Highlights

2024

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FOREWORD

We would like to address our warmest wishes to you for 2025, hoping that this year brings you health, success, and happiness for you and your loved ones!

This booklet gathers a selection of scientific highlights of SPINTEC over 2024. Besides these, we mention below a few cornerstones in the life of the laboratory, along with the prospects for SPINTEC in 2025. The scientific highlights in this booklet provide an insight in our key publications, signature for our mission to advance knowledge. In parallel to these, we maintained our high level of production of intellectual property, signature for our mission to contribute to innovation. **Several scientific highlights are described in this booklet covering various aspects of the research conducted in the lab,** namely, *Playing with more topology in quantum electronic circuits, The use of the THz emission as a tool for studying the spintronic properties of 2D materials, a special flavor of synthetic antiferromagnetic skyrmions moving at record speeds, Adjusting and minimizing the dipolar core-shell perpendicular shape anisotropy memory cell, A new altermagnetic material with remarkable properties for spintronics, Using advantageously the thermal noise and binary phase states for data encryption, A new field-free spin-orbit torque switching in Janus chromium dichalcogenides, The development and optimization of large-scale integration of 2D material in memristors, The impact of external magnetic field on spin transfer torque magnetic memory operation, The large chiral orbital texture and orbital Edelstein effect in Co/Al heterostructure, The substrate softness-dependent vortex microdiscs induced cytotoxicity.*

On the projects side, the activity was very rich and successful at different levels (national, European, international and industrial).

We want first to emphasize the key involvement of SPINTEC in the France 2030 PEPR exploratory and acceleration programs: the exploratory PEPR SPIN that we are co-leading, and involvement in three acceleration PEPR: electronics, AI and quantum. This year brought several key events linked to the France 2030 initiative. **First of all, the extended contribution of the lab within the PEPR SPIN** materialized by the organization of the institutional kick-off in Grenoble and at SPINTEC in the MINATEC amphitheater. More than 300 people took part, including Albert Fert, Nobel Prize in Physics for spintronics in 2007, decision-makers and institutional representatives from the national and local level, industrial and academic collaborators and colleagues. A private reception at the Grenoble museum allowed fruitful networking. The event was a great opportunity to organize lab visits and to emphasize the dynamism of the spintronics community. Besides the institutional kick-off, other events contributed to a rich period: scientific technical workshops, international actions with Taiwan and Japan, as well the annual day or the industrial day for the PEPR SPIN. A large number of colleagues were involved at different levels in the coordination and to specific actions: the organization of the open calls, the training part, the international action or the dissemination activities. Several colleagues are participating to the acceleration PEPRs in electronics, AI, quantum. Recently, connections were established with the exploratory PEPRs DIADEM on materials and LUMA on light-matter interactions. In this framework, we took part in the annual day of the PEPR on electronics, the kick-off of the PEPR on Artificial Intelligence, as well as in a workshop on sustainable electronics, co-organized jointly by the PhD program “Numérique Frugal”, the focused project EMCOM and BEP of the PEPR electronics, the focused project “Emergence” of the PEPR IA and the PEPR SPIN.

This year came with the funding of two new **structuring and very ambitious international research programs with Japan**, in the framework of the Top-Scientists program called ASPIRE, with Tokyo and Tohoku Universities, in addition to the existing joint international research lab with Tsukuba University. The kick-off of the project with Tokyo University will be organized in March 2025 in Grenoble. SPINTEC also continues to be an important partner **of the Infrachip European project, implementing the first integrated, distributed research infrastructure as a wider European research platform** for the sustainable development of next-generation and future semiconductor chips, and managed in Grenoble via the FMNT federation.

New strategic and game-changing innovation partnerships also started, which allow us to strengthen our actions and expand our network (Hprobe, Golana Computing, Spin Ion, NY Creates, jointly with LETI, Texas Instruments, LEM, Vertical Compute). **This year we can mention namely the creation of the start-up Nellow, which was also awarded by the BPI prize** (Banque Publique d'Investissement).

The lab continues to be involved in two very important national initiatives of Excellence EquipEx for experimental platforms, the 2D-MAG and NanoFutur projects. These are allowing us to setup platforms for the synthesis of spintronic stacks via an industry-ready pilot line, and for the emerging 2D epitaxial materials with a synthesis cluster. The SINGULUS deposition cluster was delivered, part of the spintronic pilot line to produce complex stacks and state-of-the-art tunnel junctions, and the 2D epitaxy cluster was connected altogether for the first time. Materials are indeed key in spintronics, and we are setting-up these two platforms with an ambition for international networking and visibility. **New state-of-the-art instrumentation was also delivered**, such as a PPMS, an upgraded and ambitious RPE tool in coordination with the SYMMES laboratory and funding provided by the PEPR SPIN, LUMA and University Grenoble Alps and Grenoble INP, a new MOKE setup working at low temperature, a high-frequency sample holder for magnetic holography, joint actions with LTM and IRIG for upgrading the clean room facilities through the EQUIPEX Nanofutur, the PEPR electronics and the FEDER project CARAT.

On the infrastructure side, we are pleased to announce the completion of our building's expansion and thermal shielding, as well as the addition of new experimental rooms for the AI, sensors, and IC design teams. We also warmly welcome all colleagues from the 2D spintronics team into our newly unified facility, which now includes the 2D cluster platform.

On the lab organizational side, we conducted several important actions. First, scientific strategy brainstorming days took place in February, which allowed every group of the lab to assess assets but also identify weaknesses and opportunities for the years to come. Second, we organized lab days in October in the Vercors mountains, allowing to discuss the global strategy of the lab for the forthcoming years, to be structured and formalized within the HCERES evaluation document and the visit of the evaluation committee in 2025. This will also allow to move forward with the preparation for a new management team (term 2027 to 2031). The lab days were also an opportunity to discuss all together the scientific and organizational challenges for the years to come, and sustain our collective life. Various aspects on home-office, data management and to equity in the lab were also discussed. This year, we strengthened the **SPINTEC alumni network** with two dedicated days, including scientific testimonials, becoming of the former colleagues, to round tables as the one organized during the lab days that raised a large interest from the colleagues in the lab. **On the scientific animation side,** we are proud to mention the weekly scientific clips and the 25 invited seminars in SPINTEC as illustrated at the end of this booklet.

SPINTEC welcomed several key visitors, contributing to our visibility and the sharing of our scientific strategy with policy makers and partners. Let us mention the president of IEEE, of the vice-president for Research of the Auvergne-Rhône-Alpes region and of the Lyon research rector. Is has also been a habit in the last years to organize a welcome day for the students from the Grenoble area, to present our internship offers, structured every year in a dedicated booklet. **The society visibility of our activities** is also demonstrated by the presence of some of our highlights and events in media, with illustrations in this booklet.

We keep welcoming new collaborators, to achieve our missions. One CNRS researcher Louis Desplat, one Grenoble INP assistant professor Jonathan Miquel and one CEA researcher Julien Bréhin joined the lab in 2024. The number of permanent colleagues reached a record of 53, despite several leaves that occurred in the past two years related to the creation of the spinoff companies *Golana Computing* and *Nellow*. The human component is indeed the most valuable wealth of a research lab, and as such we are also proud of our 10 PhD graduations and the different successes on the career path of several colleagues.

2025 is coming with new challenges! Indeed, 2025 is pivotal for SPINTEC's development. We can mention namely the HCERES five-yearly evaluation with a document to be produced in May 2025 and a visit expected before the end of the year. With our institutions, we have also launched a search committee for the future management team for the term 2027-2031. As regards scientific strategy, we believe that, more than ever, spintronics offers opportunities at the crossroads of fundamental research, innovation and societal challenges, from quantum electronics, neuromorphic and high-power computing, to Internet of Things. In a highly competitive environment, we need to foster internal and networking synergies and ensure the development of these strategic research topics. We will sustain our efforts to bring the innovative potential of spintronics better recognized, within *SpintronicFactory*, the *European Magnetism Association* and the *IEEE Mag Soc*, as well as through the scientific higher-education schools that we are organizing or steering: *ESONN*, *InMRAM*, *ESM* and *QEM*.

Lucian Prejbeanu, Executive Director

Olivier Fruchart, Deputy Director

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Editors: Gregory Di Pendina, / Hélène Béa

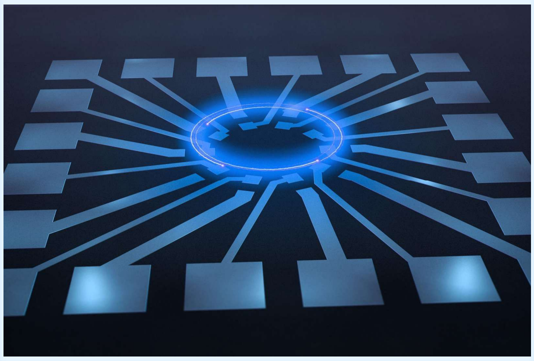
Directors of publication: Lucian Prejbeanu, Executive Director / Olivier Fruchart, Deputy Director

More topology in quantum electronic circuits

In the framework of the French-German laboratory association between SPINTEC and the IFW Dresden, and in collaboration with the C2N institute and the University of Würzburg, a novel platform was implemented to reveal the non-hermitian topology of scalable quantum electronic circuits. It opens some new perspectives to realize quantum simulators and highly sensitive sensors protected by the circuit topology, also relevant for quantum spintronics.

In quantum materials, the non-trivial band-structure topology generates some novel electronic states, being robust against perturbations. The most famous example is the quantum Hall effect in 2D systems, with 1D ballistic edge states induced by a large magnetic field.

Connecting such edge states in an electronic quantum ring, the team realized a quantum simulator mapping the 1D-chain Hatano-Nelson quantum model. The experimental results reveal the intrinsic topology of the circuit itself, specific to non-hermitian open quantum systems, known as the topological skin effect. This leads to the exponential localization of states at one end of the ring (a finite chain of ballistic conductors) in an open-boundary configuration. The extreme sensitivity of this asymmetric topological response to a change in the boundary conditions makes such circuits interesting for sensing. More generally, this platform offer some new perspectives to realize and study other quantum models, with circuits based on connected 1D chiral edge states. In quantum spintronics, such states can be realized in zero magnetic field in the quantum anomalous Hall regime of magnetic topological insulators.



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Artistic view of a multi-connected quantum ring (10 pairs) and of the ballistic transport of edge states between contacts in the quantum Hall regime (center), realizing a 1D chain quantum model (Hatano-Nelson). For an open chain, the intrinsic circuit topology leads to the asymmetric localization of states at it ends, as determined by the chirality of the system and the specific ground scheme ("topological skin effect").

The experimental device was realized from an AlGaAs 2D electron gas patterned into a ring geometry with ten ohmic contacts on its outer edge, each with an additional arm for grounding purpose (see Figure). By applying a magnetic field perpendicular to the plane, the circuit is driven into the quantum Hall regime, so that charge transport occurs via ballistic chiral edge states, in between successive contacts. The device is equivalent to a chain of chiral conductors connected by dissipative contacts, realizing the 1D Hatano-Nelson quantum model describing a non-hermitian hamiltonian. The well-designed contact geometry allows one to tune electrically the boundary conditions, continuously from an open-boundary to a periodic-bounday chain, by adding a finite resistance to the single contact connected to the ground (partially open-chain geometry). By measuring the magnetic-field dependence of the circuit conductance matrix, it was shown that the topological invariant associated to the skin effect is best quantized in the quantum Hall regime, but also that it remains quantized in the diffusive regime. This device topology appears very robust, both in magnetic field and in temperature, as long as the chirality of the system is preserved. An intriguing extension of this work is to realize some similar studies with devices patterned from magnetic topological insulators, in the quantum anomalous Hall regime in zero magnetic field, with some potential applications in quantum spintronics and metrology.

Team: Topological Spintronics

Collaboration: IFW Dresden (Germany), C2N (Palaiseau, France), Würzburg University (Germany)

Funding: H2020 FET Proactive project TOCHA; CNRS IRP SPINMAT

Further reading: *Non-Hermitian topology in a multi-terminal quantum Hall device*, K. Ochkan *et al.*, Nat. Phys. 20, 395-401 (2024). *Open access: hal-04115908*

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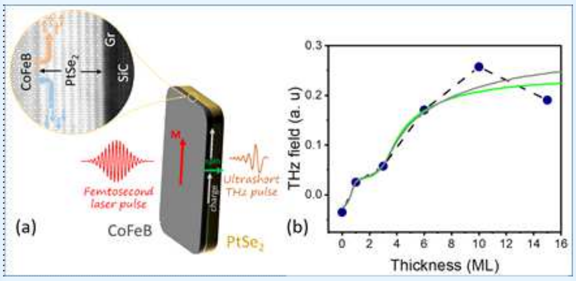
THz emission: a tool for studying the spintronic properties of 2D materials

By using THz spintronic emission, we could study the spin-charge conversion mechanisms in 2D materials. High crystalline quality 2D materials are grown by molecular beam epitaxy on large area and CoFeB is deposited on top using soft UHV sputtering to obtain sharp interfaces. Such model system allows us to identify and quantify the spin-charge conversion mechanisms in 2D $PtSe_2$.



(a) Schematics of THz spintronic emission from the CoFeB/$PtSe_2$ bilayer. An atomic scale scanning transmission electron microscopy image shows the material stacking with high quality interfaces. The photoexcitation and diffusion of spin up and down generate a pure spin current perpendicular to the film and a charge current parallel to the film. (b) Intensity of the THz electric field as a function of $PtSe_2$ thickness (in ML) showing two regimes for thin (<4 ML) and thick (>4 ML) $PtSe_2$. Blue dots are experimental data and solid lines fits using a simple spin diffusion model.

THz spintronic emission is based on the ultra-rapid conversion of a spin current into a charge current providing an intense, broadband source of THz waves. It is a formidable tool for the fundamental study of spin-to-charge conversion mechanisms in materials. Here, we have used this technique to study the spintronic properties of 2D materials. Indeed, by studying this emission according to the nature, symmetry and number of layers of the 2D material, it is possible to identify the spin-charge conversion mechanisms in theory and practice, and to quantify them. However, this kind of study is limited by two major obstacles: the growth of high quality 2D materials over large areas, and the control of the interface between the 2D material and the ferromagnet used as the spin current source.

Today, 2D materials are mostly studied in the form of micrometric flakes mechanically exfoliated from the bulk material. Moreover, the interface between 2D materials and metallic ferromagnets shows chemical reactions and atomic interdiffusion. In this work, we have overcome these two obstacles to study spin-charge conversion mechanisms in 2D $PtSe_2$ exhibiting an electronic transition from the semiconductor to the semi-metallic state by increasing the number of monolayers (ML). Large area single crystalline $PtSe_2$ was grown by molecular beam epitaxy and CoFeB was then deposited in the same chamber under ultra-high vacuum by soft sputtering giving high quality interface. To identify conversion mechanisms and quantify them, THz spintronic emission was used as illustrated in Figure (a). This technique is highly sensitive and non-destructive. Among 2D materials, $PtSe_2$ exhibits an intense THz signal, making it possible to study emission as a function of the number of ML (Figure (b)). At low thicknesses (<4 ML), in the semiconductor regime, charge transfer between the graphene substrate and the first layer of $PtSe_2$ creates an interface electric field and a strong Rashba effect responsible for spin-charge conversion by the inverse Rashba-Edelstein effect and the THz signal. This is an interface effect. For thicker layers (>4 ML), the transition to the semi-metallic state adds the inverse spin-Hall effect conversion phenomenon, which corresponds to a volume effect. Theoretical studies using a simple spin diffusion model and *ab initio* calculations have validated this interpretation and quantified these effects. 2D materials open up new horizons for the development of tunable THz spintronic emitters in a sustainable way.

Teams: 2D spintronics, Theory / Simulation

Collaboration: IRIG-MEM/SYMMES/PHELIQS (Grenoble, France), LPENS (Paris, France), LAF (Palaiseau, France), C2N (Palaiseau, France), Institut Néel (Grenoble, France)

Funding: Equipex + 2D-MAG

Further reading: *Atomic-Layer Controlled Transition from Inverse Rashba–Edelstein Effect to Inverse Spin Hall Effect in 2D $PtSe_2$ Probed by THz Spintronic Emission*, K. Abdukayumov et al., Adv. Mater. 2024, 36, 2304243. *Open access: hal-04107294*

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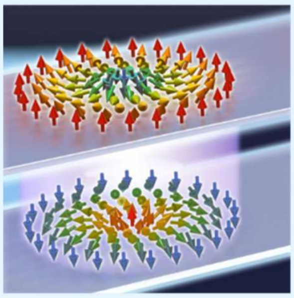
Antiferromagnetic skyrmions moving at record speeds

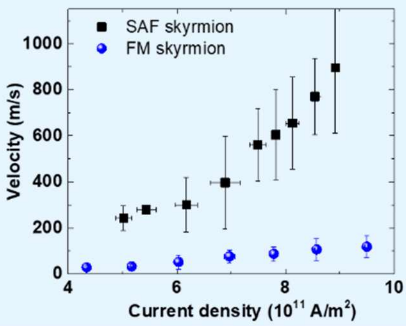
Magnetic skyrmions are magnetic nanobubbles that are envisioned as bits of information in our computers. We have demonstrated that they can be moved by electric current at record speeds, up to 900 m/s, in antiferromagnetic stacks. These results hold promise for the use of skyrmions to store and process information more efficiently and with lower energy in computers.

Skyrmions are magnetic textures with fascinating properties. This magnetic quasi-particle can reach sizes down to a few nanometers, and is composed of elementary nanomagnets (spins) that wrap to form a very stable spiral structure, like a tightly knit knot. Skyrmions can also be manipulated by small electrical currents, paving the way for their use as information carriers in computing devices. Several memory and logic devices have been proposed, promising very high information density and low energy consumption.

These devices are based on the manipulation of skyrmions in magnetic tracks by an electric current. However, such applications remained distant, as the magnetic moment of skyrmions limits their speed to 100 m/s - too slow for applications - and leads to a deflection of the skyrmions' motion towards the edge of the track, where they can annihilate. We have shown that these limitations can be overcome in synthetic antiferromagnetic materials. These materials consist of two nanometer-thick ferromagnetic layers (such as cobalt), separated by a thin non-magnetic layer, with opposite magnetizations. The skyrmions in synthetic antiferromagnets (SAF) are composed of two skyrmions whose spins are aligned in opposite directions, thus cancelling out the magnetic moment (Figure (Left)). We have shown that skyrmions in these materials can be moved by electric currents almost ten times faster than those in ferromagnetic materials, up to 900 m/s, and along the direction of the current (see Figure (Right)). The experimental results are in good agreement with the predictions of theoretical and numerical models.

The next step will be to perform memory and logic operations based on skyrmion train manipulation in these materials, a step closer to using these new quasiparticles to encode and manipulate information at the nanoscale.





(Left) Skyrmions in synthetic antiferromagnets are composed of two skyrmions whose spins are aligned in opposite directions. (Right) Skyrmion velocity as a function of injected current density for skyrmions in SAF (black squares) and in single ferromagnetic layers (blue circles).

Team: Spin Orbitronics

Collaboration: Institut Néel (Grenoble, France)

Funding: TEE DARPA, PEPR SPIN

Further reading: *Fast current-induced skyrmion motion in synthetic antiferromagnets*, V. T. Pham et al., Science 384, 307–312 (2024). *Open access: hal-04553207*

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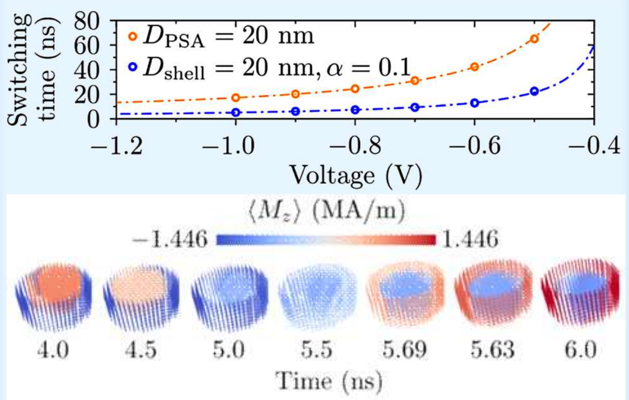
A dipolar core-shell perpendicular shape anisotropy memory cell

We propose the concept of a core-shell composite structure coupled antiparallel via dipolar interaction, as the storage layer in perpendicular-shape-anisotropy magnetic random access memory (PSA MRAM). Benefits compared with a standard PSA MRAM include reduced write time and stray field.

Magnetic Random Access Memories (MRAM) are already on the market, with markets such as cache memory and field programmable gate arrays (FPGA)/internet of things (IoT), thanks to their endurance and low power consumption. The storage element of an MRAM is an ultrathin layer with perpendicular magnetization, whose small volume limits the downsize scalability of MRAM to diameter 20 nm or so. To circumvent this limit, the concept of Perpendicular Shape Anisotropy MRAM was proposed and demonstrated independently by Tohoku University and SPINTEC. Its storage layer consists of a narrow pillar, whose vertical aspect ratio is the main source of perpendicular anisotropy, and the much larger volume allows to sustain thermal stability down to a few nanometers in diameter. However, PSA-MRAM comes with drawbacks, one of them being the difficulty to write due to larger magnetic moment involved, thus requiring a larger write current and longer switching time. Alternative designs are therefore desirable to demonstrate practical applicability.



CoFeB core with a Co shell (height 8 nm; diameters 14 and 20 nm, respectively). (Top) Decrease of the switching time for the core-shell design compared with a standard PSA; (bottom) Illustration of the sequential switching scheme.

Here, we introduce the concept of a core-shell composite storage layer coupled via dipolar interactions, which we explore by means of micromagnetic analytics and simulations. We show that a suitable choice of geometry, determining the strength of dipolar coupling and anisotropy energy of the two elements, reduces the write current and switching time with respect to a standard PSA MRAM with identical thermal stability. The underlying mechanism is twofold. (i) There is a tendency for sequential reversal, first the core connected to the leads injecting the spin-polarized current, later followed by the shell, which lowers the intermediate energy barrier. (ii) A given energy barrier can be attained for shorted cylinders, thereby remaining in the single-domain limit instead of a nucleation-propagation process. The latter is less favorable as the effect of the spin-polarized current is largest at the interface with the tunnel junction than in the bulk of the cylinder.

Our composite approach is similar to the case of coupled multilayers stacked along the vertical direction, explored by Tohoku university. However, it is specific to a three-dimensional object and brings an additional degree of freedom. Besides, the antiparallel coupling ends up in a much reduced or even canceled magnetic moment, providing an efficient mitigation strategy against dipolar cross-talk between neighboring elements, while parallel-coupled stacks do not. This is particularly crucial for PSA, having a large volume and thus magnetic moment, and allow to envision a denser integration. The challenge is now to develop successful fabrication routes and proceed to an experimental realization of this concept.

Teams: Spin Textures, MRAM, Theory / Simulation

Funding: Samsung Electronics Co., Ltd.

Further reading: *Dipole-coupled core-shell perpendicular-shape-anisotropy magnetic tunnel junction with enhanced write speed and reduced crosstalk*, N. Caçoilo, L.D. Buda-Prejbeanu, B. Dieny, O. Fruchart, and I.L. Prejbeanu, Phys. Rev. Appl. 21, 044034 (2014). *Open access: hal-04335929*

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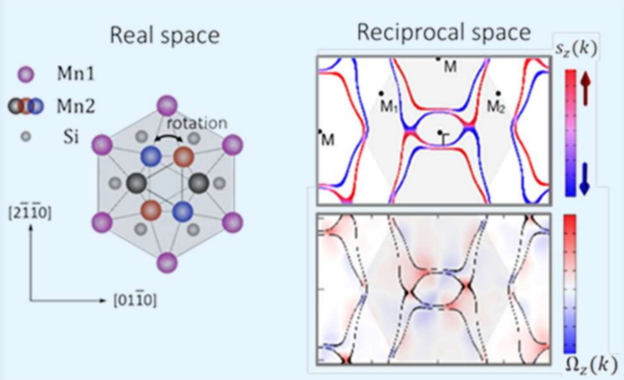
A new altermagnetic material with remarkable properties for spintronics

We have demonstrated experimentally and theoretically the altermagnetic character of the material Mn_5Si_3, proving the incomparable advantage of this type of zero-magnetization magnetic phase: the strong spintronic effects associated with it are based on non-relativistic physics.

Altermagnetism is a third class of magnetic materials. It complements and sometimes supplants the two usual classes: ferromagnetism (or ferrimagnetism) and antiferromagnetism. An altermagnet (AM) is composed of magnetic moments alternately oriented in opposite directions, like a collinear antiferromagnet (AFM). Although devoid of magnetization, it nevertheless polarizes the electric current by shifting the electronic bands of the majority and minority spins, much like a ferromagnet (FM), but alternately. The secret lies in the fact that, unlike an AFM, the two sublattices of moments that make up the AM do not have the same electronic environment, so they are linked by rotational symmetry rather than translational or inversion symmetry. More generally, seen through the prism of symmetry groups, FM (& ferrimagnets), AFM and AM crystals belong to three distinct subgroups. In addition to the above-mentioned properties, the spin configuration of AMs gives them specific properties that are inaccessible to FMs and AFMs, such as compatibility with spin-polarized superconductivity. The discovery of this new class of materials opens up a whole new world of physics which is causing quite a stir in the scientific community.



Real space: Magnetic and crystalline structure of Mn_5Si_3. Reciprocal space: shifts in the electronic bands of majority and minority spins (s_z) (red and blue), and consequences on the Berry curvature (Ω_z), which displays hot spots that are the source of certain spintronic effects, such as the anomalous Hall effect.

To date, four AMs have been experimentally proven: RuO_2, Mn_5Si_3, MnTe and CrSb. Among these materials, Mn_5Si_3 has the incomparable advantage of being composed of elements with weak spin-orbit coupling, making it possible to unequivocally link its AM character to the intrinsic, non-relativistic intermingling of the arrangement of magnetic moments with respect to its crystalline symmetries. Last but not least, Mn_5Si_3 is composed of abundant, inexpensive elements. Theoretically, a strong anomalous Hall effect (AHE) in the absence of magnetic field and magnetization, coupled with a clear influence of crystallinity, are all signatures of the altermagnetism of Mn_5Si_3. They are the subject of this pioneering paper, prepublished in arXiv barely a year after the theoretical prediction of AM.

The consortium is already looking ahead on many fronts: among other things, (i) it proposes a recipe for stabilizing the AM phase "under strain" of Mn_5Si_3 (Phys. Rev. Mat. 7, 024416 (2023)), (ii) it demonstrates the anisotropic character of the AHE (Phys. Rev. B in press, arXiv:2401.02275 (2024)) and (iii) the Nernst effect in Mn_5Si_3, despite the absence of magnetization (arXiv:2403. 12929 (2024)), and (iv) it suggests a related study on the influence of symmetries to detect phase transitions (arXiv:2311.14498 (2023)).

Team: Antiferromagnetic Spintronics

Collaboration: CINaM (Marseille, France), JGU - TUD - Uni. Konstanz (Germany), FZU - Charles Uni. (Czech rep.)

Funding: ANR ASTRONICS; ANR MATHEEIAS; IRP CNRS SPINMAT.

Further reading: *Observation of a spontaneous anomalous Hall response in the Mn_5Si_3 d-wave altermagnet candidate,* H. Reichlova et al., Nat. Commun. 15, 4961 (2024). *Open access: hal-03092623*

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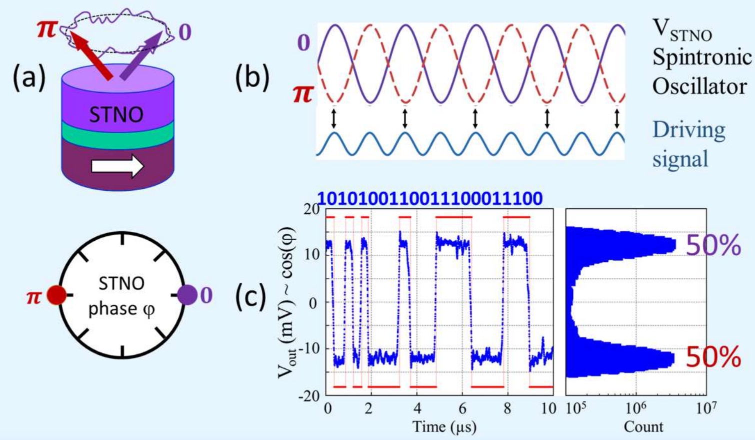
Thermal noise, binary phase states and how this can be used for data encryption

Unbiased random bitstreams are essential for encryption, secure communication, and unconventional computing, yet true randomness without bias remains challenging in hardware. By harnessing nanoscale thermal magnetization fluctuations in spintronic nano-oscillators, we introduce a new approach to generate fully unbiased bitstreams.

Thermal fluctuations provide an efficient and almost cost-free means of generating truly random bitstreams of 0 and 1, distinguishing them from predictable pseudo-random sequences. Thermal fluctuations are present in all physical systems. Thus, it could be expected that it is straightforward to generate random bitstreams from a fluctuating two-level system, described by two energy minima separated by an energy barrier. However, most hardware implementations suffer from bias, leading to unequal energy minima and energy barriers resulting in significant deviations from equal fractions of 0 and 1 levels. This will compromise their inherent unpredictability.



Operating principle for generating unbiased random bit-streams: (a) The magnetization oscillations of the STNO free layer with two stable phase states under synchronization. (b) The phase φ of the STNO signal V_{STNO} adjusts to the driving signal phase, at two degenerate and π-shifted states. (c) Experimental time-traces of the readout circuit signal $V_{out}\sim cos(\varphi)$, and the corresponding histogram, revealing 50% probability of both states.

We discovered that the phase dynamics of oscillators presents an ideal foundation for generating unbiased random bitstreams. When synchronized to an external signal at twice its own frequency, the oscillator phase settles in one of two stable, π-shifted, states (see Figure (a, b)) forming two equivalent potential wells that ensure symmetry and balance. In the presence of thermal noise, transitions between these states occur stochastically, with in average no state preference, fulfilling the core requirement for unbiased true randomness in bitstream generation. The SPINTEC team has realized this concept using spin-torque nano-oscillators (STNOs) based on magnetic tunnel junctions, ideal for their nanoscale dimensions, CMOS compatibility, room temperature operation and high-frequency capabilities. Their free layer magnetization can exhibit auto-oscillations that are converted into electrical voltage signals $V_{STNO}(t)$ via magneto-resistive effects, see Figure (a, b). The STNO's phase φ is extracted from V_{STNO} through a special phase readout circuit that outputs a voltage $V_{out}\sim cos(\varphi)$ revealing thermal-noise-induced, stochastic transitions between two levels with equal occupancy, see Figure (c). Validation through the NIST statistical test suite confirmed the corresponding digitized bitstream's suitability for secure encryption applications.

Teams: RF Spintronics, Artificial Intelligence

Collaboration: Iberian Nanotechnology Laboratory (Portugal), National Institute of Standards and Technology (USA), University of Maryland (USA).

Funding: ANR-NSF Stochnet, Grenoble INP Bourse Présidence and MIAI@Grenoble Alpes

Further reading: *Unbiased random bitstream generation using injection-locked spin-torque nano-oscillators*, Nhat-Tan Phan et al., Physical Review Applied **21,** 034063 (2024), *Editor's suggestion. Open access: hal-04666735v1*

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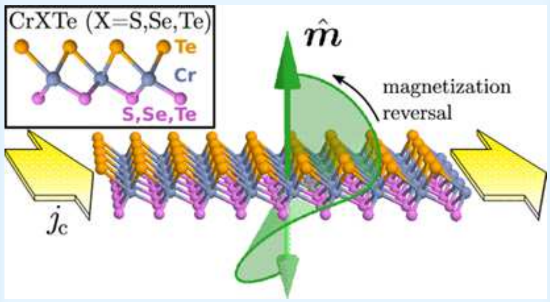
Field-free spin-orbit torque switching in Janus chromium dichalcogenides

By performing transport simulations on carefully derived Wannier tight-binding models, Janus chromium-based transition-metal dichalcogenide (TMD) monolayers are found to exhibit a spin-orbit torque (SOT) performance comparable to the most efficient two-dimensional materials, while additionally allowing for field-free perpendicular magnetization switching, due to their reduced in-plane symmetry.

The spin-orbit torque (SOT) mechanism represents an innovative method to electrically manipulate the magnetization of a magnetic material, providing remarkable energy-efficiency, writing speed, and scalability prospects. Hence, SOT has earned its insertion in magnetic random access memory (MRAM) applications, among other developing technologies. Although next-generation SOT-based technologies advance at a steady pace, they still face issues regarding massive density and integration. The development of SOT-MRAMs remains limited to multilayered devices, where SOT figures of merit are strongly sensitive to interface quality. Additionally, a densely packed SOT-MRAM requires electrical switching of magnets with perpendicular magnetic anisotropy (PMA), which is only achieved in conventional devices based on heavy metal/ferromagnet bilayers with the assistance of an external magnetic field. In this context, Janus transition-metal dichalcogenide (TMD) monolayers stand out as the materials of choice that can offer offer alternative paths to overcome these issues.



Schematic representation of the field-free current induced perpendicular magnetization switching via spin-orbit torques (SOT) in magnetic chromium-based transition-metal dichalcogenide (TMD) monolayers in their Janus forms CrXTe, with X = S, Se.

By concatenating *ab initio* and quantum transport methodologies, an exceptional SOT performance of chromium-based Janus TMD monolayers CrXTe (X = S, Se) is predicted, allowing for field-free switching of the perpendicular magnetic state. This was accomplished by deploying a robust end-to-end methodology comprising first-principles calculations, Wannier tight-binding models fully capturing reciprocal space spin textures, quantum transport simulations and critical field-free PMA switching current calculations. By comparing both the Janus and non-Janus materials under electric field, we demonstrated that Cr-based Janus monolayers constitute an optimal SOT platform for low-energy magnetization reversal. The structural inversion symmetry breaking, inherent to Janus structures is responsible for a large SOT response generated by giant Rashba splitting, equivalent to that obtained by applying a transverse electric field of ~100 V.nm^{-1} in non-Janus $CrTe_2$, completely out of experimental reach.

Altogether, we found that magnetic chromium-based Janus TMDs offer a remarkable SOT performance originating from huge internal electric fields due to their asymmetric crystal structure, yielding a competitive switching current with the additional advantage of neither requiring assistance of external fields nor the transmission of spin current through an imperfect interface. Such results present magnetic Janus TMDs as efficient materials for designing ultimate SOT-MRAM technologies.

Team: Theory / Simulation

Collaboration: ICN2 (Spain), CEA-Leti (Grenoble, France), CINaM (Marseille, France)

Funding: EU FLAG-ERA “MNEMOSYN”, EU Horizon 2020 “NUMERICS–H2020-MSCA-COFUND-2017”

Further reading: *Field-Free Spin–Orbit Torque Switching in Janus Chromium Dichalcogenides*, L. Vojáček, J. Medina Dueñas, J. Li, F. Ibrahim, A. Manchon, S. Roche, M. Chshiev, J. H García, Nano Lett. 24, 11889 (2024). *Open access: hal-04698626*

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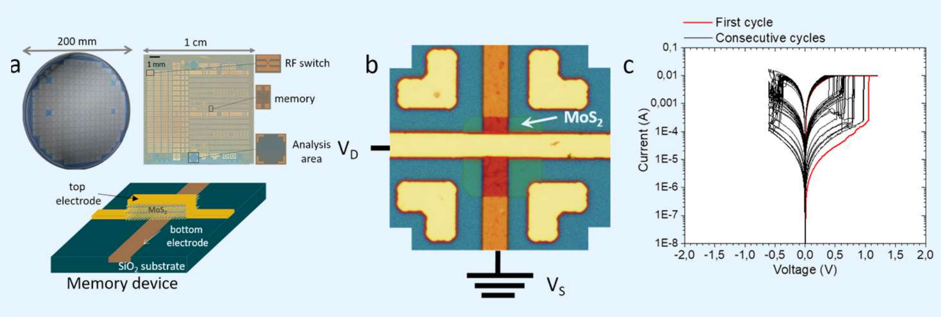
Development and optimization of large-scale integration of 2D material in memristors

Two-dimensional (2D) materials like transition metal dichalcogenides (TMD) are considered as key candidates to replace silicon in several technologies with enhanced performances. In this work, we address the two remaining challenges to reach their industrial deployment: the wafer scale growth of TMDs and their integration into operational devices using CMOS compatible process. This is achieved with MoS_2-based memristors in which we conclude that electrical switching takes place in grain boundaries.

2D materials like TMDs are promising materials to develop high-performance electronic devices. In particular, MoS_2 was used in flexible devices, sensors, high responsivity phototransistors, non-volatile memory devices, high cut-off frequency RF switches or transistors. For memory devices, MoS_2 has been integrated in nanoscale vertical metal-insulator-metal (MIM) structure with low switching voltage, fast switching speed and high ON/OFF current ratio enabling the manufacture of multi-level devices, opening the way to the development of RF switches and neuromorphic devices. However, large-scale integration of such devices has not yet been demonstrated and the exact atomic mechanisms for the formation of ON and OFF states are not yet understood in particular because of the low yield of switching devices, the lack of reproducibility and the weak endurance after manufacturing.

In this study, we have developed and optimized a complete process for integrating 2D materials into a fully CMOS-compatible vertical MIM structure in a clean room and over large area (see Figures (a) and (b)). We demonstrated the preservation of the physico-chemical properties of MoS_2 during the whole fabrication process and the high-quality of van der Waals interfaces. Electrical measurements (see Figure (c)) were performed to understand the influence of the fabrication protocol, the top electrode metal and the MoS_2 grain size on devices performances.



(a) Processed samples and schematics of the MoS_2-based memristor. (b) Optical image of the memristor with bottom, top electrodes and MoS_2 (green). (c) Electrical measurements with ON (low resistivity) and OFF states (high resistivity state).

Thanks to the process optimization, the yield of switching devices, reproducibility and performances were greatly improved. More specifically, ON/OFF current ratios up to 10^5 were obtained, which is promising for the manufacture of RF switches. By reducing the stochastic behavior of the devices, we could reliably investigate the switching mechanism. Statistics on the switching voltage and distribution of MoS_2 devices with two different grain sizes demonstrated that grain boundaries are the preferred location for the formation of conduction filaments. We concluded that the quality of MoS_2 layers, in particular the grain size, is a key factor to adjust the performances of MoS_2-based memories.

Team: 2D Spintronics

Collaboration: CEA LETI (Grenoble, France), PFNC (Grenoble, France), PTA (Grenoble, France)

Funding: PEPR Microelectronics ADICT

Further reading: *Development and optimization of large-scale integration of 2D material in memristors*, C. Ligaud, L. Le Van-Jodin, B. Reig, P. Trousset, P. Brunet, M. Bertucchi, C. Hellion, N. Gauthier, L. Van-Hoan, H. Okuno, D. Dosenovic, S. Cadot, R. Gassilloud and M. Jamet, 2D Mater. 11, 045002 (2024). *Open access: hal-cea-04724987v1*

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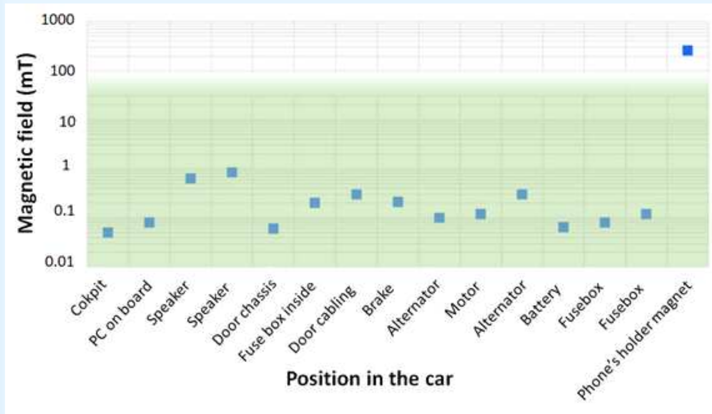
Impact of external magnetic field on spin transfer torque magnetic memory operation

The extent to which an external magnetic field can influence the operation of spin-transfer-torque magnetic random access memory (STT-MRAM) remains a critical question within the microelectronics industry in particular for automotive industry. SPINTEC is actively engaged in an international technical group comprising academic and industrial experts in MRAM technology, with a particular focus on addressing this issue.

STT-MRAM are magnetic devices based on magnetic tunnel junctions. As any magnetic device, they exhibit a certain sensitivity to parasitic magnetic field that can arise from nearby permanent magnets or current flows. Industrial players producing microcontrollers in particular for automotive industry are concerned by such sensitivity, which may potentially affect the system security. Commercial STT-MRAM exhibit large coercive field (0.2 T - 0.5 T) which makes them quite robust against magnetic field perturbation in standby mode. However, during write, external magnetic field can change the current required to write the cell. The STT-MRAM manufacturers guaranty that the failure rate during write remains negligible as long as the parasitic magnetic field does not exceed a few tens of mT to one hundred mT depending on MRAM target application (embedded FLASH (eFlash) or stand-alone). These are still quite high fields, which are not encountered in most applications except in very special cases. As a result, we show that the magnetic immunity of STT-MRAM is sufficient for most uses once the chip is mounted on a printed circuit board or inserted in its working environment. This statement is supported by the experience acquired during 60 years of use of magnetic hard disk drives, 20+ years of use of magnetic field sensors as position encoders in the automotive industry, and 15+ years of use of earlier generations of MRAM. Mainly, during chip handling, caution does need to be exercised to avoid exposing the chip to excessively high magnetic fields.



Magnetic field in a car measured at different positions. The green background indicates the safe use zone.

As an illustration, the Figure shows the magnetic field at various locations in a car. It is always much below the specified maximum field for STT-MRAM error-free operation. Only in direct contact with a permanent magnet (for instance in contact with a magnetic phone holder), the field may locally exceed the maximum specified value. However, even in this case, the issue may be circumvented by magnetically shielding the device, which is achieved by incorporating a soft magnetic material in the back cover of the cell phone.

SPINTEC is currently collaborating with IEEE Standard Association to establish a standard on magnetic field immunity of STT-MRAM, which will ease technical discussions between foundries providing the technology, chip manufacturers and end-users.

Team: MRAM

Collaboration: Everspin (USA), GlobalFoundries (USA), IMEC (Belgium), Tohoku Univ. (Japan), NUMEM (USA), Univ.Austin Texas (USA), HProbe (Eybens, France), KAIST (South Korea), Huawei (China), Netsol, Applied Materials (USA), Univ.Arizona (USA), IBM (USA)

Further reading: *Impact of External Magnetic Fields on STT-MRAM*, B. Dieny, S. Aggarwal, V.B. Naik, S. Couet, T. Coughlin, S. Fukami, K. Garello , J. Guedj, J.A.C. Incorvia, L. Lebrun, K-J. Lee, D. Leonelli, Y. Noh, S. Salimy, S. Soss, L. Thomas, W. Wang, and, D.l Worledge, IEEE Electrons devices Magazine (Sept 2024). *Open access: hal-04751421*

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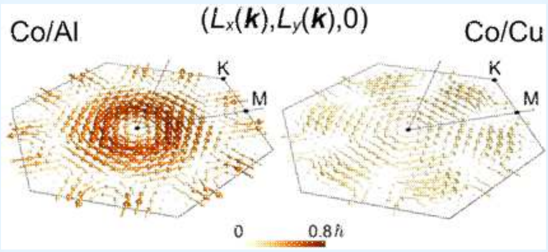
Large chiral orbital texture and orbital Edelstein effect in Co/Al heterostructure

The emergence of a large helical orbital texture due to the formation of the surface states at the metallic Co/Al interfaces originating from the orbital Edelstein effect and giving rise to a non-equilibrium orbital accumulation is revealed to produce large current-induced torques, providing an essential theoretical background for the experimental observations. Spin-orbit coupling is found to produce smaller contributions with a higher-order winding of the orbital moments.

Search for efficient ways to control the magnetization in magnetic materials has been one of the central activities in the field of spintronics, which exploits the intrinsic spin of an electron with a focus on providing novel functionalities in electronic devices. In this regard, spin-orbit coupling (SOC) has brought a progressive venue to achieving high-efficiency electrical control of magnetization via spin-orbit torques (SOT), which historically relied on two cornerstone mechanisms, i.e. spin Hall (SHE) and spin Rashba-Edelstein (REE) effects. In recent years, there has been a lot of evidence that SHE and REE may not be the only principal ways to generate SOTs. It was shown that one can realize electrical generation of the transverse orbital currents via orbital Hall effect (OHE) and/or can produce a substantial orbital accumulation under applied electric fields due to the orbital Edelstein effect (OEE). Recent experiments by S. Krishnia et al. [Nano Lett. 23, 6785 (2023)] reported an unprecedentedly large enhancement of torques upon inserting thin Al layer in Co/Pt heterostructure that suggested the presence of a Rashba-like interaction at the metallic Co/Al interface.



In-plane orbital textures at the interfacial Co layer in the Brillouin zone calculated for 12Co(0001)/12Al(111) and 12Co(0001)/12Cu(111) heterostructures. Arrows for the Co/Cu interface are magnified by a factor of 2 for clarity.

In order to uncover the physical mechanisms responsible for these experimental observations, first-principles calculations combined with Wannier interpolation of the electronic structure were carried out for Co(0001)/Al(111) and Co(0001)/Cu(111) heterostructures comprising between 6 and 12 monolayers of each element. Drastic changes in electronic and magnetic properties at the Co/Al and Co/Cu interfaces are revealed by calculating the orbital and spin profiles in reciprocal space, $\boldsymbol{L}(\boldsymbol{k})$ and $\boldsymbol{S}(\boldsymbol{k})$, respectively. Both are found to exhibit a 3-fold rotational texture in agreement with the C3v symmetry of the constructed heterostructures. More strikingly, peculiar hybridization between the surface states at the Co/Al interface turns out to give rise to an exceptionally large chiral orbital texture with an in-plane helical locking at the interfacial Co layer due to the so-called orbital Rashba effect, as opposed to the Co/Cu interface where the in-plane orbital texture is much less pronounced (see Figure). The in-plane orbital texture at the Co/Al interface is preserved without SOC, as opposed to the transverse spin texture, which is identically zero in the absence of relativistic effects that found to produce much smaller contributions with a higher-order winding of the orbital moments.

These results unveil that the orbital texture gives rise to a nonequilibrium orbital accumulation producing large current-induced torques, thus providing an essential theoretical background for the experimental data and advancing the use of orbital transport phenomena in all-metallic magnetic systems with light elements.

Team: Theory / Simulation

Collaboration: Univ. of Osaka (Japan), Laboratoire Albert Fert (Palaiseau, France)

Funding: PEPR-SPIN “SPINTHEORY”, ANR “ORION”, EU Horizon 2020 “OBELIX”

Further reading: *Large Chiral Orbital Texture and Orbital Edelstein Effect in Co/Al Heterostructure*, S. A. Nikolaev, M. Chshiev, F. Ibrahim, S. Krishnia, N. Sebe, J.-M. George, V. Cros, H. Jaffres and A. Fert, Nano Lett. 24, 13465 (2024). *Open access: hal-04747758*

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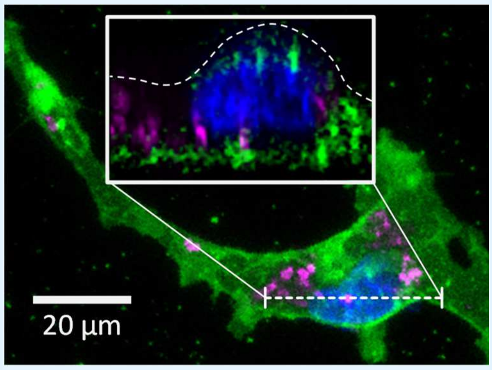
Substrate softness-dependent vortex microdiscs induced cytotoxicity

This work focuses on the study of the intrinsic cytotoxicity of magnetic particles, developed at SPINTEC for the application of local forces at the cellular level. More precisely, we were interested in the effect of the rigidity of the cellular growth substrate on the response induced by the presence of particles.

The study of the cytotoxicity of nanoparticles is a major challenge in biomedical research. This is true with regard to the environmental risks that they may represent, but also in the context of the development of new therapies using nanoparticles as drug vectors or as therapeutic agents. SPINTEC's Magnetic Biotechnologies team has been working for several years on the use of magnetic particles to generate, at the cell level, forces capable of modifying their physiology. These forces (few nN) result from the vibration of the magnetic particles by application of variable magnetic fields. Among the notable results obtained with this technique are the destruction of cancer cells and the stimulation of insulin production in pancreatic cells.

In this paper, we looked at the intrinsic cytotoxicity of such magnetic particles, and more particularly nanometer thick microdiscs. More specifically, as the cytotoxicity of nanoparticles is routinely assessed with cells grown in plastic culture plates that are a million times stiffer than most of the human tissues, we questioned whether nanoparticles cytotoxicity is sensitive to the stiffness of the extracellular environment. To this end, we studied the metabolic activity, proliferation, death rate, as well as the motility of a 3T3 fibroblast and a U87 glioblastoma cancer cell line exposed to magnetic particles. More precisely, we compare cells physiological reaction when they are grown on a rigid glass substrate, or on a soft hydrogel substrate whose mechanical properties are close to physiological ones.



Top-view confocal microscopy image of microdiscs internalized by a U87 cell grown on soft hydrogel substrate. Insert: zoom of a side-view image of the cell, showing particles dispersed within the cell body - without crossing the nucleus membrane. Cell membrane appears in green, cell nucleus in blue, and microdiscs in magenta.

Our main result is that cells grown on soft substrates ingest more microdiscs, which results in greater toxic effects, but also that toxicity at similar particle load is more pronounced on soft substrates especially at large concentration of nanoparticles. These results suggest that both microdiscs uptake and their intracellular processing differ between soft and rigid substrates.

This observation should be compared with the large impact the stiffness of the extracellular matrix has on basic cellular responses such as cell metabolism, which suggests that *in vitro* cytotoxicity assessment of nanomaterials may gain relevance by considering growing the cells on softer substrates, whose stiffness is representative of the tissue of interest. Interestingly, our study also shows that the evaluation of the sensitivity of particles cytotoxicity to the stiffness of the extracellular environment cannot be restricted to the sole cell metabolic activity, as we have observed various impact on the cell behavior, including cell proliferation, death, migration and endocytosis, which all contribute to the metabolic activity.

Team: Magnetic Biotechnologies

Collaboration: LTM/CNRS (Grenoble, France)

Funding: UGA IRGA MagCell Project

Further reading: *Substrate softness increases magnetic microdiscs induced cytotoxicity*, A. Visonà, S. Cavalaglio, S. Labau, S. Soulan, H. Joisten, F. Berger, B. Dieny, R. Morel, and A. Nicolas, Nanoscale Advances (2024). DOI: 10.1039/d4na00704b. *Open access: hal-04788344*

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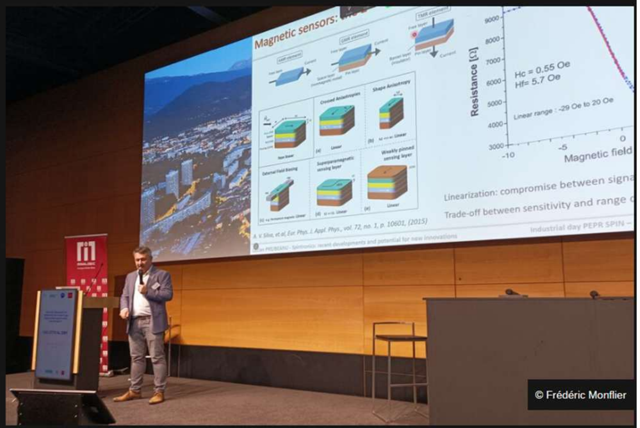
SPINTEC in the press

Comment la spintronique doit progresser pour élargir son impact dans l'industrie

Pour lire l'intégralité de cet article, **abonnez-vous à Industrie & Technologies - édition Abonné**

La première journée industrielle du PEPR Spin s'est tenue à Grenoble le 28 novembre dernier. Si la spintronique est en bonne position pour faire advenir de nouvelles applications numériques moins énergivores, elle doit encore s'améliorer, sur le plan de la conception et de la fabrication, pour étendre son périmètre dans l'industrie.



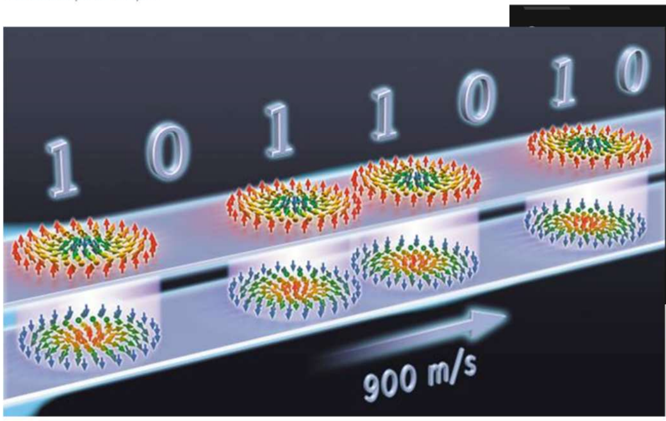
Lucian Prejbeanu, directeur exécutif au laboratoire Spintec et co-directeur du PEPR Spin (avec Vincent Cros), au Centre de congrès de Grenoble, le 28 novembre 2024.

Le Monde

Le skyrmion, cette étrange structure qui pourrait bousculer l'électronique

Les travaux d'une équipe française publiés le 19 avril dans « Science » ouvrent la voie à l'utilisation de ces structures magnétiques pour des fonctions de mémoire et de calcul.

Par Jean-Baptiste Jacquin



EMBARQUÉ
Logiciels & systèmes

Mémoires magnétiques : la clôture du projet Atemi apporte des avancées notoires pour l'industrie au niveau des tests

Publié le 26-11-2024 par Francois Gauthier

Composant

Annoncée par la société grenobloise **Hprobe**, fondée en mars 2017 et émanation du laboratoire français **Spintec**, l'un des principaux centres de recherche en spintronique dans le monde, la clôture du projet **Atemi** (Automated Test Equipment for MRAM In Production) (*) sur les mémoires magnétiques non volatiles MRam (Magnetoresistive Random Access Memory) a permis de mettre en évidence des avancées concrètes sur les méthodes de test et de caractérisation des technologies MRam, en cours de déploiement au niveau industriel. Et ce dans le cadre du programme qui était de développer des technologies avancées de tests sous champ magnétique pour contrôler la production de mémoires magnétiques.

Le projet Atemi a ainsi permis le déploiement d'un premier équipement de test chez plusieurs fondeurs de silicium avec à la clé l'émergence de nouvelles techniques de caractérisation et de protocoles de test de circuits intégrés complexes, ainsi que des contributions à la définition de standards mondiaux pour les tests d'immunité magnétique.

Présences
LE MAGAZINE DES ENTREPRISES DU SUD-ISÈRE

Je recherche...

Nellow invente les futures générations de puces

#EFFICACITÉ ÉNERGÉTIQUE #INTELLIGENCE ARTIFICIELLE #MICROÉLECTRONIQUE #LEVÉE DE FONDS #STRATÉGIE DE DÉVELOPPEMENT

Créée en octobre 2024, la jeune start-up ambitionne de révolutionner l'industrie des semi-conducteurs en développant des puces à ultrabasse consommation énergétique.

Manuel Bibes, Jean Philippe Attané, et Laurent Vila, cofondateurs de la start-up Nelow © F. Ardito

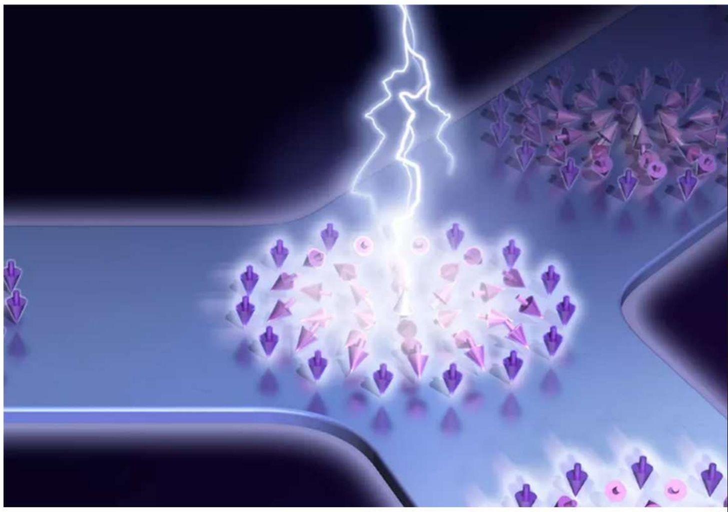
Pour la Science

Physique

Les skyrmions, des bulles magnétiques sous contrôle

Dans certains matériaux, il est possible d'influencer les caractéristiques magnétiques d'ensembles d'atomes, qui forment alors des structures nommées « skyrmions ». Ces étranges objets ont le potentiel de devenir un support de mémoire efficace pour l'électronique.

Charles-Élie Fillion et **Hélène Béa**



Ferroélectricité et spin-orbitronique : le pari technologique de la deeptech Nellow pour une microélectronique 1000 fois plus économe

Pour lire l'intégralité de cet article, abonnez-vous à Industrie et Technologies - édition Abonné

Présentée au lancement du PEPR Spin à Grenoble fin janvier, la deeptech française Nellow prépare l'industrialisation du composant FESO, entremêlant ferroélectricité et spin-orbitronique. Son ambition, à l'horizon 2035, est d'écrire un futur de la microélectronique 1000 fois plus sobre.

Réservé aux abonnés

Frédéric Monflier

07 février 2024 | 14h25

4 min. de lecture

3 auvergne rhône-alpes | changer de localité

Accueil > Auvergne-Rhône-Alpes > Isère > Grenoble

Une économie numérique "frugale et durable" : qu'est-ce que la "spintronique", au cœur d'un nouveau programme lancé à Grenoble ?

L'Université Grenoble Alpes est un des partenaires du program
CLATOT / AFP

POC
LE MÉDIA DES DEEPTECH

NUMÉRIQUE | CEA | PEPR

LUCIAN PREJBEANU (CEA) : « NOUS N'AVONS PAS EXPLOITÉ TOUT LE POTENTIEL DE LA SPINTRONIQUE POUR LES MÉMOIRES »

PhD defenses in 2024

Congratulations to all our new PhD colleagues!

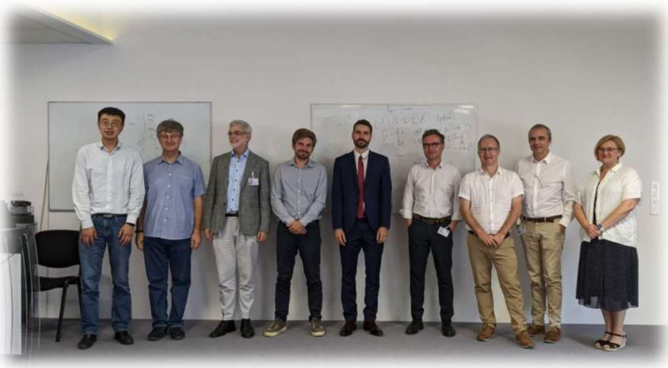
David Salomoni, February 2

Louis Farcis, February 16

Eric Clot, April 17

Khasan Abdukamuyov, April 23

Libor Vojacek, September 19



Salvatore Teresi, October 3

Kamal Danouchi, October 18

Aurelie Kandazoglou, October 22

João Henrique Quintino Palhares, October 23

Georgy Ziborov, November 9

2024 in pictures – Science

January: Kick-off PEPR SPIN, Grenoble

March: Annual days of PEPR électronique, Grenoble

March: Kick-off of PEPR IA, Grenoble

April: Assises France Taiwan, Taipei

May: Visit of the IEEE president, Tom Coughlin – Grenoble

June: FMNT day – Seyssins

June: Alumni day – Grenoble

July: Inauguration of the 1005 new building

July: Visit of Catherine Staron, VP Research, AURA, Gabriele Fioni, rector of the Academy of Lyon

September: PEPR SPIN annual day, Nancy

September:

Workshop on sustainable electronics (FOCUS Numérique Frugal, PEPR électronique, IA & SPIN)

October: Lab days, Méaudre, Vercors mountains

October: Delivery of the deposition cluster for the spintronic pilot line, Grenoble

November: Industrial day of the PEPR SPIN, Grenoble

December: MRAM workshop at IEDM, San Francisco

2024 in picture – Social events

May: Cake contest

December: Gift exchange and end-of-year party

Invited seminars at SPINTEC in 2024

On Tuesday, January 30 Thibaut Devolder from C2N - Centre de Nanosciences et de Nanotechnologies will give a seminar at SPINTEC on electrical methods for the study of spin-wave dynamics #spintronics #magnonics #magnetism CNRS ...more

seminar - Spin waves: electrical methods for the study of their dynamic - Spintec
spintec.fr

On Thu. Feb. 1st, Oksana Chubykalo-Fesenko from Instituto de Ciencia de Materiales de Madrid (ICMM - CSIC) will give a seminar at SPINTEC on ultrafast manipulation of antiferromagnetic order and domain wall dynamics by ...more

seminar - Ultrafast manipulation of antiferromagnetic Order and domain wall dynamics by novel laser induce...
spintec.fr

On Thu. Feb. 15th Juan F. Sierra from Institut Català de Nanociència i Nanotecnologia (ICN2) and CSIC will give a seminar at SPINTEC on recent experimental progress on proximity-induced phenomena and the potential ...more

seminar - Spintronics with two-dimensional materials - Spintec
spintec.fr

On Friday March 8th, Maki Umeda from Japan Atomic Energy Agency will give a seminar at SPINTEC on experimental procedures for the detection of tiny signals from the Barnett effect in rotating ferrofluids #spintronics #magnetism #ferı ...more

seminar - Barnett effect in ferrofluids - Spintec
spintec.fr

On Wed. March 13, Tristan da Câmara Gomes presently at Université catholique de Louvain will give a seminar SPINTEC on his work done in Laboratoire Albert Fert on neuromorphic computing with magnetic skyrmions #spintronics #magnetisr ...more

seminar - Neuromorphic weighted sum with magnetic skyrmions - Spintec
spintec.fr

On Monday April 8th, Jose Luis Prieto Martin from ISOM - UPM Universidad Politécnica de Madrid will give a seminar at SPINTEC on transport mechanisms of a beam of electrons in a uniformly rotating ...more

seminar - Free electrons travelling in a uniformly rotating magnetic field - Spintec
spintec.fr

On Friday April 26th, Opel Matthias from Walther-Meissner-Institute (WMI) will give a seminar at SPINTEC on electrical magnon injection, detection and diffusive magnon spin transport in antiferromagnetic insulators #spintronics #magne ...more

seminar - Magnon Spin Transport in Antiferromagnetic Insulators - Spintec
spintec.fr

On Monday, April 29th 2024, Advait Madhavan (Advait M.) from University of Maryland and National Institute of Standards and Technology (NIST) will give a seminar at SPINTEC on novel encoding schemes for energy-efficient ...more

seminar - Novel information encoding schemes for energy efficient cognitive computing - Spintec
spintec.fr

On Tuesday May 14, 2024 Stephan Roche from Institut Català de Nanociència i Nanotecnologia (ICN2) will give QuantAlps Colloquium on more than 10 years of research and exploration of the potential of 2D materials and van der Waals ...more

Seminar - Ten Years of 2D Materials based Spintronics Research: Highlights and Future - Spintec
spintec.fr

On Tuesday May 28th Valentin Alek Dediu from CNR - ISMN (Bologna) will give a seminar at SPINTEC on theoretical and experimental evidences of a new Ferromagnetic-Glass State induced in thin cobalt films hybridized with ...more

Seminar - Ferromagnetic Glass State observed in thin cobalt films hybridised with molecular layers: collapse ...
spintec.fr

On Friday May 31st, Thomas Coughlin (President of IEEE) will give a seminar at SPINTEC on IEEE missions, the organization's involvement towards a more sustainable world and the benefits that young professionals stand to gain ...more

Seminar - The Institute of Electrical and Electronics Engineers (IEEE), Advancing Technology for Humanity ...
spintec.fr

On Friday, June 14, William Legrand from Institut Néel CNRS will give a seminar at SPINTEC entitled "Towards magnonics at low temperatures" #spintronics #magnetism #magnonics #cryogenics Université Grenoble Alpes CNRS CE/ ...more

Seminar - Towards magnonics at low temperature - Spintec
spintec.fr

On Wed. June 19 2024, Andy THOMAS from Leibniz Institute for Solid State and Materials Research will give a seminar at SPINTEC on in-situ transport investigations in a Lorentz transmission electron microscopy #spintronics #magnetism ...more

Seminar by Andy THOMAS - In-situ transport investigations in a (Lorentz-)TEM - Spintec
spintec.fr

On Friday June 28 Tomoya Nakatani from National Institute for Materials Science (Japan) will give a seminar at SPINTEC on recent studies on magnetic sensors using tunnel magnetoresistance and anomalous Hall effect #spintronics #magneti: ...more

Seminar - Functionalizing tunnel magnetoresistance and anomalous Hall effect as magnetic sensors - Spintec
spintec.fr

On Thu. July 25th Ondřej Wojewoda from CEITEC - Central European Institute of Technology will give a seminar at SPINTEC on experimental observation of unidirectional propagation of zero-momentum magnons in synthetic ...more

seminar - Unidirectional propagation of zero-momentum magnons in synthetic antiferromagnets -...
spintec.fr

On Thu. Sept. 5th, Jakub Železný from FZU - Institute of Physics of the Czech Academy of Sciences will give a seminar at SPINTEC on
recent advances in understanding of how electrical current can induce spin ...more

Seminar - Non-Relativistic Spin Currents and Torques in Antiferromagnets - Spintec
spintec.fr

On Friday October 11th, Quintin Meier from Institut Néel CNRS will give a seminar at SPINTEC on novel magneto-structural coupling effects beyond the classical multiferroics Université Grenoble Alpes CNRS CEA Grenoble CEA-Irig ...more

seminar - Beyond multiferroicity: Structural order parameters enabling unconventional magnetism -...
spintec.fr

On Thursday October 24, Anjan Soumyanarayanan from National University of Singapore will give a seminar at SPINTEC on robust electrical signatures of individual and ensemble spin textures stabilized across a tunable material ...more

seminar - Decoding Electrical Signatures of Chiral Spin Textures - Spintec
spintec.fr

On Wednesday November 13th, Irinel Chiorescu from Florida State University will give a seminar at SPINTEC on engineering quantum coherence and control in diluted spin systems #quantum #qubit #quantumtechnology #magnetism ...more

seminar - Engineering quantum coherence and control in diluted spin systems - Spintec
spintec.fr

On Friday November 29 Johannes Paul from Sensitec GmbH will give a seminar at SPINTEC on existing applications of magnetoresistive sensors in very different areas and some main trends for the next years #spintronics #sensors ...more

Seminar - Selected applications and trends in magnetoresistive sensors - Spintec
spintec.fr

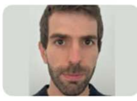
On Wed. August 28th, Hans Josef Hug from Empa and University of Basel will give a seminar at SPINTEC on the capabilities of a magnetic force microscope (MFM) for precise measurement of magnetic fields at the nanoscale unveiling its ...more

Seminar - Nanoscale Magnetic Field Quantification Using In-Vacuum Magnetic Force Microscopy - Spintec
spintec.fr

On Friday Sept. 13th, Louise Desplat from SPINTEC will give a seminar on atomistic exploration of the mechanisms governing thermal stability of magnetic skyrmions and nanopillars, envisioned as information carriers and stochastic p-bits for ...more

seminar - Atomistic exploration of topological states in ultrathin magnetic films and nanopillars - Spintec
spintec.fr

On Friday October 18, Jonathan Miquel from SPINTEC will give a seminar on identifying and addressing energy bottlenecks in software and hardware aspects in computing Université Grenoble Alpes Grenoble INP - UGA CEA Grenoble C ...more



seminar - Energy and computing : Identifying and addressing bottlenecks - Spintec
spintec.fr

On Monday November 4th, Clément Pellet-Mary from the University of Basel will give a seminar at SPINTEC on measuring and controlling the antiferromagnetic order in a 2D magnets using NV center magnetometry #magnetism ...more

seminar - Engineering anti-ferromagnetic domains in atomically thin magnet - Spintec
spintec.fr

On Friday November 29, Johannes Müller from GlobalFoundries (Dresden, Germany) will give a seminar at SPINTEC on the challenges and required MTJ stack innovations on the road towards an automotive capable embedded ...more

Seminar - Embedded STT-MRAM - Building Trust and Moving Ahead - Spintec
spintec.fr

International collaborations

International collaborations are more than ever a crucial aspect of scientific research and innovation.

They allow benefiting from **expertise and ideas complementary to our known**, enabling us to achieve **broader objectives**; they provide opportunities to access European and bilateral funding, contributing to accelerate our research; they foster **staff exchange**, outwards to provide career-development secondments for our PhDs, inwards to establish contact with early-career scientist to fuel our positions.

Collaborations may take a variety of forms, from large structured networks to focused collaborations, considering research, innovation, education and outreach.

The list below provides a list of our recent network of collaborations.

EUROPE

- **Austria** (Universität Wien, Vienna)
- **Belgium** (Université Catholique de Louvain La Neuve; IMEC, Leuven)
- **Czech Republic** (Charles University, Prague)
- **Estonia** (MPhysX, Tallinn)
- **Germany** (Forschung Zentrum Jülich; Paul Drude Institute, Freie Universität, Berlin ; Technical University Dortmund ; IFW, Dresden; Martin Luther Universität, Halle; University of Erlangen-Nürnberg; RPTU, Kaiserslautern; JGU, Mainz; Universität München; Karlsruhe Institute of Technology)
- **Greece** (FORTH, Heraklion)
- **Italy** (University of Ancona; Politecnico di Milano; University Sapienza, Roma)
- **Netherlands** (University of Groningen; Radboud University, Nijmegen)
- **Portugal** (INL, Braga, INESC, Lisbon)
- **Romania** (IMT, Bucharest; National Institute for Materials Physics, Bucharest; Babes-Bolyai University, Cluj-Napoca, Transilvania University, Brasov, Technical University, Cluj-Napoca)
- **Spain** (Universitat Autònoma de Barcelona, Catalan Institute of Nanotechnology ICN2, Barcelona; ICMM-CSIC, IMDEA, Complutense University, Madrid; Nanogune, San Sebastian)
- **Switzerland** (ETH, Zürich)
- **Turkey** (Ankara University, METU, ODTU-MEMS, Ankara)
- **United Kingdom** (University of Cambridge; University of York)

ASIA

- **Saudi Arabia** (King Abdullah University of Science and Technology, Thuwal)
- **China** (Zhejiang University, Hangzhou)
- **India** (SN Bose National Centre for Basic Sciences, Kolkata)
- **Japan** (Osaka University; JAEA, Tokai; ISSP, Tokyo; NIMS, University of Tsukuba; AIST, Tsukuba; RIKEN CEMS, Wako, Tohoku University)

AMERICAS

- **Argentina** (Centro Atómico Bariloche CNEA)
- **Chile** (USACH, Santiago)
- **USA** (Argonne National Labs, Chicago; University of Maryland, College Park; NIST, Gaithersburg; NIST, Boulder; University of Nebraska, Lincoln; Western Digital Corporation, San Jose; University of G. Washington, Washington D.C.; Purdue University, West Lafayette; Applied Materials, Silicon Products Group, Sunnyvale; NY Creates, New-York)

SPINTEC research topics

SPIN ORBITRONICS

The team covers new concepts to devices: exploring new concepts in spintronics based on spin-dependent transport with various systems: structure inversion asymmetry (spin orbit torques, Rashba effect, Spin Hall Effect, Topological Insulators), and alternative geometries in order to develop innovative architectures of devices.

TOPOLOGICAL SPINTRONICS

The team aims at manipulating spins currents in nanostructures of novel quantum materials (Dirac/Weyl matter, topological states at interfaces/edges, van der Waals heterostructures, oxides). Some important aspects of future spintronics devices, such as the efficient spin-charge interconversion at interfaces controlled by ferroelectricity or the ballistic transport of spin states for quantum metrology or topological devices, are studied by magneto-transport measurements.

2D SPINTRONICS

The team deals with spin-dependent phenomena in several important classes of materials: Si and Ge, which are the materials of today's microelectronics, and transition metal dichalcogenides and surfaces of topological insulators, which are emerging 2D materials with exceptional optical and spin-orbit properties. We are studying model systems grown by molecular beam epitaxy and their spin properties.

ANTIFERROMAGNETIC SPINTRONICS

The team explores the spin-dependent properties of compensated magnets such as antiferromagnets and altermagnets. These materials possess unrivalled properties in terms of spin physics, putting them in a good position to integrate spin active parts of future generations of memories, sensors and transceivers for applications in sectors such as automotive, classical and quantum information, and artificial intelligence.

SPIN TEXTURES

The team investigates novel spin textures and their magnetization dynamics, especially in curvilinear systems such as wires and core-shell tubular structures. This involves the three components of magnetization and their three-dimensional distributions, with topology specific to these 3D phase spaces. The team designs the systems, images the spin textures with advanced techniques, and addresses these with spin-polarized current. The applied background are concepts for 3D magnetic memories and sensors.

SPIN INSULATRONICS

The team aims at understanding and controlling microwave oscillations of magnetization around its equilibrium, which are the natural dynamical response to external perturbations (*e.g.*, thermal fluctuations, microwave fields). This offers the promise for a new class of microwave devices based on magnetic insulators, benefiting from their small footprint, their ability to be controlled electrically, and their integrability with CMOS technology to design local oscillators, microwave filters, detectors, and non-reciprocal devices.

RF SPINTRONICS

The aim of the team is to provide a fundamental understanding and control of the excitation, manipulation and detection of the linear, non-linear and complex magnetization dynamics in single and coupled magnetic nanostructures such as magnetic tunnel junctions. Potential applications lie within smart sensor networks and unconventional computing.

MAGNETIC SENSORS

The team explores and develops new concepts for magnetic sensors and covers the entire value chain, from fundamental studies to industry support. The team i) explores the effect of gate voltage on interfacial magnetic properties for new concepts of controllable sensors; ii) develops proofs of concept for ultra-low field sensors; and iii) valorizes its expertise by supporting industrial R&D. The research is essentially experimental, based on material expertise of active stacks and magnetic flux guides, on design and microfabrication of complex devices in clean-room and on magnetic (VSM, MOKE) and electric (magnetotransport and noise) characterization. In addition, micromagnetic simulations and analytical macrospin modeling are used both to deepen our understanding of experimental observations and to further optimize our devices.

MRAM

The team develops memory concepts with improved thermal stability, low power consumption and/or ultrafast writing. The targeted applications range from standalone to embedded memories, for various usages ranging from in-memory computing to artificial intelligence. Electric-field control of magnetization, possibly in combination with spin-charge interconversion, as well as optical switching of magnetization, are studied as further extension of spintronic memories beyond-CMOS technologies.

SPINTRONICS IC DESIGN

The team is dedicated to the evaluation of the benefits of using magnetic devices in Integrated Circuits (ICs). It is expected that integrating non-volatility in ICs could contribute to push forward the incoming limits in the microelectronics scaling. This work includes integrating the magnetic devices in standard design tools, design hybrid circuits and evaluate their performance for various applications, *i.e.*, low power, neuromorphic, security, radiation hardening.

MAGNETIC BIOTECHNOLOGIES

The team's research deals with mechanobiology i.e. the study of the physiological reactions of living cells to mechanical stresses. These stresses are applied by dispersing anisotropic magnetic particles among the cells and actuating the particles by external varying magnetic fields. We already demonstrated that the magneto-mechanical stimulation of cancer cells can trigger their apoptosis (spontaneous death) or can produce insulin release from pancreatic cells. Further work is in progress on magnetically assisted neuroregeneration. Our team contributions consist in fabricating the engineered magnetic mesoparticles, providing the magnetic field sources adapted to the biology experiments and leading the collaborations with our biology and medical partners.

ARTIFICIAL INTELLIGENCE

The team brings together various expertise of SPINTEC in spintronic devices: nanofabrication, characterization, circuit integration, architecture, and algorithm techniques, to implement hardware solutions for artificial intelligence (AI) and unconventional computing. Spintronic devices provide substantial opportunities to improve the energy efficiency of next-generation computing hardware. The team also takes advantage of brain-inspired computing models to deploy cutting-edge neuromorphic algorithms, closing the gap between current hardware AI implementations and exceptional brain computing ability.

THEORY / SIMULATION

The team covers all aspects of fundamental and applied physics related to spin electronics by employing a wide range of theoretical approaches including ab initio, tight-binding, free electron and diffusive methods, combined with micromagnetic and atomistic simulation approaches. This allows explaining experimental observations, providing solutions for specific problems and predicting novel properties and phenomena guiding the experimental work to optimize spintronic nanostructures.

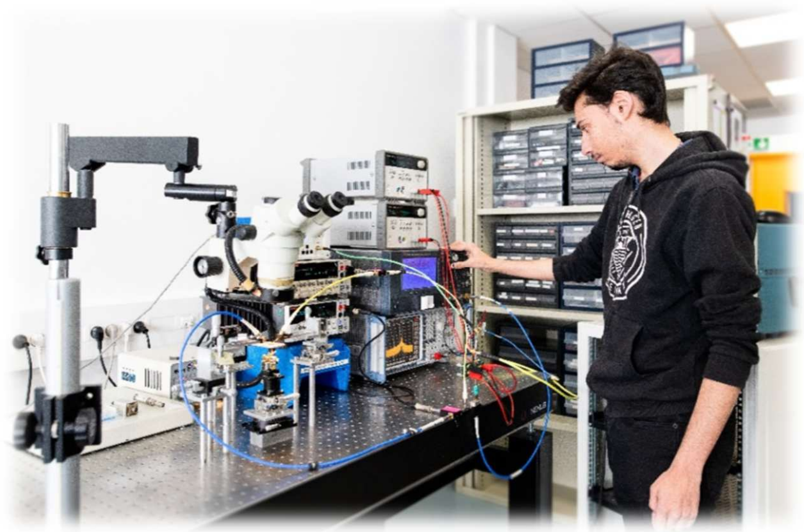
About SPINTEC

Positioned at the crossroad of science and technology, SPINTEC (SPINtronique et TEchnologie des Composants) is one of the leading spintronics research laboratories worldwide, ideally located on the *MINATEC* campus in Grenoble. The laboratory was created in 2002 and rapidly expanded to now exceed 120 persons of which 53 Permanent staff and almost 70 interns, Ph.D. students, post-docs and international visitors. **The scientific institutions taking part in the lab are**: *CEA*, *CNRS*, and the *University of Grenoble Alpes* including the *Grenoble Institute of Technology*.

SPINTEC's objective is to **bridge fundamental research and innovative devices in the fast-growing field of spin electronics** (spintronics). Indeed, the *international technology roadmap for semiconductors (ITRS)* now reckons that spintronics devices will play a major role in tomorrow's semiconductor chips, with high potential for fast and low-power stand-alone (e.g. DRAM) and embedded memories, magnetic field sensors, hardware components for artificial intelligence and bio-applications. **In this context, SPINTEC brings together top-level scientists and applicative engineers** who work in close collaboration, to ensure that discoveries at the forefront of research can be swiftly translated into technological proofs of concepts and functional devices. As such, **the outcome of the laboratory is not only scientific publications and communications at international conferences**, but also a **coherent patents portfolio**, implementation of **relevant functional demonstrators**, and partnerships for technology transfer. Our large scale provides the critical mass to master all required steps ranging from materials, nanofabrication, electrical and magnetic characterization, condensed-matter theory, simulation and the design of dedicated integrated circuits.

Whereas our fundamental research is mostly operated through collaborative grants with other research laboratories, **applied research is often carried out in partnership with private actors**. These can be large corporations (Applied Materials, Samsung, Seagate, INTEL, Texas Instruments, Allegro Microsystems), SME's (Singulus, Spin Ion) or **start-up companies spun-off from SPINTEC**: Crocus Technology in 2006, eVaderis in 2014, HProbe in 2016, Antaïos in 2017, Golana Computing in 2023 and Nellow in 2024.

SPINTEC plays also a major role in higher education in magnetism and nanotechnology, through chairing or steering four highly-visible international schools: *the European School on Nanosciences and Nanotechnology* ESONN, the *European School on Magnetism* ESM, the school on applied spintronics InMRAM, and the school *Quantitative Electron Microscopy* QEM.



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company/spintec-lab