195, VEGA 1/0674/24, VEGA 1/0488/23, KEGA 001TUKE-4/2025, KEGA 009STU-4/2025.

Part 5

Satellite workshop

Satellite Workshop

Developing Standards in Magnetics: IEEE Magnetics Society and IEEE Standards Association Workshop

Theme 1: Standardizing Sensors

Magnetic sensing and actuation technologies are rapidly advancing across automotive, industrial, biomedical, MEMS, and emerging quantum applications. However, progress toward large-scale deployment and certification is often hindered by inconsistent measurement protocols, limited reference materials, and fragmented reporting standards. MSSROAD2030 aims to bridge the EMSA research community with metrology institutes, industry leaders, and standardization bodies to:

1. Identify urgent gaps in measurement, interfaces, materials, and system integration
2. Define concrete standardization priorities
3. Establish a working roadmap toward ISO, CEN, and EURAMET initiatives

Support

This workshop is sponsored by the **IEEE Standards Association (IEEE SA)** and organized by the IEEE Magnetic Society Standards Committee – Technical Subcommittee on Sensors, Communications, Instrumentation, and Measurement.

About IEEE Standards Association (IEEE SA)

The IEEE Standards Association develops global consensus standards that drive innovation, interoperability, and trust across technologies. Within the IEEE Magnetics community, the Standards Committee supports initiatives related to measurement protocols, materials characterization, sensor interfaces, and system-level validation.

More information:
https://standards.ieee.org
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IEEE SA STANDARDS ASSOCIATION

IEEE MAGNETICS

From laboratory methods to standardization: lessons from microfluidics for magnetic sensor systems.

Vania Silverio

INESC-MN, Lisboa, Portugal
Department of Physics, Instituto Superior Técnico, Universidade de Lisboa, Portugal
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This talk draws on my experience leading ISO standardization efforts in microfluidics to illustrate how laboratory methods mature into internationally recognized standards. I will discuss governance structures, stakeholder engagement, and roadmap development, highlighting parallels and transferable strategies for magnetic sensing systems. Particular attention will be given to traceability, inter-laboratory comparisons, and aligning academic innovation with industrial and regulatory needs.

Micromagnets, magnetic sensors and magnetic position systems: design, fabrication, integration, and standardization challenges in magnetic microsystem applications

Stefano Lumetti

Silicon Austria Labs GmbH, Europastraße 12, 9524 Villach/St. Magdalen, Austria
stefano.lumetti@silicon-austria.com

The development of magnetic microsystems relies on precise fabrication, advanced characterization, and integration of magnetic materials and devices. This talk presents current R&D activities at Silicon Austria Labs on micromagnets, AMR sensors, and magnetic position systems, highlighting key technical challenges encountered in practice. It further tries to identify critical standardization gaps and discuss their impact on magnetic microsystem technology development and industrial uptake.

Magnetic characterization at the nanoscale

Paola Tiberto

Advanced Materials and Life Sciences Division, INRIM, Torino, Italy
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Highlighting both the key challenges and the reliability of current measurement methodologies, particularly in the context of advanced materials and nanomagnetism.

Standardization of magnetic measuring scales for linear and angular position systems: industry perspectives and challenges.

Michael Ortner[1], Jürgen Gerber[2], Rolf Slatter[3]

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[2]*INNOMAG e. V., Germany*
[3]*ITK Precisioning GmbH, Lahnau, Germany*
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In 2022, members of the INNOMAG network developed DIN SPEC 91411 to standardize the technical representation of magnetic measurement scales in design drawings, with an expanded guideline on terminology, classification, and characterization to follow this year. Together, these documents reflect a coordinated industry initiative to harmonize standards for linear and rotary scales used in magnetic encoder systems.

Satellite Workshop

Developing Standards in Magnetics: IEEE Magnetics Society and IEEE Standards Association Workshop

Theme 1: Standardizing Sensors

Parallel Sessions: Group Discussions

Topic 1: Academic & Research Perspectives

Moderators:

Lior Klein, Bar-Ilan University, Israel
Vania Silverio, INESC-MN and Instituto Superior Tecnico, Portugal
Marco Coisson, INRIM, Italy

Topic 2: Materials, Thin Films, Patterning & Reference Structures

Moderators:

W. Li, NIMTE, China
Takahide Kubota, Tohoku University, Japan
Nora Dempsey, University Grenoble Alpes, CNRS, France)

Topic 3: System Integration and Emerging Platforms

Moderators:

Rastislav Varga, RVMagnetics, Slovakia,
Yevhen Zabila, Helmholtz-Zentrum Dresden-Rossendorf, Germany
Stefano Lumetti, Silicon Austria Labs, Austria
Karen M. Dowling, TU Delft, Netherlands

Topic 4: Instrumentation and Electronics

Moderators:

Hadi Heidari, Neuranics, United Kingdom
Helmut Koeck (Infineon Technologies, Austria)
Proloy T. Das Helmholtz-Zentrum Dresden-Rossendorf, Germany
Mahmoud Rasly, Neuranics, United Kingdom

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The XV European Magnetic Sensors and Actuators Conference 2026

Book of Abstracts

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