MML2025

12th International Symposium on Metallic Multilayers

University of Leeds, Leeds, UK
13–18 July 2025

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Programme: Monday 14 July 2025

10:00 AM - 10:15 AM	Registration and Arrival Refreshments
10:00 AM - 10:15 AM	Welcome
10:15 AM - 11:00 AM	Plenary Talk: Laura Heyderman Magnetic multilayers: patterning functionality and adding functionality to patterned structures
11:00 AM - 11:30 AM	Invited Speaker: Silvia Tacchi Exploring new strategies for developing reconfigurable magnonic systems
11:30 AM - 12:00 PM	Invited Speaker: Haiming Yu Interlayer magnon coupling in magnetic metal/insulator hybrid nanostructures
12:00 PM - 1:30 PM	Lunch
1:30 PM - 2:00 PM	Invited Speaker: Shugo Yoshii Ultrastrong coupling of magnon polaritons in on-chip thin ferromagnetic films
2:00 PM - 2:15 PM	Contributed Talk: Huaiyang Yuan Interplay of spin waves and surface plasmons in hybrid magnet/2D material structures
2:15 PM - 2:30 PM	Contributed Talk: Troy Dion Magnon frequency combing in strongly dipolar coupled magnetic layers
2:30 PM - 3:00 PM	Invited Speaker: Akash Kumar Spin-wave mediated mutual synchronization in spin Hall nano-oscillators
3:00 PM - 3:30 PM	Afternoon Break
3:30 PM - 3:45 PM	Contributed Talk: Matthieu Bailleul Magneto-resistive detection of spin-waves
3:45 PM - 4:00 PM	Contributed Talk: Gianluca Gubbiotti Magnon confinement in a nanomagnonic waveguide by a magnetic Moiré superlattice
4:00 PM - 4:30 PM	Invited Speaker: Amal El-Ghazaly Tuning Magnetic Thin-Film Behavior for Microwave Operation
4:30 PM - 5:00 PM	Invited Speaker: Gustav Bihlmayer Lanthanide-transition metal heterostructures

5:00 PM - 5:15 PM	**Contributed Talk: Tsz Chung Cheng** Determination of exchange stiffness in Pt/Co/Ni multilayer system
5:15 PM - 5:30 PM	**Contributed Talk: Peter Fischer** Curvature induced spin textures in thin magnetic films deposited on nanowire networks

Programme: Tuesday 15 July 2025

9:00 AM - 9:45 AM	**Plenary Talk: Pietro Gambardella** Orbital torques and orbital transport in metallic multilayers
9:45 AM - 10:15 AM	**Invited Speaker: Thomas Saunderson** Superconductivity and Orbitronics - Exploring Rashba Edelstein Effects with Broken Inversion Symmetry
10:15 AM - 10:30 AM	**Contributed Talk: Koki Takanashi** Spin-dependent transport in ferromagnetic high-entropy-alloy thin films
10:30 AM - 11:00 AM	**Morning Break**
11:00 AM - 11:30 AM	**Invited Speaker: Fatima Ibrahim** Dzyaloshinskii-Moriya interaction chirality reversal with ferromagnetic thickness
11:30 AM - 11:45 AM	**Contributed Talk: Sophie A. Morley** Investigating topological Hall effect using simultaneous soft x-ray scattering
11:45 AM - 12:00 PM	**Contributed Talk: Hari Babu Vasili** Tunable Spin Blocking and Unidirectional magnetoresistance in YIG/PtMn/C60
12:00 PM - 1:30 PM	**Lunch**
1:30 PM - 2:00 PM	**Invited Speaker: Jacob Gayles** Tunable of Universal Quantum States at Weyl Semimetal Interstitial Interfaces with Magnetic Textures
2:00 PM - 2:15 PM	**Contributed Talk: Emily Heppell** Search for proximity-induced magnetism in CrTe2/Bi2Te3 ferromagnet-topological insulator heterostructures
2:15 PM - 2:30 PM	**Contributed Talk: Dario Arena** Probing Exchange Interactions in Epitaxial Multilayers and Topological Weyl Semimetal Thin Films
2:30 PM - 3:00 PM	**Invited Speaker: Tim Moorsom** Imaging plasmon-polaritons at Topological-Insulator/Nanocarbon interfaces using STEM-EELS
3:00 PM - 4:30 PM	**Afternoon Break and Poster Session 1**
4:30 PM - 4:45 PM	**Contributed Talk: Servet Ozdemir** Thickness dependent investigation of single target grown c-plane epitaxial Kagome crystal Mn3Ge films

4:45 PM - 5:00 PM	**Contributed Talk: Agustina Asenjo** Anomalous Nernst Effect of strained multilayers
5:00 PM - 5:30 PM	**Invited Speaker: Masahito Mochizuki** Thermal Dynamics and Related Material Functions of Magnetic Skyrmions
5:30 PM - 7:00 PM	**Early Career Networking event** Room: Riley Smith Theatre, Leeds University Union

Programme: Wednesday 16 July 2025

9:00 AM - 9:45 AM	**Plenary Talk: Andrew Kent** Spin-Oscillators based on Ferrimagnetic Insulators
9:45 AM - 10:15 AM	**Invited Speaker: Freya Johnson** Navigating Chiral Spin Architectures in Non-Collinear Antiferromagnetic Thin Films
10:15 AM - 10:30 AM	**Contributed Talk: Alexey Kovalev** Spin-transfer torque in altermagnets with magnetic textures
10:30 AM - 11:00 AM	**Morning Break**
11:00 AM - 11:30 AM	**Invited Speaker: Takahiro Moriyama** Magnetization dynamics in nanoscale antiferromagnets
11:30 AM - 12:00 PM	**Invited Speaker: Del Atkinson** Rare Earth-Transition Metal Ferrimagnetic Thin-Films For Spintronics: Mapping Magnetization and Compositional Gradients
12:00 PM - 1:30 PM	**Lunch**
1:30 PM - 2:00 PM	**Invited Speaker: Vincent Cros** Neuromorphic weighted sums with topological spin textures
2:00 PM - 2:15 PM	**Contributed Talk: Valentin Ahrens** Skyrmion Brownian Motion in Ion Irradiated W/CoFeB/MgOFilms
2:15 PM - 2:30 PM	**Contributed Talk: Philippe Talatchian** Entropy-Assisted Nanosecond Stochastic Operation in Perpendicular Superparamagnetic Tunnel Junctions
2:30 PM - 3:00 PM	**Invited Speaker: Tom Hayward** Integrated Magnonic Reservoir Computing with Magnetic Metamaterials
3:00 PM - 4:30 PM	**Afternoon Break and Poster Session 2**
4:30 PM - 5:00 PM	**Invited Speaker: Christos Panagopoulos** Topological spin textures for quantum operations
5:00 PM - 5:15 PM	**Contributed Talk: Alex Jenkins** Local reconfiguration of antiferromagnetic layer in magnetic tunnel junctions in the context of radio-frequency spintronic neuromorphics
5:15 PM - 5:30 PM	**Contributed Talk: Paul Keatley** Magnetization dynamics driven by displacement currents across a magnetic tunnel junction

Programme: Thursday 17 July 2025

9:00 AM - 9:45 AM	**Plenary Talk: Roopali Kukreja** Unraveling Optically Induced Ultrafast Modification of Nanoscale Magnetic Textures
9:45 AM - 10:15 AM	**Invited Speaker: M. Benjamin Jungfleisch** Terahertz Pulse Shaping and Chirality Control using a Spintronic-Semiconductor Hybrid Emitter
10:15 AM - 10:30 AM	**Contributed Speaker: Evangelos Papaioannou** Spin-to-charge current conversion and THz emission in graded tetragonal L1o-FePt alloyed interfaces
10:30 AM - 11:00 AM	**Morning Break**
11:00 AM - 11:30 AM	**Invited Speaker: Oliver Gueckstock** Terahertz interface probing of spintronic heterostructures
11:30 AM - 11:45 AM	**Contributed Speaker: Shreya Shrestha** Correlating ultrafast demagnetization with terahertz radiation using spintronic bilayer heterostructures
11:45 AM - 12:00 PM	**Contributed Speaker: Oscar Cespedes** Low-energy, ultrafast anisotropy switching at competing hybrid interfaces
12:00 PM - 1:30 PM	**Lunch**
1:30 PM - 2:00 PM	**Invited Speaker: Anjan Soumyanarayanan** Chiral Spin Textures: Stability, Readout, and All-Electrical Control
2:00 PM - 2:15 PM	**Contributed Speaker: Robert Frömter** Equilibrium density of dipolar-stabilized Skyrmion lattices at zero field
2:15 PM - 2:30 PM	**Contributed Speaker: Sophie A. Morley** Investigating magnetic domain dynamics in an amorphous Fe-Ge thin film through X-ray Photon Correlation Spectroscopy with an MCP/TimePix3 detector
2:30 PM - 3:00 PM	**Invited Speaker: Lucas Caretta** Manipulating spin textures in magnetic and multiferroic heterostructures
3:00 PM - 3:30 PM	**Afternoon Break**

3:30 PM - 4:00 PM	**Invited Speaker: Timo Kuschel** Static and dynamic depth profiling of magnetic multilayers using advanced x-ray reflectivity and spectroscopy techniques
4:00 PM - 4:15 PM	**Contributed Speaker: Markus Goessler** Magneto-ionic control of coupled spin-valve heterostructures
4:15 PM - 4:30 PM	**Contributed Speaker: Toshiaki Morita** Strain induced reversible modulation of magnetism in transition-metal thin film near Curie temperature
4:30 PM - 5:00 PM	**Invited Speaker: Jorge Puebla** On-chip hybrid magnetoelastic waves
5:00 PM - 5:15 PM	**Contributed Speaker: Shunsuke Sakai** Giant Nonreciprocity in Surface Acoustic Wave Transmission Using Simple $SiO_2/Ni/SiO_2$ Multilayer Structure
5:15 PM - 5:30 PM	**Contributed Speaker: Fanfan Meng** Strain-Mediated Magnetoelectric Coupling in Scaled Devices for Out-of-Plane Magnetization Switching
6:20 PM - 6:45 PM	**Coaches Depart for the Conference Dinner**
6:45 PM - 10:30 PM	**Conference Dinner at the Royal Armouries Museum** Armouries Drive, Leeds, LS10 1LT

Programme: Friday 18 July 2025

9:00 AM - 9:45 AM	**Plenary Talk: Teruo Ono** Superconducting diode effect in metallic multilayers
9:45 AM - 10:15 AM	**Invited Speaker: Stuart Parkin** Magnetic and superconducting junctions formed with 2D van der Waals layers
10:15 AM - 10:30 AM	**Contributed Talk: Henry de Libero** Spin relaxation determined by ferromagnetic damping in large-area CVD monolayer MoS_2/permalloy heterostructures
10:30 AM - 11:00 AM	**Morning Break**
11:00 AM - 11:30 AM	**Invited Speaker: Divine Kumah** Probing emergent metallicity and superconductivity at oxide heterointerfaces
11:30 AM - 11:45 AM	**Contributed Talk: Samira Dorri** Artificial superlattices with abrupt interfaces by monolayer-controlled growth kinetics during magnetron sputter epitaxy
11:45 AM - 12:00 PM	**Contributed Talk: Sabine Pütter** The impact of hydrogen absorption on the magnetic properties of Pd/Co/Pd
12:00 PM - 1:30 PM	**Lunch**
1:30 PM - 2:00 PM	**Invited Speaker: Jagadeesh Moodera** Majorana Bound States and Diode Phenomenon in Superconductor-Ferromagnet Proximity Coupled Systems
2:00 PM - 2:15 PM	**Contributed Talk: David Dekadjevi** Electrical, optical and mechanical tailoring of magnetic properties in an extrinsic multiferroic : a case study
2:15 PM - 2:30 PM	**Contributed Talk: Marco Hoffmann** Real-time observation of VCMA-assisted magnetization switching
2:30 PM - 3:00 PM	**Invited Speaker: Marios Hadjimichael** Probing the nature of nanoscale domain walls in ferroelectric superlattices
3:00 PM - 3:15 PM	**Closing**

Plenary Speakers

Orbital torques and orbital transport in metallic multilayers

Pietro Gambardella[1]
[1]ETH Zurich, Switzerland

Plenary Talk: Prof. Pietro Gambardella, July 15, 2025, 09:00 - 09:45

The study of magnetic multilayers began in earnest during the 1970s and 1980s, driven by advances in ultra-high vacuum deposition techniques and sensitive characterization methods. Early breakthroughs included the discovery of magnetism in two-dimensional systems, the induction of perpendicular magnetic anisotropy via interfacial effects, and the observation of giant magnetoresistance. Remarkably, even after more than five decades of extensive research, metallic multilayers—including topologically trivial systems—continue to reveal novel physical phenomena that pose intriguing fundamental questions and technological opportunities. This talk will explore the emerging field of electric-field-induced nonequilibrium orbital magnetism in metallic multilayers. Key topics include the generation, transport, and relaxation of orbital momenta, as well as experimental evidence for magnetoresistive effects and spin-orbital torques in magnetic layers coupled to orbital current sources. If time allows, I will provide a perspective on the potential applications of orbital effects in next-generation spintronic technologies.

Magnetic multilayers: patterning functionality and adding functionality to patterned structures

Laura Heyderman[1,2]
[1]ETH Zurich, Switzerland, [2]PSI Center for Neutron and Muon Sciences, Switzerland

Plenary Talk: Prof. Laura Heyderman, July 14, 2025, 10:15 - 11:00

Nanopatterning of magnetic multilayers can both unlock fascinating physics and lead to new paradigms for applications. I will begin by discussing how functionality can be added to nanomagnets by introducing magnetic multilayers. In particular, incorporating perpendicular magnetic multilayers in artificial spin systems gives interesting behaviour resulting from frustration and opens the way for bioinspired computation. I will then show how our newly developed method of direct write laser annealing can be used to directly pattern functionality in the form of complex 2D gradients in thin films and multilayers.

Artificial spin systems, also referred to as artificial spin ices, are arrays of coupled nanoscale single-domain magnets. The ordering of the magnetic moments in such arrays depends on the lattice geometry, nanomagnet shape and magnetic anisotropy [1]. We have fabricated arrays of dipolar-coupled circular multilayer nanomagnets with out-of-plane anisotropy, placed on the vertices of the Archimedean lattices [2]. Following demagnetization in an alternating magnetic field, we have characterised the magnetic states with magnetic force microscopy. Performing Monte Carlo simulations, we find that the lattices fall into three main categories: bipartite lattices with a perfect antiferromagnetic ground state, frustrated lattices where ordering proceeds via a single step, and highly-frustrated lattices with two-step-ordering.
With such arrays of dipolar-coupled multilayer nanomagnets with perpendicular magnetic anisotropy, we can engineer the energy landscape to realise 2D lattices of out-of-plane Ising macrospins that spontaneously order at room temperature at timescales that can be precisely tuned [3]. This property, together with straightforward electrical interfacing, make such artificial spin systems a promising platform for reservoir computing.

By chirally coupling nanoscale magnets through the Dzyaloshinskii–Moriya interaction (DMI), artificial spin systems with strongly-coupled nanomagnets can be realized [4]. Through voltage-control of the lateral magnetic coupling with solid-state ionic gating, the magnetic ordering can be modulated and novel devices such as a programmable nanomagnetic Ising solver can be created [5]. An artificial probabilistic neuron device can also be constructed by combining voltage control of the chiral coupling, ultrafast laser excitation, and Hall resistance versus magnetic field measurements. These devices, with their intrinsic non-linearity and electrically tunable stochasticity, can then be implemented to give robust stochastic deep neural networks [6].

With direct write laser annealing of thin films and multilayers, complex nanoscale patterns with continuous variations in magnetic anisotropy, interlayer exchange coupling, and ferrimagnetic compensation can be manufactured in several different application-relevant magnetic and non-magnetic materials [7]. With such engineered gradients in the magnetic properties, we have demonstrated novel magnetic domain wall and magnonic devices.

[1] S.H. Skjærvø et al., Nat. Rev. Phys. (2020)
[2] A. Pac et al., Cond. Mat. arXiv:2503.08462
[3] A. Kurenkov et al., Cond. Mat. arXiv:2408.12182
[4] Z. Luo et al., Science (2019)
[5] C. Yun et al., Nat. Commun. (2023)
[6] Z. Liang et al., Adv. Funct. Mater. (2024)
[7] L. Riddiford et al., Cond. Mat. arXiv:2401.09314

Spin-Oscillators based on Ferrimagnetic Insulators

Andrew Kent[1]
[1]New York University, United States

Plenary Talk: Prof. Andrew Kent, July 16, 2025, 09:00 - 09:45

Spin-Hall nano-oscillators (SHNO) are spintronic devices that convert direct electrical current into coherent microwave and spin-wave signals. Their compact footprint and electrical tunability make them promising for integrated magnonic circuits, neuromorphic computing, and nonlinear networks. In this talk, I will present a new class of SHNO based on lithium aluminate ferrite (LAFO) thin films—ferrimagnetic insulators that combine low damping with tunable magnetic properties [1]. We demonstrate two distinct device architectures: 1) Hybrid SHNOs comprising transition metal Pt/Py nanowires on extended LAFO thin films, where the ferrimagnetic layer enhances the oscillator quality factor and significantly lowers the auto-oscillation threshold [2] and 2) Insulating ferrimagnetic SHNOs using Pt nanowires on LAFO films, where current-induced auto-oscillations are detected via spin-Hall magnetoresistance [3]. Both devices exhibit single-mode operation, narrow linewidths, and a field-current polarity of excitations consistent with spin-Hall torque symmetry. Using micromagnetic simulations, we show that ferrimagnetic layers not only reduce effective damping but also change the spin-wave mode profile, enabling spatially tunable localization and propagation [4]. These hybrid and insulating ferrimagnetic SHNOs offer a path toward programmable magnonic logic, coupled oscillator arrays, and Ising-type computing architectures.

References

[1] X. Y. Zheng, S. Channa, L. J. Riddiford, J. J. Wisser, K. Mahalingam, C. T. Bowers, M. E. McConney, A. T. N'Diaye, A. Vailionis, E. Cogulu, H. Ren, Z. Galazka, Andrew D. Kent & Y.Suzuki, "Ultra-thin lithium aluminate spinel ferrite films with perpendicular magnetic anisotropy and low damping," Nature Communications 14, 4918 (2023).
[2] H. Ren, X. Y. Zheng, S, Channa, G. Wu, D. A. O'Mahoney, Y. Suzuki, and A. D. Kent, "Hybrid spin Hall nano-oscillators based on ferromagnetic metal/ferrimagnetic insulator heterostructures" Nature Communications 14, 1406 (2023).
[3] H. Ren, Y-A. Lai, S. Channa, Daisy A. O'Mahoney, X. Y. Zheng, Y. Suzuki, and A. D. Kent, "Electrical Detection of Spin-Hall-Induced Auto-oscillations in Lithium Aluminate Ferrite Thin Films," Nano Letters 25, 6399 (2025).
[4] R. Xi, Ya-An Lai, and A. D. Kent, "Optimizing hybrid ferromagnetic metal–ferrimagnetic insulator spin-Hall nano-oscillators: A micromagnetic study," Journal of Applied Physics 136, 193901 (2024).

Unraveling Optically Induced Ultrafast Modification of Nanoscale Magnetic Textures

Roopali Kukreja[1]
[1]University of California Davis, United States

Plenary Talk: Prof. Roopali Kukreja, July 17, 2025, 09:00 - 09:45

Ultrafast control of magnetization has emerged as a new paradigm for the next generation memory and data storage devices. Numerous studies have been performed to understand the mechanism of transfer of angular momentum at such fast timescales. However, it has been recently recognized that nanoscale heterogeneities can play a critical role in dictating the ultrafast behavior. I will discuss our recent experimental results at x-ray free electron laser (XFEL) sources where we uncovered magnetic texture dependent magnetization dynamics at ultrafast timescales in CoNi/Fe and Co/Ni/Pt multilayers with perpendicular magnetic anisotropy. These experimental findings have been possible due to recent advances in x-ray and extreme ultraviolet sources which combine the power of coherent x-rays with femtosecond (fs) temporal resolution. Our results shows that the symmetry of magnetic texture dictates the magnitude and timescale of the ultrafast response. We observed fluence threshold dependence for distortions of diffraction pattern which are not seen for magnetization quenching in CoNi/Fe. Supported by simulations, we show that a speed of ~66 km/s for highly curved domain walls can explain the experimental data. Our results also show surprisingly distinct dynamics of Co and Ni in Co/Ni/Pt. Our results show that domain wall speeds above theoretically predicted breakdown can be achieved in non-equilibrium conditions driven by laser excitation. Our results show that far from equilibrium behavior can be used to manipulate spin degrees of freedom at mesoscopic lengthscales.

Superconducting diode effect in metallic multilayers

Teruo Ono[1,2]
[1]Institute for Chemical Research, Kyoto University, Japan, [2]Center for Spintronics Research Network, Kyoto University, Japan

Plenary Talk: Prof. Teruo Ono, July 18, 2025, 09:00 - 09:45

The diode effect is fundamental to electronic devices and is widely used in rectifiers and AC-DC converters. However, conventional diodes suffer from energy loss due to finite resistance. We found the superconducting diode effect (SDE) in Nb/V/Ta superlattices with a polar structure, which is the ultimate diode effect exhibiting a superconducting state in one direction and a normal state in the other [1-3]. The SDE can be considered as the nonreciprocity of the critical current for the metal-superconductor transition. We have also found the reverse effect, i.e., the nonreciprocal critical magnetic field under the application of supercurrent [4]. We also found that the polarity of the superconducting diode shows a sign reversal when the magnetic field is increased [5], which can be considered as the crossover and phase transitions of the theoretically predicted finite-momentum pairing states [6, 7]. SDE in Nb/V/Ta superlattices requires the application of an external magnetic field to break the time-reversal symmetry, which is a drawback in applications. Recently, we have succeeded in demonstrating zero-field SDE by introducing ferromagnetic layers into superlattices [8, 9]. The polarity of the SDE is controlled by the magnetization direction of the ferromagnetic layer, leading to the development of novel non-volatile memories and logic circuits with ultra-low power consumption.

This work was partly supported by JSPS KAKENHI Grant Numbers (18H04225, 18H01178, 18H05227, 20H05665, 20H05159, 21K18145), MEXT Initiative to Establish Next-generation Novel Integrated Circuits Centers (X-NICS) Grant Number JPJ011438, the Cooperative Research Project Program of the Research Institute of Electrical Communication, Tohoku University, and the Collaborative Research Program of the Institute for Chemical Research, Kyoto University.

References

[1] F. Ando et al., J. Magn. Soc. Japan 43, 17 (2019).
[2] F. Ando et al., Nature 584, 373 (2020).
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[4] Y. Miyasaka et al., Appl. Phys. Express 14, 073003 (2021).
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[6] A. Daido et al., Phys. Rev. Lett. 128, 037001 (2022).
[7] K. Nakamura et al., Phys. Rev. B 109, 094501 2024).
[8] H. Narita et al., Nat. Nanotechnol. 17, 823 (2022).
[9] H. Narita et al., Adv. Mater., 10.1002/adma.202304083.

Invited Speakers

Rare Earth-Transition Metal Ferrimagnetic Thin-Films For Spintronics: Mapping Magnetization and Compositional Gradients

Del Atkinson[1]
[1]*Durham University, United Kingdom*

Invited Speaker: Del Atkinson, July 16, 2025, 11:30 - 12:00

Rare Earth:Transition Metal (RE:TM) ferrimagnetic alloys have been of scientific and technological interest for around fifty years, most recently research has been stimulated by promising applications in spintronics. These metallic alloys consist of two antiferromagnetically coupled sublattices, each with distinct magnetization and angular momentum characteristics, which depend on both the temperature and the composition resulting in the occurrence of compensation points, where either the net magnetization or angular momentum are minimised. Typically, functional RE:TM alloys thin-films have PMA and an amorphous structure with the RE component around the 22-24 at% level, which is interesting considering the RE and TM components individually form polycrystalline films, the onset of the amorphous state is briefly considered as function of RE:TM composition [1]. The distribution of atomic species within these sublattices plays a crucial role in determining the electronic structure of the bulk material as well as the properties of the interfaces, which influence phenomena such as perpendicular magnetic anisotropy (PMA), proximity-induced magnetization (PIM), compensation points, and spin transport. PIM has been linked to the efficiency of interfacial spin transport [2], so the PIM in Pt interfaced with RE:TM alloys is also discussed [3]. While RE:TM systems are typically assumed to be compositionally uniform, recent investigations have revealed significant spatial heterogeneity in the elemental distribution, a factor that may have important implications for applications. Here the uniformity of the composition and the associated magnetic behaviour are discussed and it is shown that uniformity through the ‘bulk’ of a thin-film alloy should not be assumed, fig 1 [4], which has implications for RE:TM alloys in spintronics as these compositional variations affect the magnetization, compensation, PMA and potentially the spin transport. More recently, researchers have demonstrated that deliberately designed RE:TM compositional gradients can result in field-free SOT switching. In these works it is assumed the gradient drives a transition from in-plane to out-of-plane magnetization in the thin-films. Here magnetization profiles of the RE component and the total magnetization were mapped, using resonant x-ray and neutron reflectivity analyses, through the thickness of compositionally-graded RE:TM thin films to determine the in-plane and PMA regions. The results highlight the contrast between in-plane and out-of-plane regions and reveals a complex RE magnetic profile, influenced not only by RE concentration but also the local TM environment, which enhances the RE moments. These results advance our understanding of the magnetization profile through such compositionally-graded layers, which is key to field-free SOT switching, enabling a new generation of spintronic devices.

[1] Inyang, O., et al. "The role of low Gd concentrations on magnetisation behaviour in rare earth: transition metal alloy films." Sci. Rep. 10.1 (2020)
[2] C. Swindells et al. "Magnetic damping in ferromagnetic/heavy-metal systems: The role of interfaces and the relation to proximity-induced magnetism" Phys Rev B 105, 094433 (2022)
[3] Swindells et al. "Proximity-induced magnetism in Pt layered with rare-earth–transition-metal ferrimagnetic alloys." Phys. Rev. Res. 2.3 (2020)
[4] Inyang, O., et al. "Non-uniform Gd distribution and magnetization profiles within GdCoFe alloy thin films." Appl. Phys. Lett. 123.12 (2023)

Lanthanide-transition metal heterostructures

Gustav Bihlmayer[1]
[1]Peter Grünberg Institute, Germany

Invited Speaker: Gustav Bihlmayer, July 14, 2025, 16:30 - 17:00

Atomically thin layers of lanthanide materials are ideal systems to study the stability of magnetic order in two dimensions. Open shell atoms such as Dy or Ho show large magnetic anisotropies even in small crystal fields [1]. Species with quenched orbital moments (Gd or Eu) can be adsorbed on or intercalated between graphene and magnetic substrates like Co or Ni [2,3], also stacking several layers is possible [4]. We analysed the exchange interaction between the 4f layers and the 3d substrates and their modification by the graphene layers using density functional theory with appropriate extensions. Comparison with experimental data shows good agreement where available. Remarkably, the interaction between the 4f states and graphene leads to spin-selective modifications of the π band that is observed both in angle resolved photoemission spectroscopy experiments and the calculated band structures. We investigate the origin of this effect and consequences for graphene's transport properties.

I would like to thank my collaborators on these works, M. Jugovac, P. Perna, P. M. Sheverdyaeva, L. Ferrari, J. P. Carbone, J. Bouaziz, N. Atodiresei, and S. Blügel as well as the FLAG-ERA grant SOgrapMEM and the CRC 1238 of the Deutsche Forschungsgemeinschaft for their funding.

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[2] M. Jugovac et al., Adv. Mater. 35, 2301441 (2023).
[3] P. M. Sheverdyaeva et al., Phys. Rev. Lett. 132, 266401 (2024).
[4] M. Jugovac et al., Carbon 230, 119666 (2024).

Manipulating spin textures in magnetic and multiferroic heterostructures

__Lucas Caretta__[1]
[1]Brown University, United States

Invited Speaker: Lucas Caretta, July 17, 2025, 14:30 - 15:00

Excitations in magnetic materials, such as domain walls, skyrmions, merons, and vortices provide a rich playground for studying intriguing physical phenomena like chirality, topology, and spin-orbit interactions. Additionally, these excitations hold vast technological potential. For example, domain walls and skyrmions, which can be nucleated, annihilated, and translated by electrical stimuli, provide a promising approach to encode bits of information for next-generation memory and logic. One technological and scientific challenge is to stabilize and manipulate these magnetic excitations efficiently. This is critical for dense, power efficient, and fast beyond-CMOS memory and logic. However, in traditional ferromagnetic materials, these excitations face latency, energy consumption, and bit size challenges preventing their use in any competitive technologies. On the other hand, complex oxides exhibit a rich spectrum of functional responses, including multiferroicity, highly correlated electron behaviour, etc. By synthesizing and engineering new classes of spintronic metal/oxide multilayer materials systems, we show a pathway to overcome these fundamental limitations. Specifically, by using a combination of epitaxial growth techniques, interface design, and magnetic sublattice engineering, we drive magnetic domain walls to velocities over 4,300 m/s and stabilize room temperature topological spin textures smaller than 10 nm in size. Furthermore, I will show how low-power and scalable electric-fields can be used in magnetoelectric materials to drive spin textures at comparable speeds to spin currents with orders-of-magnitude less energy. By using advanced electrical and optical techniques (and developing new ones), we show that these systems provide a new platform to study complex fundamental phenomena like inversion symmetry-breaking and even relativistic dynamics.

Neuromorphic weighted sums with topological spin textures

T. da Câmara Santa Clara Gomes[1], B Paikaray[1], W. Boukaert[1], D. Sanz-Hernandez[1], S. Krishnia[1], M.-B. Martin[1], P. Seneor[1], L. Herrera-Diez[2], J. Grollier[1], N. Reyren[1], <u>Vincent Cros</u>[1]
[1]Laboratoire Albert Fert, CNRS, France, [2]C2N, CNRS, Univ. Paris-Saclay, France
Invited Speaker: Vincent Cros, July 16, 2025, 13:30 - 14:00

Magnetic skyrmions—topologically protected magnetic solitons—exhibit a combination of advantageous properties, including room-temperature stability, nanoscale dimensions, non-volatility, and particle-like behavior. These features make them particularly promising for neuromorphic computing applications [1–3]. In this work, we leverage the particle-like nature and non-volatility of skyrmions to implement basic neuromorphic functions, focusing on the weighted summation of synaptic inputs [4].

Our neuromorphic architecture consists of a crossbar array, where parallel magnetic tracks (representing synapses) are connected by transverse electrodes (acting as neurons). Electrical pulses applied to these electrodes control skyrmion nucleation and propagation (Fig. 1a). The number of skyrmions generated is proportional to the input signal, scaled according to the synaptic weight. To enable non-volatile and reversible tuning of synaptic weights, we employ magneto-ionic effects, where voltage gating modulates local magnetic properties [5]. Skyrmions are detected via anomalous Hall voltage measurements, which directly correlate with their count.

The crossbar configuration demonstrates successful weighted summation, as confirmed by the Hall voltage readings that match the expected skyrmion accumulation (Fig. 1b). This approach highlights a scalable and energy-efficient path toward neuromorphic computing. With further development in magneto-ionic modulation and nonlinear detection, this platform could support ultra-low-power brain-inspired hardware, targeting energy consumptions as low as 1–100 aJ per synaptic operation.

Acknowledgements : This work is supported by a France 2030 government grant managed by the French National Research Agency (grant no. ANR-22-EXSP-0002 PEPR SPIN CHIREX) and ANR/DFG (Topo3D), by the EU project SkyANN (reference no. 101135729) and the European Research Council advanced grant GrenaDyn (reference no. 101020684) and by CEFIPRA project n°6508-2.

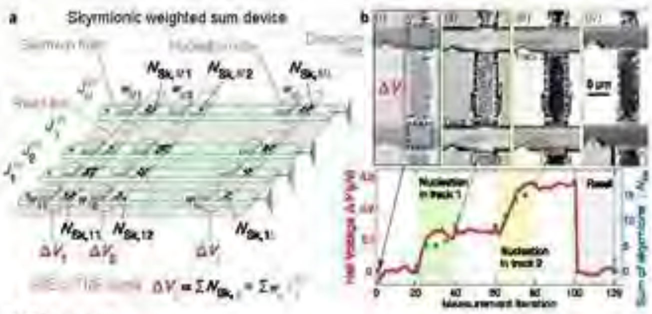

Figure 1. a, Schematics of a skyrmions crossbar array for realizing a weighted sum operation **b**, Top, Kerr microscopy images showing the skyrmion nucleation in two tracks, before they are erased by a magnetic field. Bottom, the measured Hall voltage ΔV (red) accurately reflects the total number of skyrmions observed $\sum N_{Sk,detec}$ (blue circles).

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Tuning Magnetic Thin-Film Behavior for Microwave Operation

Amal El-Ghazaly[1]
[1]*Cornell University, United States*

Invited Speaker: Amal El-Ghazaly, July 14, 2025, 16:00 - 16:30

Magnetic thin films have made their way into microwave electronics as noise suppressors [1], inductors [2], antennas [3], and filters [4], among other components. Of particular interest are thin film magnetoelectric composites, i.e., composites made of magnetostrictive and piezoelectric materials, which offer the opportunity to tune the magnetic permeability and resonance frequency by means of an electrical voltage signal, thereby producing voltage-tunable inductors, filters, etc. In this talk, we will present thin-film magnetic and magnetoelectric materials developed for microwave electronics applications, including tunable filter components.

The talk will focus on three primary advances: ferromagnetic arrays, ferrimagnetic heterostructures, and magnetoelectric composites. First, we will present how the effective permeability of thin-film ferromagnet arrays can be increased while still achieving microwave frequency operation, through shape anisotropy, with a bandwidth of up to 9-12 GHz. Then, we will show how ferrimagnetic Gd-Co-O was optimized to maximize its single layer anisotropy; the single layer was then repeated to make a multilayer heterostructure that achieves a bandwidth of operation up to ~30 GHz [5]. Once high frequency, microwave operation of the magnetic materials is secured, our attention turns to voltage-tunability. Thus, finally, we will show how magnetoelectric thin film composites of CoFeB/PNZT were used to demonstrate fully-integrated, voltage-tunable coplanar waveguide resonators that can be used for adaptive filtering in wireless systems [4].

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Tunable of Universal Quantum States at Weyl Semimetal Interstitial Interfaces with Magnetic Textures

Jacob Gayles[1]
[1]*University of South Florida, United States*

Invited Speaker: Jacob Gayles, July 15, 2025, 13:30 - 14:00

Magnetic multilayers of alternating Weyl and Skyrmionic topologies are highly sought for novel device technology due to the possibility of efficiently manipulating magnetic textures and realizing phenomena such as the quantum anomalous Hall effect. In magnetic Weyl semimetals, the electronic band structure features pairs of Weyl nodes with opposite chirality charges, and the momentum space position of these nodes can reverse across a planar interface, giving rise to Fermi-arc-like bound states. We use a low-energy approximation to show that a magnetic interstitial layer can tune these states in three distinct ways: the electrostatic potential and in-plane magnetic potential components control the shape of the bound-state Fermi-arcs, with moderate in-plane magnetic potentials spin-filtering electrons across the interface1. Additionally, both in-plane magnetic components and electrostatic potentials regulate electron transmission, while the ratio of in-plane to out-of-plane magnetic components modulates magnetic potential effects. This tunability stems from spin-momentum locking and chirality reversal at the interface, allowing for a material-dependent interchange of states. Our model can be universally extended to investigate 2D planar twinning interfaces in B20 compounds using first-principles calculations, focusing on the Weyl semimetal CoGe2 with a FeGe3 interstitial. By employing supercell calculations that restrict the interface to the primitive cell, we demonstrate that the spin and anomalous Hall effects are significantly enhanced due to increased spin-orbit coupling and atomic potential variations at the interface. We explore the interplay between nonmagnetic Weyl semimetals and magnetic skyrmion-hosting systems in heterostructures across two thickness regimes: one with a semi-infinite Weyl system and a thin skyrmion-hosting film and the other with a semi-infinite skyrmion system and a thin Weyl film. This work defines the physical bounds of skyrmion-Weyl interactions and determines methods to maximize the synergy of these two systems.

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Terahertz interface probing of spintronic heterostructures

Oliver Gueckstock[1]
[1]*University of Berlin, Germany*

Invited Speaker: Oliver Gueckstock, July 17, 2025, 11:00 - 11:30

To extend current charge-based electronics by new features and functionalities, the electron spin, as a new degree of freedom, is likely to play a major role in future information technology. Devices using spin-based electronics need to be competitive with other information carriers and, therefore, it is required to push the bandwidth of the elementary spintronic operations to the terahertz (THz) frequency range.
To study ultrafast spin transport in prototypical magnetic-non-magnetic (F|N) bilayers, we excite them with femtosecond laser pulses. Following absorption of the pulse, a spin current in F is launched and converted into a transverse charge current in N and/or F, giving rise to the emission of a THz electromagnetic pulse. Using this approach, we first can get insights into the driving forces of the spin current: (i) a gradient in temperature gradient (Seebeck-like effect) [3] and (ii) a gradient in spin voltage between F and Pt [4]. In metallic F, (ii) dominates and relies on conduction electrons, while (i) is stronger for insulating F and mediated by magnons [3,4]. We can clearly observe a cross-over of both driving forces in the ferrimagnet magnetite Fe2O3 [5]. Surprisingly, we find only Seebeck-type dynamics in the fully metallic ferromagnet Gd [6].
In a further study, we leverage the interface sensitivity of ultrafast photo induced spin currents that are typically confined to within only ~1 nm around the F/N interface. More specifically, we investigate the impact of the F/N interface morphology and sample temperature on the THz-emission signal. We find that the temperature-dependence of the THz emission signal depends critically on the roughness and composition of the F/N interface. Furthermore, we obtain insights into the exact interface properties with transmission electron microscopy and are able to connect the amplitude and dynamics of the emitted THz pulse with the F/N interface. We conclude that the Curie temperature of F at the F/N interface is strongly reduced relative to the bulk by the higher degree of disorder at the F/N interface [7].

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Probing the nature of nanoscale domain walls in ferroelectric superlattices

Edoardo Zatterin[1], Petr Ondrejkovic[2], Louis Bastogne[3], Céline Lichtensteiger[4], Ludovica Tovaglieri[4], Daniel A. Chaney[1], Alireza Sasani[3], Alexei Bosak[1], Steven Leake[1], Pavlo Zubko[5,6], Philippe Ghosez[3], Jirka Hlinka[2], Jean-Marc Triscone[4], Marios Hadjimichael[7]
[1]ESRF—The European Synchrotron, France, [2]Institute of Physics of the Czech Academy of Sciences, Czech Republic, [3]Theoretical Materials Physics, Q-MAT, Université de Liège, Belgium, [4]Department of Quantum Matter Physics, University of Geneva, Switzerland, [5]University of Warwick, United Kingdom, [5]University College London, United Kingdom, [6]London Centre for Nanotechnology, United Kingdom

Invited Speaker: Marios Hadjimichael, July 18, 2025, 14:30 - 15:00

In ferroelectrics, the large strain-polarisation coupling originally led researchers to believe that rotations of the polarisation away from the polar axis were forbidden and all domain walls in these systems had Ising character. However, the observation of unexpected polarisation textures such as vortices, skyrmions and merons in ferroelectric heterostructures has challenged the widely accepted Ising-like picture of ferroelectric domain walls [1-3]. Further reports of domain wall chirality due to Bloch-like polarisation rotation in $PbTiO_3/SrTiO_3$ superlattices have opened exciting perspectives [4-5], yet the ubiquitous nature of this Bloch component remains to be further explored. Nevertheless, efforts in the characterisation of ferroelectric domain walls are hindered by limitations in experimental techniques, as the sizes of these domain walls are extremely small compared to their ferromagnetic counterparts.

In this talk, I will present a comprehensive investigation of domain walls in $PbTiO_3/SrTiO_3$ superlattices, involving a combination of first- and second-principles calculations, phase-field simulations, diffuse scattering calculations, and synchrotron based diffuse x-ray scattering. Our theoretical calculations highlight that the previously predicted Bloch polarisation in the domain walls of $PbTiO_3/SrTiO_3$ superlattices is extremely sensitive to the boundary conditions of the system and interacts adversely with the flux-closure polarisation. To probe this complex interaction, we develop an experimental method based on synchrotron diffuse x-ray scattering measurements, and through this approach, we investigate depolarization-driven ferroelectric polarization rotation at the domain walls.

Finally, I will compare our findings to the expected experimental signatures of Bloch components in the centres of the 180° domain walls of our $PbTiO_3/SrTiO_3$ superlattices. Our results suggest that the precise nature of ferroelectric domain walls is more intricate than previously thought and deserves more attention, and that diffuse x-ray scattering is an ideal tool for the characterisation of complex polarisation textures in nanoscale ferroelectrics [6].

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Integrated Magnonic Reservoir Computing with Magnetic Metamaterials

Charles Swindells[1], Ian Vidamour[1], Guru Venkat[1], Eleni Vasilaki[1], Tom Hayward[1]
[1]*University Of Sheffield, United Kingdom*

Invited Speaker: Tom Hayward, July 16, 2025, 14:30 - 15:00

Reservoir computing (RC) is a machine learning paradigm where computation is performed using the intrinsic memory and nonlinearity of a dynamical system. Traditionally, the dynamic system is provided algorithmically by a recurrent neural network, but such a network can be replaced with a physical dynamic system to realise the paradigm in hardware [1]. Substituting the complex simulation of a neural network with measurements of the intrinsic physical dynamics of a device has the potential to greatly reduce the energy costs of both training and inference.

Magnetic metamaterials such as artificial spin ices and interconnected magnetic nanoring arrays (NRAs) [2] exhibit rich, emergent dynamics that stem from the local interactions between the constituent elements in an array. The complex, history dependent and highly non-linear magnetisation dynamics of these arrays, coupled with their enormous state spaces, make magnetic metamaterials compelling candidates for use as physical reservoirs.

Motivated by this, we have shown state-of-the-art performance of interconnected NRAs as reservoir computers, where their global anisotropic magnetoresistance was used as an output [3]. However, this low dimensional readout of restricts the representation of the NRA's complex state space to a scalar value, thus sacrificing computationally useful information. Alternatively, measuring spin wave spectra offer a route to obtaining rich, multidimensional representations of reservoir state, but previous demonstrations have been restricted to flip-chip measurements of macroscopic arrays (~mm^2) via coplanar waveguide ferromagnetic resonance (FMR) measurements, which lack device compatibility.

Here, we present new experimental results that demonstrate how this approach can be made device compatible. We integrate a single 100 x 100 μm^2 NRA onto a Pt waveguide allowing us to measure Spin Orbit Torque FMR spectra as a reservoir output (Figure 1(a)). This approach also offers additional functionality: applying small bias currents (~100 μA) to the waveguides produce transformations of the FMR spectra that provide further information on the NRAs magnetic state, enhancing the computational power of the output when compared to standard FMR measurements (Figure 1(b)&(c)). We use this approach to demonstrate strong computing performance on both waveform transformation and time series prediction tasks. Finally, we show how our device can be used to perform powerful computation in the absence of the external magnetic fields that are normally used to drive the device's magnetisation dynamics. We utilise the non-linear, frequency dependent transformations provided by the bias current to create Extreme Learning Machine (ELM) capable of classifying digits from MNIST dataset with ~94 % accuracy. Our work provides a clear route to realising magnonic fingerprinting of magnetic states as a computational tool in novel neuromorphic devices.

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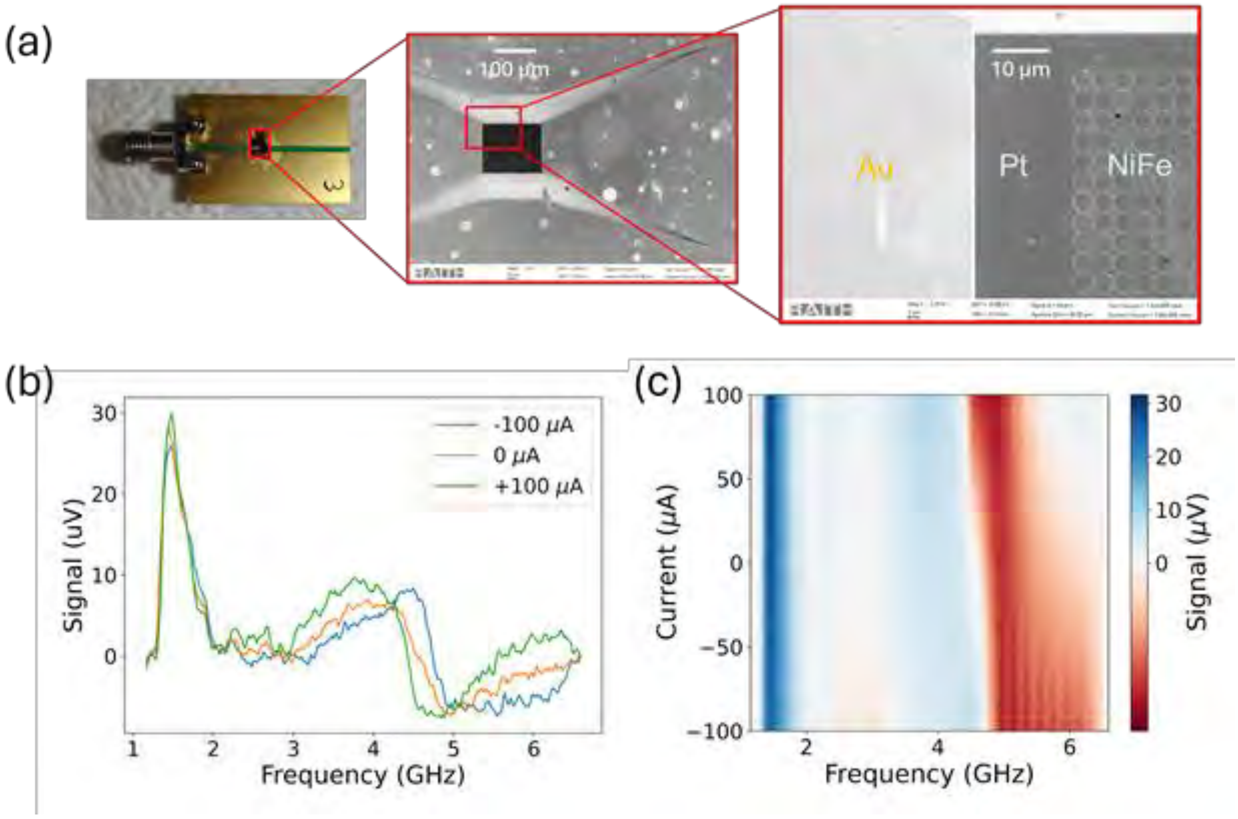
Figure 1: (a) SEM images illustrating a NiFe nanoring array integrated onto a Pt waveguide for SOT-FMR measurements. (b) Example SOT-FMR spectra measured from the NRA post-saturation for three different bias currents. (c) Colour plot illustrating the SOT-FMR response over a range of bias currents and frequencies.


(a)
100 μm
10 μm
Au
Pt
NiFe
(b)
Signal (uV)
Frequency (GHz)
-100 μA
0 μA
+100 μA
(c)
Current (μA)
Frequency (GHz)
Signal (μV)

Dzyaloshinskii-Moriya interaction chirality reversal with ferromagnetic thickness

__Fatima Ibrahim__[1], Capucine Gueneau[1], Johanna Fischer[1], Libor Vojáček[1], Charles-Élie Fillion[1], Stefania Pizzini[2], Laurent Ranno[2], Isabelle Joumard[1], Stéphane Auffret[1], Jérôme Faure-Vincent[1], Claire Baraduc[1], Mairbek Chshiev[1,3], Hélène Béa[1,3]
[1]Univ. Grenoble Alpes, CEA, CNRS, France, [2]Univ. Grenoble Alpes, CNRS, Néel Institute, France, [3]Institut Universitaire de France (IUF), France

Invited Speaker: Fatima Ibrahim, July 15, 2025, 11:00 - 11:30

Interfacial Dzyaloshinskii-Moriya interaction (DMI) plays a key role in stabilizing spin textures such as skyrmions or chiral domain walls in ultrathin heavy metal/ferromagnet/oxide (HM/FM/MOx) heterostructures with perpendicular magnetic anisotropy [1]. This antisymmetric exchange interaction arises from the combination of spin-orbit coupling (SOC) and structural inversion asymmetry at HM/FM and FM/MOx interfaces. The material-dependence of DMI in HM/FM [2,3] and tuning its chirality by the oxidation of FM/MOx interfaces [4-6] were predicted and observed. However, the dependence of the DMI chirality solely on the ferromagnetic thickness has not been systematically studied yet.

Here, we present a joint experimental and theoretical study of the DMI sign variation with both the ferromagnet thickness and oxidation state; untangling the mechanisms governing the DMI chirality in Ta/FeCoB/TaOx. An experimental DMI chirality map was determined from the current-driven direction of domain walls motion and skyrmions in crossed double wedge designed samples enabling to differentiate oxidation effects from ferromagnetic thickness-related DMI changes. Surprisingly, we observed a DMI chirality inversion when varying FeCoB thickness that is evident across several oxidation states.

To understand the observed DMI sign inversion with the FM thickness, we conducted ab-initio calculations on Fe_n/Ta_m bilayers with variable Fe thickness and Ta oxidation state, n and m representing the number of monolayers. From the calculated DMI energies, a DMI sign change between three and five Fe monolayers is obtained for the unoxidized interface. The layer-resolved difference in the chirality-dependent SOC energy ΔE_soc^k(Fig. 1(a)), predominantly located at the interfacial Ta1 layer, shows a remarkable sign crossover between Ta_3Fe_3 and Ta_3Fe_5 structures, which is at the origin of the overall DMI sign change. Microscopically, the variation of 5d orbital-resolved SOC energy of Ta1 layer (Fig. 1(c, d)) shows a substantial difference in the SOC matrix element contribution corresponding to the hybridization between d_(z^(2)) and d_xz orbitals, which is strongly negative for Ta_3Fe_3 and becomes positive by increasing the Fe thickness in Ta_3Fe_5. We analyze this in the framework of first-order perturbation theory where a variation in the 5d orbital occupation of Ta1 is induced by structural relaxation namely a decrease of the Fe-Ta interfacial distance ‘z’ when increasing the Fe thickness (Fig. 1(b)). This study paves the way to a deterministic control of skyrmions and chiral domain walls through strain engineering via tuning the ferromagnetic thickness [7].

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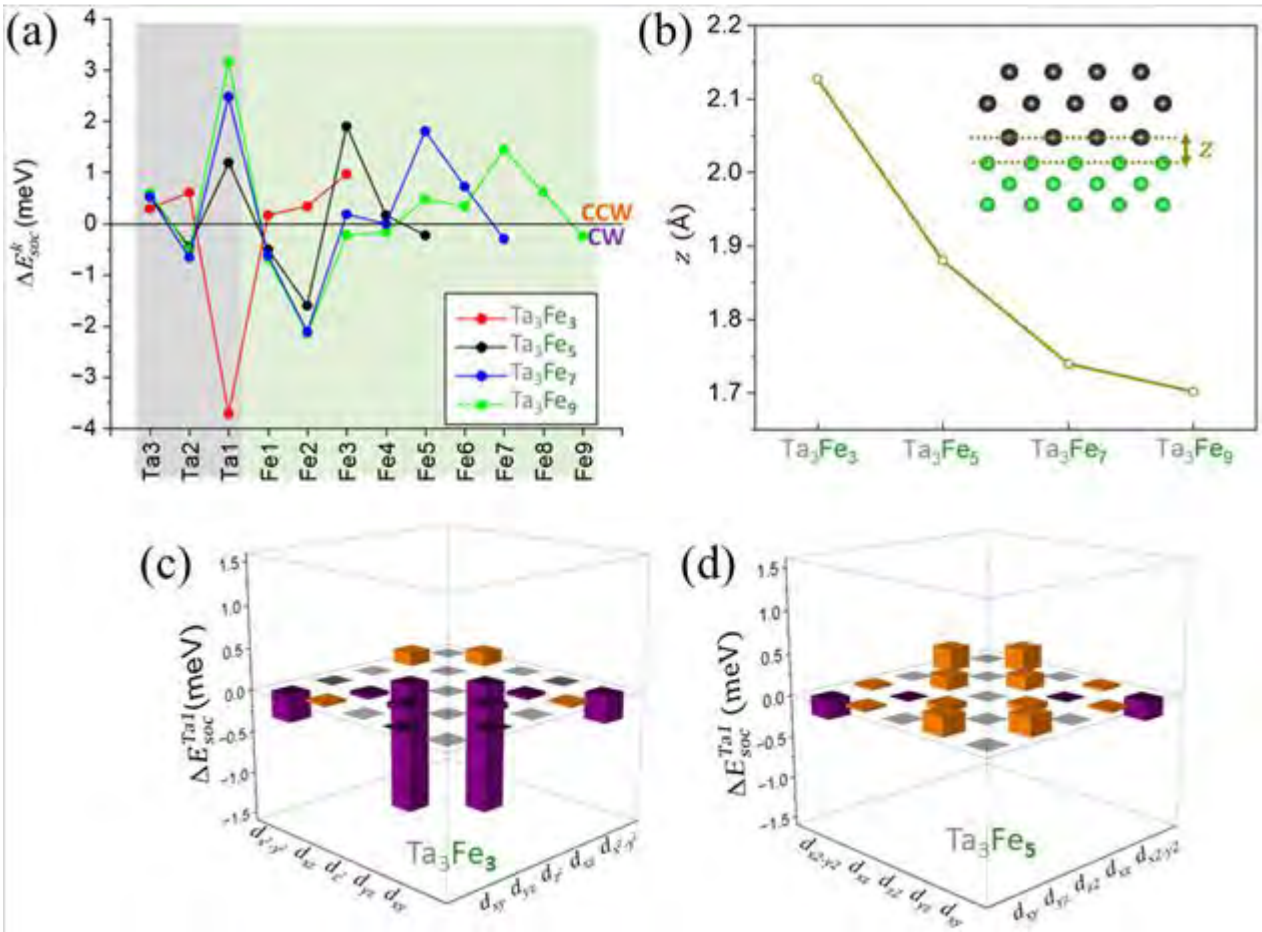
Fig. 1 (a) Layer resolved difference in the chirality-dependent spin-orbit coupling energy ΔE_soc^k calculated for Ta/Fe with variable Fe thickness. (b) Variation of interfacial distance 'z' (inset) for the different calculated structures. Variation of 5d orbital-resolved SOC energy of interfacial Ta1 layer in (c) Ta_3Fe_3 and (d) Ta_3Fe_5.



Navigating Chiral Spin Architectures in Non-Collinear Antiferromagnetic Thin Films

Freya Johnson[1]
[1]University of Cambridge, United Kingdom

Invited Speaker: Freya Johnson, July 16, 2025, 09:45 - 10:15

Non-collinear antiferromagnets (nc-AFM) hosting triangular spin textures that break time reversal symmetry are recognised as having attractive properties for next-generation memory and computing technologies, with the advantageous properties of ferromagnetic and antiferromagnetic materials combined. The topology of their band structure allows for enhanced intrinsic physical properties, such as the anomalous Hall (AHE), Nernst and magneto-optical Kerr effects, which have been used to understand the underlying magnetic order. In thin films of nc-AFMs, strain plays a crucial role in modifying the intrinsic electronic and magnetic properties. In particular, we have recently shown how large local strain fields, generated by dislocation networks, influence the antiferromagnetic domain state and the intrinsic AHE in nc-AFM by examining films that are either highly lattice mismatched or closely matched to their substrate [1]. These effects are distinct from those caused by global strain fields as measured from X-ray diffraction.

Building upon this work, in this talk I will demonstrate how post-growth annealing in Mn3NiN may be used to trap defects within a thin layer of the film, allowing for coherent growth beyond this layer. By controlling the coherent thickness, we are able to modify the non-collinear antiferromagnetic order. For certain thicknesses, we are able to extend the operational temperature range while simultaneously maximizing the AHE. This result will be critical for application of this material in future spintronic devices.

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Terahertz Pulse Shaping and Chirality Control using a Spintronic-Semiconductor Hybrid Emitter

M. Benjamin Jungfleisch
[1]*University of Delaware, United States*
Invited Speaker: M. Benjamin Jungfleisch, July 17, 2025, 09:45 - 10:15

Terahertz (THz) radiation, spanning from 0.3 - 30 THz, fills the crucial gap between the microwave and infrared spectral range. THz technology has applications in various fields, from imaging and sensing to telecommunication and biosensing. However, the full potential of these applications is often hindered by the need for precise control and manipulation of the frequency and polarization state, which typically requires external THz modulators [1].
Here, we demonstrate a hybrid THz source that overcomes this limitation by integrating two THz emitters into a single device to enable pulse shaping and chirality control of the emitted radiation without external components [2]. The two sources are a spintronic emitter (SE) [3] and a semiconductor photoconductive antenna (PCA) [4]. The two emitters respond independently to external parameters: the PCA is controlled by the applied bias voltage while the SE is controlled by the applied magnetic field. Moreover, a dual-wavelength excitation scheme allows for control of the relative time delay between the THz emission from each constituent. These properties of the hybrid emitter enable precise control of the mixing of the two signals to control the frequency, polarization, and chirality of the overall THz radiation. This on-chip hybrid emitter thus provides a powerful platform for engineered THz radiation with wide-ranging potential applications.

This research was primarily supported by NSF through the University of Delaware Materials Research Science and Engineering Center, DMR-2011824.

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Probing emergent metallicity and superconductivity at oxide heterointerfaces

Divine Kumah[1]
[1]*Duke University, United States*

Invited Speaker: Divine Kumah, July 18, 2025, 11:00 - 11:30

Perovskite-structured complex oxides exhibit a diverse array of physical properties, including magnetism, superconductivity, ferroelectricity, and metal-insulator transitions. The electronic, structural, and magnetic interactions at interfaces formed between crystalline, atomically-thin layers of these materials lead to the emergence of novel phases. Advances in the atomic-scale synthesis of crystalline two-dimensional multilayered systems have driven progress in this field, enabling the systematic tuning of strain and interfacial interactions to realize novel electronic and magnetic ground states. Furthermore, the development of high-resolution synchrotron X-ray diffraction and spectroscopy techniques allows for non-destructive and in-operando probing of materials, elucidating structural and electronic changes at interfaces between dissimilar oxide thin films.

This presentation will illustrate the intimate link between interface-driven atomic-scale distortions and the physical properties of low-dimensional systems by focusing on two specific cases where metallicity and superconductivity emerge from interfaces formed between nominally insulating materials. First, recent results on anisotropic superconductivity at $KTaO_3$ interfaces will be discussed. Second, the role of structural reconstructions at interfaces formed by the charge-ordered insulator $BaBiO_3$ in stabilizing two-dimensional superconductivity will be presented. Guided by first-principles theory, this talk will highlight how atomic-scale materials growth techniques and state-of-the-art methods for characterizing physical properties at the picometer scale provide a powerful approach for discovering novel quantum materials.

Spin-wave mediated mutual synchronization in spin Hall nano-oscillators

Akash Kumar[1,2], Avinash K. Chaurasiya[1], Victor H. González[1], Nilamani Behera[1], Roman Khymyn[1], Ahmad A. Awad[1,2], Johan Åkerman[1,2]
[1]University of Gothenburg, Sweden, [2]Research Institute of Electrical Communication, Tohoku University, Japan
Invited Speaker: Akash Kumar, July 14, 2025, 14:30 - 15:00

Generation and manipulation of propagating spin waves (PSWs) in magnetic multilayer systems have opened new frontiers for magnonics and spin-wave-based computing [1]. The precise control of frequency and phase of PSWs in nanoscopic CMOS compatible systems is of high importance for emerging applications such as reservoir computing and Ising machines [1,2,3]. Recently spin-orbit torques have been shown to drive PSW auto-oscillations in perpendicular magnetic anisotropy (PMA)-based nano-constriction spin Hall nano-oscillators (SHNOs) [2]. Due to their long-range propagation, the mutual synchronization of SHNO, previously demonstrated in 1D chains [4,5] and 2D arrays [6], can also benefit from these PSWs.

In this work, just accepted in Nature Physics [7], we report spin-wave mediated variable-phase mutual synchronization in nano-constriction SHNOs, enabling both in-phase and anti-phase synchronization of their individual auto-oscillatory modes, Fig. 1a. Using W/CoFeB/MgO trilayers with PMA, SW auto-oscillations were observed and characterized via electrical measurements and phase resolved micro-focused Brillouin light scattering (μ-BLS) microscopy. Electrical power spectral density measurements on W/CoFeB/MgO samples (Fig. 1b) with 500 nm spacing reveal distinct synchronization regimes, including constructive (in-phase) and destructive (anti-phase) interference patterns. These patterns (denoted as regions II and III) can be further controlled through the applied magnetic field and direct current. In contrast, in-plane magnetized W/NiFe systems (Fig. 1c) showed no phase control due to the absence of PSWs. Phase-resolved μ-BLS confirms both in-phase and out-of-phase states, providing conclusive evidence of long-range SW coupling. Micromagnetic simulations corroborate the experimental results and highlight the role of SW dispersion in phase tuning. Additionally, voltage-controlled magnetic anisotropy (VCMA) is proposed for localized phase control, offering a scalable mechanism for phase-tunable SHNO arrays. These findings hold significant promise for SW-based Ising machines, neuromorphic computing, and reconfigurable logic devices [1,3,6].

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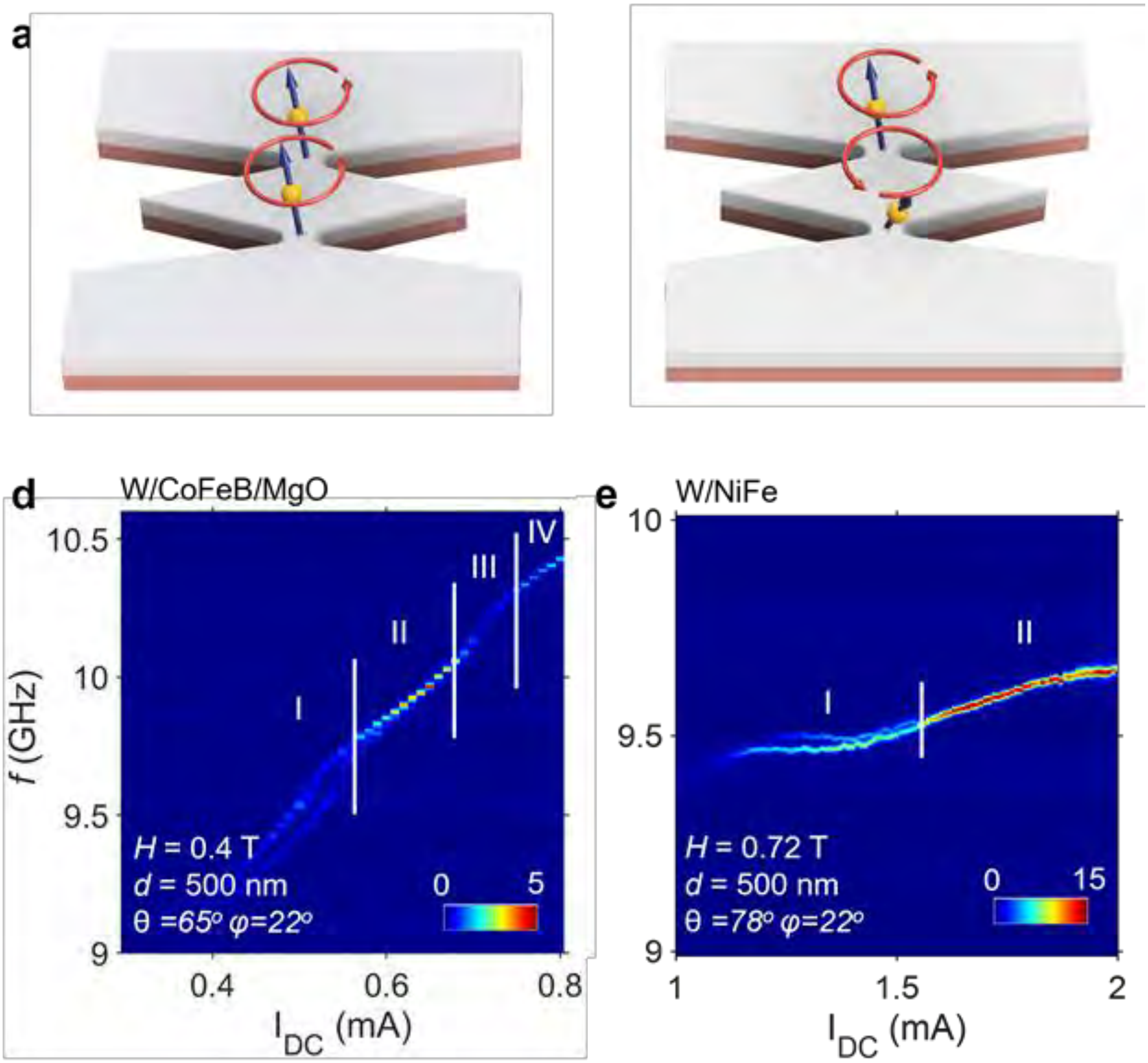
Figure Caption: (a) Schematic of in-phase and out-of-phase mutual synchronization between two spin Hall nano-oscillators (SHNOs). Power spectral density as a function of applied current (IDC) for two mutually synchronized SHNOs fabricated using (b) perpendicularly magnetized W/CoFeB/MgO thin films and (c) in-plane magnetized W/NiFe thin films. Panel (b) highlights various synchronization regimes, ranging from in-phase (region II and IV) to out-of-phase (region III) mutual synchronization, while panel (c) demonstrates the lack of phase control due to the absence of propagating spin waves.



Static and dynamic depth profiling of magnetic multilayers using advanced x-ray reflectivity and spectroscopy techniques

Timo Kuschel[1, 2]
[1]Bielefeld University, Germany, [2]Johannes Gutenberg University Mainz, Germany

Invited Speaker: Timo Kuschel, July 17, 2025, 15:30 - 16:00

The determination of structural, chemical and magnetic properties of magnetic multilayers is important for investigating magnetic heterostructures that are utilized, e.g., for spin transport experiments. Especially the interface and, more general, the depth-resolved properties should be known when discussing how well a spin current can pass the individual layers and interfaces. Here, non-destructive experimental approaches based on x-ray reflectivity and spectroscopy techniques are the key to studying exactly the same sample that is used for spin transport investigations. Even the magnetization dynamics can be analyzed layer-resolved based on the presented approaches.

I will discuss three depth profiling techniques along with three research directions of our group:

1) Oxidic depth profiling via x-ray photoelectron spectroscopy (XPS):
We use ionic liquid gating to manipulate the oxidic content of magnetic multilayers and, thus, alter the magnetic properties [1]. In order to identify the oxidic depth profile, we developed a new approach based on XPS and a combined analysis of spectra at multiple energy regions [2].

2) Magnetic depth profiling via x-ray resonant magnetic reflectivity (XRMR):
The interface properties of Pt layers, which are used for spin current detection, can be magnetically altered by the so-called magnetic proximity effect. Here, we study the magnetic interface properties of Pt by synchrotron-based XRMR element-selectively [3] and obtain the quantitative static magnetization depending on the depth of the sample [4]. In addition, we can use XRMR to study the magnetic depth profile cation- and lattice-site-selective as shown for the magnetic termination of Fe3O4 layers [5].

3) Magnetization dynamics depth profiling via x-ray detected ferromagnetic resonance (XFMR):
XFMR uses time-resolved x-ray magnetic dichrosim to trace the spin precession that is excited by ferromagnetic resonance [6]. This synchrotron-based and element-selective technique allows to identify a spin current that passes, e.g., an antiferromagnetic insulator [7].

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Thermal Dynamics and Related Material Functions of Magnetic Skyrmions

Masahito Mochizuki[1]
[1]*Waseda University, Japan*

Invited Speaker: Masahito Mochizuki, July 15, 2025, 17:00 - 17:30

Thermally induced dynamics of magnetic topology in magnets has turned out to host rich phenomena and device functions, which are subjects of intensive studies in the research of spintronics recently. In this presentation, we discuss following two phenomena related with thermal motion of skyrmions, which were revealed in our recent theoretical studies.

Heat-electricity conversion with skyrmions in the presence of thermal gradient [1,2] A confined skyrmion crystal exhibits rotational motion when a radial temperature gradient is present due to an inverse effect of the topological magnon Hall effect [2]. We discuss that this thermally induced rotational motion of skyrmions can be exploited for the DC-voltage generation. A moving skyrmion texture generates a spinmotive force perpendicular to its moving direction. Consequently, the rotational motion of skyrmions confined in a circular disk generates DC electric voltage in the radial direction. The proposed phenomenon can be exploited as spintronic thermoelectric devices to realize the heat-electricity conversion.

Active-matter-like behaviors of skyrmions due to the chiral Brownian motion [3] Skyrmions as chiral objects show chiral nature in interactions with nanostructures, which can lead to intriguing phenomena. We discuss that the Brownian dynamics of skyrmions interacting with a chiral flower-like obstacle in a ferromagnet exhibits topology-dependent outcomes, which can be regarded as a spontaneous mesoscopic order-from-disorder phenomenon driven by thermal fluctuations. This phenomenon can be utilized to control the skyrmion position and distribution without any external driving force and can be exploited as a new way to design topology-sorting devices.

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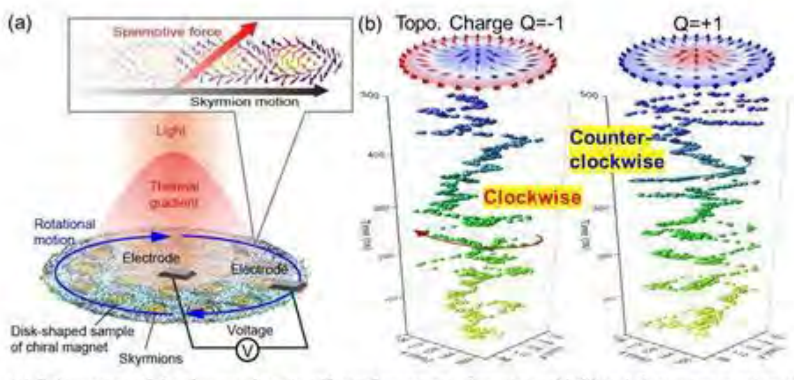

(a) Schematics of the thermoelectric effect of magnetic skyrmions (b) Chiral Brownian motion of skyrmions as a source of active-matter-like behaviors.

Majorana Bound States and Diode Phenomenon in Superconductor-Ferromagnet Proximity Coupled Systems

Jagadeesh Moodera[1]
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Invited Speaker: Jagadeesh Moodera, July 18, 2025, 13:30 - 14:00

The excitement and challenge become richer when superconductors (SC) are proximity coupled to ferromagnets (FM). Recently with strong interest, among various other schemes, there is the prediction of exotic Majorana bound states (MBS) in superconducting proximity coupled (111) Au surface state. Combining with the ideal Heisenberg FM such as semiconducting EuS proximity coupled with superconductor V, the (111) Au gives us an excellent topological SC platform to seek MBS. This led us to observe the signature of candidate MBS pair by scanning tunnel spectroscopy. For further confirmation we are pursuing nanostructured planar junctions, aiming to show the highly challenging MBS pair entanglement, a precursor for enabling topological qubits.

The SC/FM platform utilized in the search of MBS has also led us to 'rediscover' another phenomenon - the observation of the nonreciprocal critical supercurrent flow, called SC diode effect. We demonstrated a strong SC diode effect in conventional SC thin films interfaced with EuS, reaching efficiencies ~ 70% including in zero magnetic field. We identify that the critical supercurrent nonreciprocity in SC thin films to be arising from asymmetrical vortex edge/surface barriers and the universal Meissner screening current. It may be noted that the geometrically asymmetric SC films/strips showing rectifying current flow has been reported in the literature for over 50 years. Further with our SC and FM layer geometry we realize nonvolatile SC memory as well. The evolution of SC order parameter, and its influence on the magnetic ordering in FM/SC/FM trilayer adds richness. We will show the device possibilities such as cryogenic rectifiers, nonvolatile memory and logic circuits, opening the pathway for complimentary SC electronics for superconducting qubit development and dark matter detection.

Work is supported by NSF, AFoSR, ARO, ONR and Lincoln Lab ACC grants.
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Imaging plasmon-polaritons at Topological-Insulator/Nanocarbon interfaces using STEM-EELS

Tim Moorsom[1], Mairi McCauley[2], Donald MacLaren[2], Ahmad Nizamuddin Bin Muhammad Mustafa[3], Sami Ramadan[3], Peter Petrov[3], Joel Burton[1], Satoshi Sasaki[1], Craig Knox[1], Matt Rogers[1], Quentin Ramasse[4], Lida Ansari[5], Farzan Gity[5], Paul Hurley[5]
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Invited Speaker: Tim Moorsom, July 15, 2025, 14:30 - 15:00

A major barrier to the development of practical plasmonic devices is electronic scattering. [1] However, low dimensional systems including graphene offer high mobility and low scattering rates, making them attractive for the development of plasmonic devices. [2] Topological insulators are especially interesting for operation at both THz and optical frequencies [3] because of their topologically protected surface states (TSS).

Practical TI-based plasmonic devices will require a means of tunable control of 2D plasmons. One approach is to dope the surface with impurities to create a 2D electron gas (2DEG). [4] However, these dopants are extremely reactive, so the effect is unstable outside ultra high vacuum. A more robust alternative is the use of thin films of organic molecules and dyes. [5] The ultimate goal is to find a stable molecular thin film that supports reversible charge transfer to an underlying TI. [6]

Electron Energy Loss Spectroscopy (EELS) provides a useful probe of localised surface effects where interfacial electronic structure can be mapped with sub-nm resolution. In particular, the 2D π plasmon mode observed in both topological interfaces and 2D materials such as graphene provides a sensitive probe of 2D confined surface states. [7]

We have found that C60 forms highly ordered crystals on TI surfaces at very low deposition energy, producing atomically sharp interfaces that are free from structural defects and stable to degradation. C60 was chosen for its high electron affinity, resulting in significant charge transfer from the TI interface.

Using STEM-EELS and momentum resolved EELS (QEELS) we have performed a high resolution study of the plasmonic excitations in Bi2Se3/C60 heterostructures with sub-atomic resolution in the optical and UV regime. We have demonstrated that there are fundamental differences in the pi states at the interface between a TI and trivial insulator, and an interface between a TI and a molecular film. These manifest as differences in band bending and 2D confinement of the surface states, as well as changes in the dispersion relation of the pi plasmon. This shows that molecular layers profoundly change the surface behaviour of TIs. [8]

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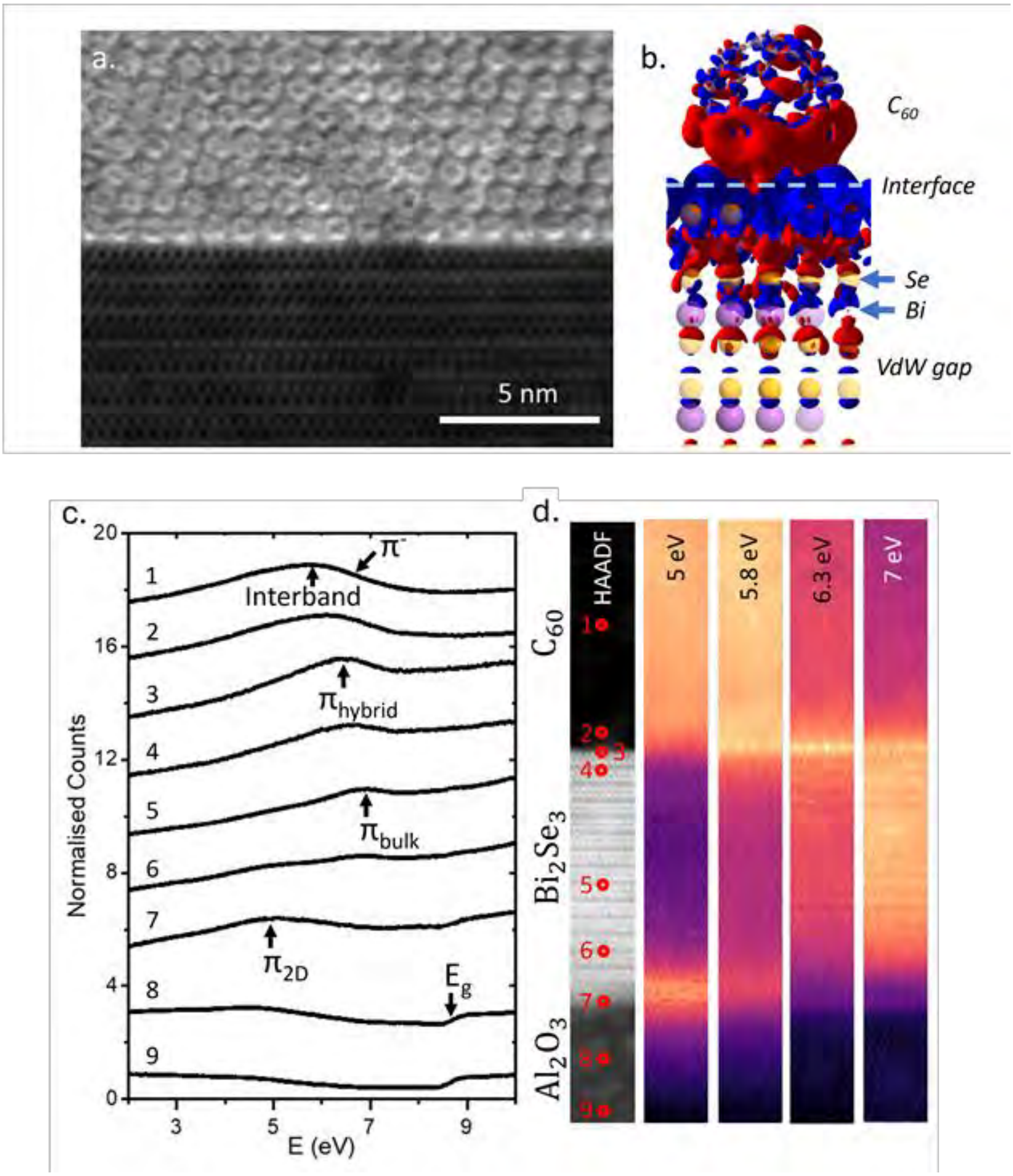
Figure 1 - a. STEM-BF image of Bi2Se3/C60 interface. b. DFT model of interfacial charge transfer. c. Low-loss EELS spectra recorded at various positions across the interface. d. STEM-EELS maps across different energy windows, capturing different surface and bulk excitations in the heterostructure.



Magnetization dynamics in nanoscale antiferromagnets

Takahiro Moriyama[1]
[1]*Nagoya University, Japan*

Invited Speaker: Takahiro Moriyama, July 16, 2025, 11:00 - 11:30

Antiferromagnets are one of the few materials which can magnetically couple to THz electromagnetic waves and are a candidate material which can work in the terahertz gap [1]. This talk will discuss the current challenge of the THz measurements for antiferromagnetic dynamics and reviews our recent research results on the electrical detection of the magnetization dynamics in antiferromagnetic thin films with a particular focus on the conversion of THz electromagnetic waves to spin currents. Our measurements, which were made possible by using gyrotron, the strong CW-THz source, for the antiferromagnetic dynamics of GdCo and α-Fe_2O_3 have revealed selective excitation of the dynamics modes [2] as well as the microscopic mechanism of the spin pumping in antiferromagnets [3]. The spin pumping effect in the antiferromagnetic thin film multilayer systems demonstrated here is directly relevant to the technology of spintronics where various interfacial effects, which would be more highlighted in thin films, are utilized.

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Topological spin textures for quantum operations

Christos Panagopoulos[1]
[1]NTU, Singapore

Invited Speaker: Christos Panagopoulos, July 16, 2025, 16:30 - 17:00

The transformation of quantum computing architectures from research laboratories to industrial prototypes necessitates platforms that cater to different quantum information processing tasks. The underexplored platform - nanomagnets - is rapidly demonstrating unique features that could further invigorate the advancement of quantum technologies [1-3]. I will discuss the nascent connection between quantum technology and nanomagnetism via a novel quantum hybrid platform for braiding-based topological quantum computation [4,5]. As well as our efforts to quantize helicity, joining the likes of electrical charge and light, and offering a new class of building blocks for realizing quantum logic elements [3,6-8].

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Prospects for 2D and 3D Racetrack Memory

Stuart Parkin[1]
[1]Max Planck Insitute Halle, Germany

Invited Speaker: Stuart Parkin, July 18, 2025, 09:45 - 10:15

Spintronics allows for advanced memory and storage technologies that go beyond today's charge-based devices. Of especial interest is Magnetic Racetrack Memory (RTM) that is a unique memory-storage device that relies on the current driven motion of multiple domain walls along magnetic conduits. Racetrack Memory has evolved in several distinct stages that we have dubbed versions 1.0-4.0 1. In version 4.0 we showed that chiral domain walls can be driven at speeds exceeding 1 km/s in synthetic antiferromagnetic racetracks by spin currents generated via the spin Hall effect in proximal metallic layers 2. We discuss recent developments in both 2D and 3D Racetrack Memory. In particular, we show that Racetrack Memory can be scaled to dimensions that are technologically relevant. Using integrated anomalous Hall read sensors, we demonstrate that domain walls can be positioned by nanosecond long current pulses along racetracks just 50-80 nm wide with a spatial resolution of ~10 nm 3. We discuss recent advances in materials for Racetrack Memory including highly efficient current induced domain wall motion in 2D ferromagnets4, and high entropy alloys as efficient spin-orbit torque sources 5. Finally we present several schemes for building prototype 3D racetracks. In one case freestanding membranes composed of atomically engineered thin film heterostructures that form the racetrack are formed on a sacrificial water-soluble sacrificial release layer. The freestanding membranes are transferred onto protrusions that have been pre-patterned on sapphire wafers to create 3D racetracks 6,7. In a second approach we fabricate 3D chiral magnetic racetracks via a novel state-of-the-art multi-photon super-resolution lithography system. We show how the interplay between the geometrical chirality and the spin chirality of the individual domain walls allows for domain wall diode devices 8.

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On-chip hybrid magnetoelastic waves

Jorge Puebla[1]
[1]RIKEN, Japan

Invited Speaker: Jorge Puebla, July 17, 2025, 16:30 - 17:00

The interaction between surface acoustic waves (SAWs) and spin waves is gaining attention in spintronics and magnetism research [1]. Spin waves in ferromagnets, usually excited by microwave photons, can also be triggered by phonons, as predicted by Charles Kittel [2]. When SAWs and spin waves reach strong coupling, their interaction surpasses the relaxation rates of both phonons and spin waves. This leads to the formation of hybridized quasiparticles, combining features of both phonons and magnons. Our recent experiments demonstrated this hybridization of waves at room temperature within an on-chip SAW device [3]. We used acoustic wave reflectors to create an acoustic cavity [4, 5], reducing phonon losses, and employed CoFeB layers with low magnetic damping.

We investigated the avoided crossing or anticrossing between magnon and phonon dispersions as a strong coupling signature. In our experiments, SAW transmission data revealed a bending in the phonon dispersion when the externally applied magnetic field approached magnon resonance. With a CoFeB layer thickness of 10 nm, the phonon dispersion exhibited energy absorption at resonance around 30 mT, maintaining a constant and linear behaviour. However, when the thickness increased to 20 nm, the phonon dispersion not only absorbed energy at resonance but also showed noticeable bending, indicating strong magnon-phonon coupling. This coupling implies that phonons now exhibit magnon-like characteristics and can be influenced by magnetic fields, and vice versa, with implications for hybrid wave information and communication devices. Additionally, in the thin film limit where the acoustic wavelength exceeds the magnetic layer thickness, we observed a monotonic increase in coupling strength with CoFeB layer thickness, providing a route to achieve ultra-strong coupling.

In this talk, I will show and elaborate on this recent experimental demonstration of surface acoustic wave (SAW) hybridization with spin waves in the strong coupling regime, highlighting the anticipated implications for information and communication technologies. We anticipate that with advancements in experimental techniques offering enhanced phase, spatial, and temporal resolutions, the intriguing characteristics of this novel hybridized magnon-phonon wave will be unveiled in the short to medium term.

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Superconductivity and Orbitronics - Exploring Rashba Edelstein Effects with Broken Inversion Symmetry

Thomas G Saunderson[1,2,3], Yuriy Mokrousov[3], Dongwook Go[3], Jacob Gayles[2]
[1]University Of Mainz, Germany, [2]University of South Florida, USA, [3]Research Center Jülich, Germany

Invited Speaker: Thomas Saunderson, July 15, 2025, 09:45 - 10:15

Modern spintronics must adapt to meet the challenges of the new era. Computer processors can no longer follow Moore's law yet the demand for greater computational power is ever increasing. Inventive solutions are therefore required to achieve the desired processing power whilst also being more energy efficient to combat the increasing effects of climate change. Recently "altermagnetism" [1], orbitronics [2], chiral magnetization dynamics [3] have been pushing the boundaries of what can be achieved using the spin of an electron for classical computation, whilst combining magnetic impurities, superconductivity and spin-orbit coupling provides a new platform for the generation of Majorana zero-modes needed for topological quantum computation [4]. Furthermore, recent advancements in orbitronics demonstrate remarkable efficiency gains using cost-effective materials [5], while spin-Hall mediated responses notably intensify near the superconducting transition [6]. Breaking inversion or time-reversal symmetry efficiently extracts these unconventional currents, however for material-specific predictions first principles techniques are essential.

In this talk I will address the current status of spintronics, whilst addressing how superconductivity can enhance it. Although theoretical methods for orbital currents are well-established, first principles techniques for supercurrents are still in their infancy. This talk aims to explore two approaches. Firstly, we employ maximally localized Wannier functions to investigate the influence of p-d hybridizations on enhancing the orbital Rashba Edelstein effect on particular surfaces of known metallic systems. Secondly, we utilize a Green's function-based superconducting first principles code which incorporates superconductivity [7] and magnetism [8] with substitutional impurities [7–10] on the same footing. This method combines the full complexity of the underlying electronic structure and Fermi surface geometry of the normal state with an effective parametrization of the superconducting state. Here, we will induce unconventional triplet densities in superconductors featuring complex orbital degrees of freedom and inversion symmetry breaking. Such methods will pave the way for first principles-based modeling of superconducting spintronics. [1] Nature 619, 52 (2023) [2] ACS Nano 14, 15874 (2020)

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Chiral Spin Textures: Stability, Readout, and All-Electrical Control

Anjan Soumyanarayanan[1]
[1]*NUS and A*STAR, Singapore*

Invited Speaker: Anjan Soumyanarayanan, July 17, 2025, 13:30 - 14:00

Chiral spin textures such as magnetic skyrmions represent the smallest realizable emergent magnetic entities in functional materials [1]. Their topological stability and ease of tunability in ultrathin magnetic multilayered films has generated considerable promise as robust, mobile bits for sustainable computing [2]. While spin textures are readily visualized, their electrical signatures have been a topic of intense research and debate.

Here, we establish the ambient stability of individual and ensemble spin textures on a tunable multilayer platform [3-6], and elucidate their electrical signatures across distinct modalities. First, we examine Hall transport across spin texture ensembles. In contrast to the claimed presence of a topological Hall effect, we unveil a sizable nonlinear anomalous Hall effect arising from spin texture morphology (geometry) [7]. Next, we show that their microwave spectrum universally hosts a trifecta of resonance modes arising from irreversible textural transitions. Notably, their GHz spectrum can be deterministically and widely modulated via in situ analogue knobs [8].

Finally, we present a nanoscale chiral magnetic tunnel junction (MTJ) hosting a single, ambient skyrmion [9]. The MTJ nucleates skyrmions of fixed polarity via two distinct mechanisms, with readout signal quantifying skyrmion size. Crucially, it can electrically write and delete skyrmions to both uniform states with energies 1,000 times lower than state-of-the-art MTJs. Here, the applied voltage emulates a magnetic field, and reshapes both the transition energetics and kinetics. Demonstrations of skyrmion readout, switching, and motion establish a much-anticipated backbone for all-electrical skyrmionics.

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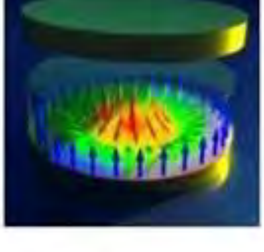

Exploring new strategies for developing reconfigurable magnonic systems

Silvia Tacchi[1]
[1]IoM, Italy

Invited Speaker: Silvia Tacchi, July 14, 2025, 11:00 - 11:30

In the past decade the field of magnonics, aiming to use spin waves (SWs), the collective excitations of ordered magnetic materials, for data transport and processing, has rapidly grown due to its potential to develop technologies enabling high-frequency data transmission, in the GHz ranges, while minimizing energy consumption. [1-3] However, integrating magnonic devices with traditional electronics remains a challeng particularly in providing low-power solutions for applying bias magnetic fields strong enough to affect SW propagation.

In this presentation, I will introduce an innovative method for developing tunable magnonic devices, where the magnetic field produced by permanent micromagnets, is exploited to control SW propagation. I will show a first example of devices, where two permanent SmCo micromagnets are placed symmetrically with respect to a CoFeB magnonic conduit at varying distance D. An external bias field was applied parallel to the short axis of the conduit, either parallel or antiparallel to the field produced by the micromagnets. The propagation of SWs, excited in Damon-Eshbach geometry by using a coplanar waveguide, was investigated by micro-focused Brillouin light scattering. By switching from the antiparallel to the parallel configuration we observe a significant reduction in the SWs propagation distance. Moreover, we find that this effect depends on the distance between the micromagnet and the conduit. [4]

In the second part of the talk, I will present a standalone magnonic device, consisting of permanent micro-magnets and magnetic flux concentrators (MFCs), all fabricated on the same silicon chip as the magnonic waveguide. The micromagnets serve as source of the magnetic field, while the MFCs are exploited to enhance the intensity and uniformity of the bias field in the waveguide. I will show that a good propagation of SWs excited by an inductive antenna in DE geometry, is observed even at zero external applied magnetic field. These findings demonstrate the capability to fabricate monolithically integrated magnonic device on silicon that can operate without the need for an external magnetic field.

Support from the EU project MandMEMS, Grant No. 101070536, is acknowledged. Financial support from the Italian national project TEEPHANY-(PRIN2022P4485M), and NextGeneration EU National Innovation Ecosystem grant ECS00000041−VITALITY (CUP B43C22000470005), under the Italian Ministry of University and Research is acknowledged.
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Ultrastrong coupling of magnon polaritons in on-chip thin ferromagnetic films

Shugo Yoshii[1,2], Manuel Müller[3], Ryo Ohshima[1,2], Yuichiro Ando[4], Matthias Althammer[3], Hans Huebl[3], Masashi Shiraishi[1,2]
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Invited Speaker: Shugo Yoshii, July 14, 2025, 13:30 - 14:00

Magnon-photon polariton, a strong coupling between electromagnetic microwave (photons) and quantized spin waves (magnons), has been fascinating research with regard to the light-matter interaction. In the context of light-matter interaction, the achievement of the ultrastrong coupling regime represents a crucial milestone for the exploration of the veiled quantum phenomena induced by counter-rotating terms (CRTs) [1]. The CRTs have been expected to be the fundamental physics in the next generation of quantum technologies. Despite the existence of multiple reports on the realization of ultrastrong coupling in magnon polaritons, the majority of studies have been constrained to bulk $Y_3Fe_5O_{12}$ [2, 3].

Here we present the experimental demonstration of ultrastrong coupling magnon-photon interaction between a thin metallic ferromagnetic film on a superconducting high-TC $YBa_2Cu_3O_7$ (YBCO) resonator. In particular, we observe the Bloch-Siegert shift, a key signature of the existence of CRTs [4].

For our experiment, we use ferromagnetic thin films of NiFe (Permalloy) embedded in a layer stack of SiO2 (10 nm) / MgO (2 nm) / Py (30 nm) / Ti (3 nm) / SiO2 (20 nm), which has been deposited onto the superconducting resonator made of high-Tc YBCO. We perform our microwave transmission experiment in a cryogenic environment (T=10K, see Fig. 1) and apply the magnetic field in the plane. Figure 2 shows the normalized transmission spectra, ΔS_21. The dispersion of the magnon photon polariton manifests as an absorption signature. A quantitative analysis of the data allows to estimate the coupling strength (g) to be 674 MHz, corresponding to a g/ω-ratio exceeding 0.1. Thus the hybrid system enters the ultrastrong coupling regime. The system also shows the expected Bloch-Siegert shift originating from the counter-rotating terms of the coupling. In the presentation, we will discuss the experiment, data analysis, and the implications of the results regarding the generation of non-classical states.

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[2] M. Goryachev et al., Phys. Rev. Appl. 2, 054002 (2014).
[3] A. Ghirri et al., Phys. Rev. Appl. 20, 024039 (2023).
[4] S. Yoshii et al., submitted.

Fig. 1 Schematic of measurement.
Fig. 2 Transmission spectra of magnon polariton within 30 nm-thick Py film.

Fig. 1

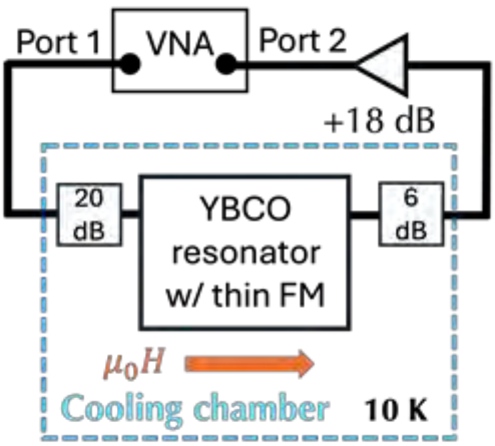
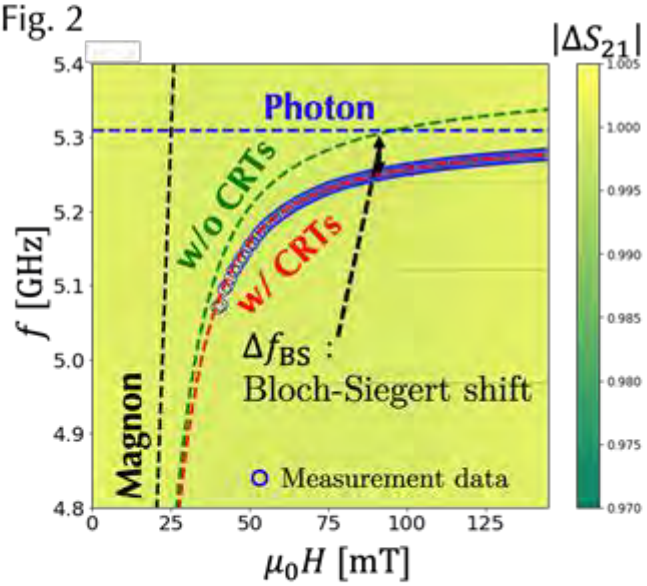


Fig. 2



Interlayer magnon coupling in magnetic metal/insulator hybrid nanostructures

Haiming Yu[1]
[1]*Fert Beijing Institute, China*

Invited Speaker: Haiming Yu, July 14, 2025, 11:30 - 12:00

Magnons, the quanta of spin waves, are collective excitations of electron spins in magnetic materials, which do not rely on charge transport, and can thus avoid Joule heating in information processing, making them potential candidates for next-generation of low-power spintronic devices. In this talk, I will introduce the observation of strong interlayer magnon-magnon coupling in magnetic metal-insulator hybrid nanostructures. A large anti-crossing gap up to 1.58 GHz is observed between the ferromagnetic resonance of the metallic nanowires and the in-plane standing spin waves of a low-damping yttrium iron garnet (YIG) film [1]. Based on this effect, we also experimentally observe the long-distance propagation of ultra-short-wavelength spin waves with wavelengths down to 50 nm [2], and demonstrate the unidirectional behavior of such spin waves [3]. Furthermore, I present the experimental observation of nonlocal three-magnon scattering between spatially separated magnetic systems. Above a certain threshold power, one CoFeB Kittel magnon splits into a pair of counter-propagating YIG magnons which can be detected by the inverse spin-Hall effect [4]. Our results demonstrate the nonlocal detection of two separately propagating magnons emerging from one common source that may enable quantum entanglement between distant magnons for quantum information technologies.

[1] J. Chen, G. E. W. Bauer, H. Yu* et al. Phys. Rev. Lett. 120, 217202 (2018).
[2] C. Liu, H. Yu*, M. Wu* et al. Nat. Commun. 9, 738 (2018).
[3] J. Chen, G. E. W. Bauer*, H. Yu* et al. Phys. Rev. B 100, 104427 (2019).
[4] L. Sheng, H. Yu* et al. Phys. Rev. Lett. 130, 046701 (2023).

Contributed Orals

Skyrmion Brownian Motion in Ion Irradiated W/CoFeB/MgO Films

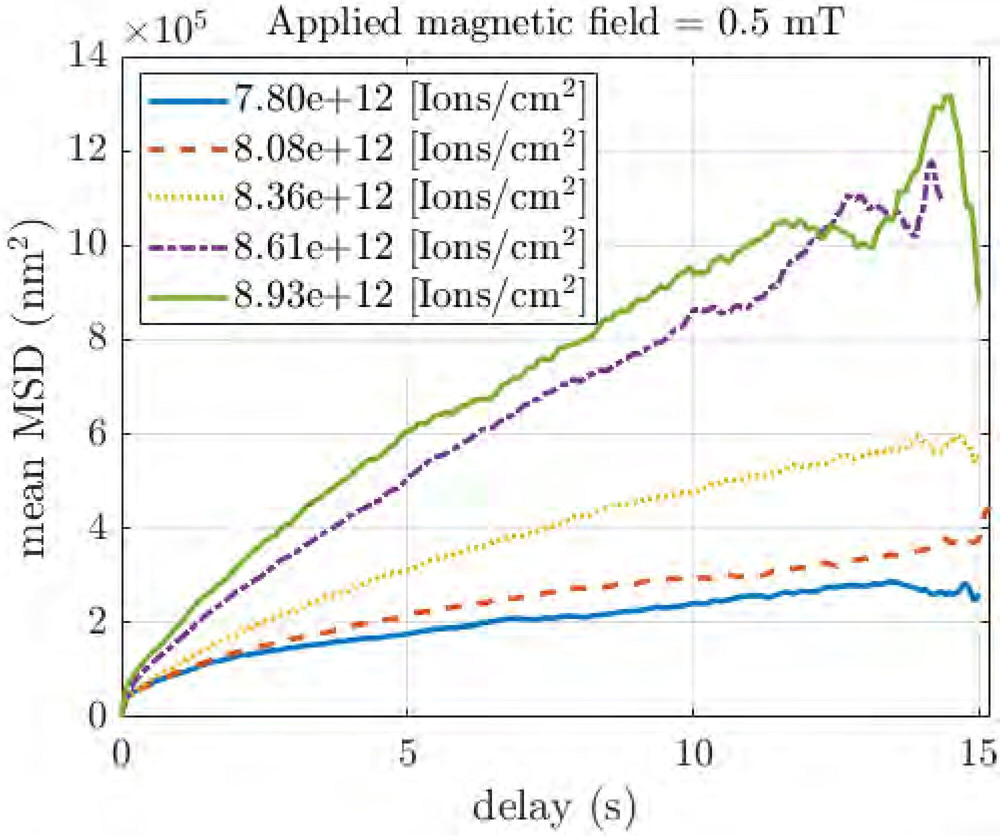
Valentin Ahrens[1], Donatella Albano[2], Johannes Greil[1], Felix Naunheimer[1], Manuel Wilke[1], Fabrizio Riente[2], Markus Becherer[1]
[1]Technical University Of Munich, Germany, [2]Politecnico di Torino, Italy
Contributed Talk: Valentin Ahrens, July 16, 2025, 14:00 - 14:15

Brownian computing is dealt as a promising approach towards ultra-low power data processing as it harvests energy from the environment to perform basic logic operations [1]. Skyrmions undergoing thermally activated Brownian motion are one prospective data carrier for this kind of computing network. Focused ion beam irradiation now is a versatile tool to locally engineer magnetic properties and create tracks and nucleation points for skyrmions [2]. In this work, we scrutinize how skyrmion Brownian motion can be altered locally by Ga+ focused ion beam irradiation with different ion doses and disentangle the effects caused by changes in the skyrmion density from those fundamentally originating in the irradiation effects.

First, we analyze the Brownian motion of skyrmions in a sputtered W/CoFeB/MgO thin film in 80 μm × 80 μm large squares irradiated with ion doses in a range from 1×10^{12} Ions/cm² to 1×10^{13} Ions/cm², employing magneto-optical microscopy and particle tracking. In an ion dose range from 7.5×10^{12} Ions/cm² to 1×10^{13} Ions/cm², we can stabilize skyrmions at low fields between 0.3 mT and 1 mT, with increasing density for higher doses and lower fields. Higher ion doses hereby also yield a higher diffusion coefficient rising from 0.01 μm/s² to over 0.03 μm/s². Additionally diffusion in the higher dose squares lead to a more free diffusion while lower doses show more confined motion. This transition is likely caused by a homogenization of the interfaces by the ion irradiation [3]. However, also a variation in skyrmion density is ought to alter their diffusivity. Hence, we also investigate the changes in the diffusion coefficient over external field to disentangle these effects. At the same ion dose with different external fields, we encounter significantly smaller variations in the diffusivity underlining the stability of our evaluation platform. Nonetheless, we see a reduction of the diffusivity for higher fields, i.e. fewer skyrmions, indicating that at higher external fields preferably pinned skyrmions are stabilized. Finally, we apply small DC-currents to the films to reveal that directional diffusion by spin-orbit torques is achievable with low current densities ($<1 \times 10^9$ A/m²).

[1] Brems, Maarten A., et al. "Circuits and excitations to enable Brownian token-based computing with
skyrmions." Applied Physics Letters 119.13 (2021).
[2] Ahrens, Valentin, et al. "Skyrmions Under Control—FIB Irradiation as a Versatile Tool for Skyrmion
Circuits." Advanced Materials 35.2 (2023): 2207321.
[3] Zhao, Xiaoxuan, et al. "Enhancing domain wall velocity through interface intermixing in W-CoFeB-MgO
films with perpendicular anisotropy." Applied Physics Letters 115.12 (2019).

Figure 1 Analysis of skyrmion diffusivity for ion doses from 7.8 × 10^{12} Ions/cm2 to 8.9 × 10^{12} Ions/cm2, by mean squared displacement analysis at a field of 0.5 mT. The plots reveal a clear increase in the diffusivity for higher ion doses. Additionally a transition from confined to free diffusion is apparent by the increase of the linearity of the MSD plot for higher doses



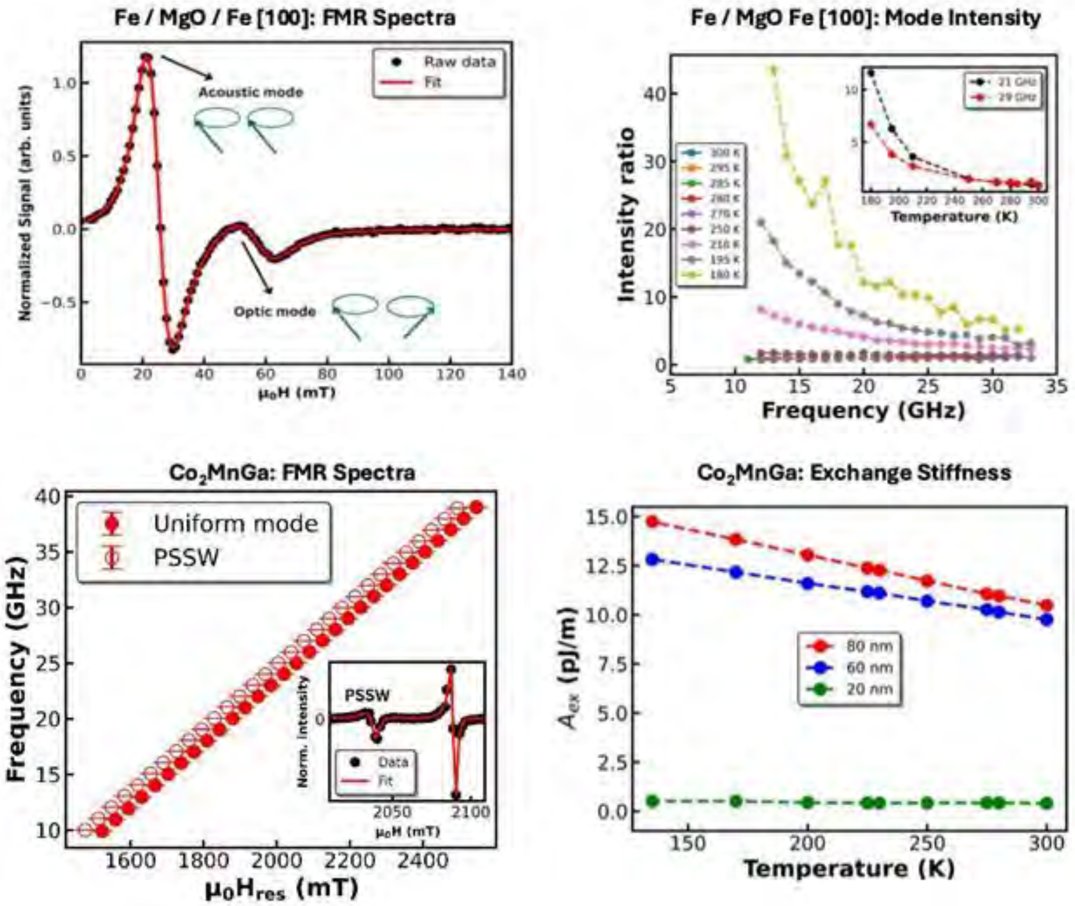
Probing Exchange Interactions in Epitaxial Multilayers and Topological Weyl Semimetal Thin Films

Ayomipo Ojo[1], A.L. Ravensburg[2], M.P. Grassi[2], V. Kapaklis[2], A. Markou[3], C. Felser[3], Dario Arena[1]
[1]University Of South Florida, United States, [2]Uppsala University, Sweden, [3]Max Planck Institute for Chemical Physics of Solids, Germany

Contributed Talk: Dario Arena, July 15, 2025, 14:15 - 14:30

We employ broadband ferromagnetic resonance (FMR) to investigate the temperature dependence of exchange interactions in two distinct epitaxial systems: Fe/MgO/Fe bilayers and topological Weyl semimetal Co2MnGa (CMG) thin films. In Fe/MgO/Fe bilayers, the interlayer exchange coupling (IEC) through the MgO spacer layer is studied with the applied magnetic field aligned along the Fe [100], [110], and [001] crystallographic directions. The FMR spectra reveal two distinct eigenmodes: a low-field acoustic mode and a high-field optic mode. The resonance field difference between these modes indicates that the IEC is antiferromagnetic with a coupling field of ~ -4 mT at 300 K, increasing to~ -15 mT at 180 K while probing the Fe [100] direction. Additionally, the amplitude ratio of the acoustic to optic modes increases with decreasing temperature, signifying an enhancement of the coupling strength.

In CMG thin films, the applied magnetic field is perpendicular to the plane of the sample permitting excitation of perpendicular standing spin wave (PSSW) modes. The difference in effective magnetization between the PSSW and uniform modes is used to quantify the exchange stiffness. Thin CMG films (20 nm) show low exchange stiffness (~1 pJ/m) which is independent of temperature. Thicker CMG films (>50 nm) exhibit much larger exchange stiffness (>10 pJ/m), which increases as the temperature is lowered, indicating a competition between exchange interactions and thermal agitation.



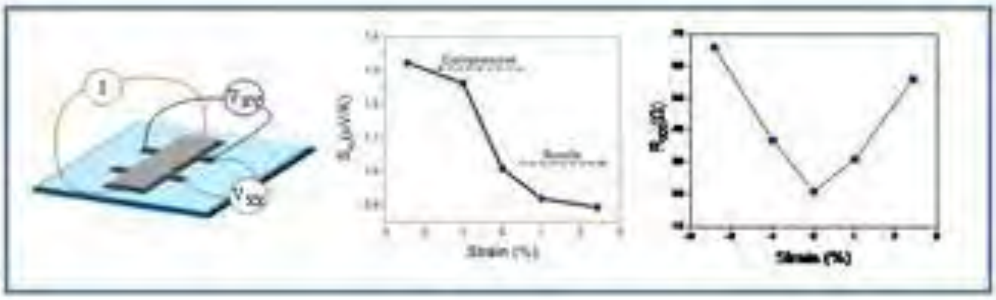
Anomalous Nernst Effect of strained multilayers

Guillermo López-Polín[2], Pablo Martínez-Outomuro[1], Cantia Belloso[1], <u>Agustina Asenjo</u>[1]
[1]Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC), Spain, [2]Dept. Física de Materiales, Universidad Autónoma de Madrid, Spain

Contributed Talk: Agustina Asenjo, July 15, 2025, 16:45 - 17:00

The conversion of waste heat into usable electricity is a critical challenge for sustainable energy solutions. In this context, thin film materials exhibiting strong Anomalous Nernst Effect (ANE) have emerged as promising candidates for thermoelectric devices [1, 2]. Among these, Co/Pt multilayers hold particular interest due to their high ANE coefficient, low electrical resistivity, and perpendicular magnetic anisotropy (PMA) [3,4]. These properties allow Co/Pt multilayers to efficiently convert temperature gradients into electric voltage via the ANE. This work explores strategies to further enhance the ANE coefficient in Co/Pt multilayers, aiming to improve their efficiency for thermoelectric waste heat harvesting.

This work investigates the impact of strain on the Anomalous Nernst Effect (ANE) of Co/Pt multilayers deposited on polyimide substrates. Thanks to the use of flexible substrates, we introduce strain directly into the growing film by controllably bending the substrates during the deposition of the multilayers. The strain applied to the multilayers varies between +/- 2.4%. The ANE measurements, in the range of ~1μV/K exhibit an increasing tendency on the applied compressive strain and opposite tendency when the films are stretched. We also performed Hall effect measurements on the multilayers. While the longitudinal resistivity increases with both compressive and tensile strains, the hall resistivity shows a similar trend to the ANE, i.e. an increase with compressive and decrease with tensile strains. We attribute the ANE enhancement with compressive strains to an increase of interface scattering, which governs the ANE and Hall resistivity of these multilayers. This finding suggests that strain engineering of magnetic multilayers could be useful to tune the thermomagnetic and transport properties of magnetic multilayers, leading to an enhance of their longitudinal and hall resistivity, and the consequently increase of the ANE coefficient.



Magneto-resistive detection of spin-waves

Quentin Rossi[1], Hicham Majjad[1], Grégoire De Loubens[2], Hugo Merbouche[2], Igor Ngouagnia[1], Daniel Stoeffler[1], Aurélie Solignac[2], **Matthieu Bailleul**[1]
[1]IPCMS, CNRS/Université de Strasbourg, France, [2]SPEC CEA/Université Paris-Saclay, France

Contributed Talk: Matthieu Bailleul, July 14, 2025, 15:30 - 15:45

Spin-waves are conventionally detected either by magneto-optical imaging (magneto-optical Kerr effect, micro Brillouin light scattering[1]) or by inductive microwave measurements[2]. These methods are now reaching their limits in terms of signal sensitivity and spatial resolution, which constitutes a technological bottleneck for the miniaturization of magnonic devices and for the exploration of the fundamental physics of spin-waves. In this work, we demonstrate a novel detection method based on a standard element of spintronics, which is a giant magneto-resistive (GMR) sensor. The sensor is directly integrated below a ferromagnetic track serving as a waveguide for spin-waves It is electrically insulated from the track, but is located close enough to be coupled to it via stray dipole fields. When the spin-wave passes over the sensor, it generates an oscillating dipole field which induces a precession of the magnetization of the free layer. This translates in an oscillation of the impedance of the sensor, which, for a given current bias, results in a voltage that can be accessed via suitable microwave measurements.

The fabricated device includes a coplanar waveguide which, upon injection of a microwave current, generates spin-waves with wavelength about 1 µm in the nearby ferromagnetic waveguide. This waveguide consists of a long Permalloy slab. Its magnetization is saturated along the width using an external static field H_0 (so-called Damon-Eshbach configuration of spin-wave propagation). The microwave voltage is measured at the output of a second coplanar waveguide connected to the 300×600nm^2 rectangular GMR sensor[3]. The measurements are performed for two polarities of a direct current flowing in the GMR sensor, which allows one to separate the magneto-resistive contribution from the inductive one related to the magnetic flux across the second waveguide. These experiments show an increase of the signal by a factor of 5 when going from inductive detection to the magneto-resistive one, and this factor increases further to 50 if the signal is scaled with the detection volume. We will discuss these results in the light of micromagnetic simulations addressing directly the coupling at play. The favorable scaling law expected upon miniaturization, opens realistic perspectives for the implementation of several advanced computing architectures proposed in the field of magnonics[4].

This work has benefited from a government grant operated by the French National Research Agency as part of the France 2030 program, reference ANR-22-EXSP-0004 (SWING).

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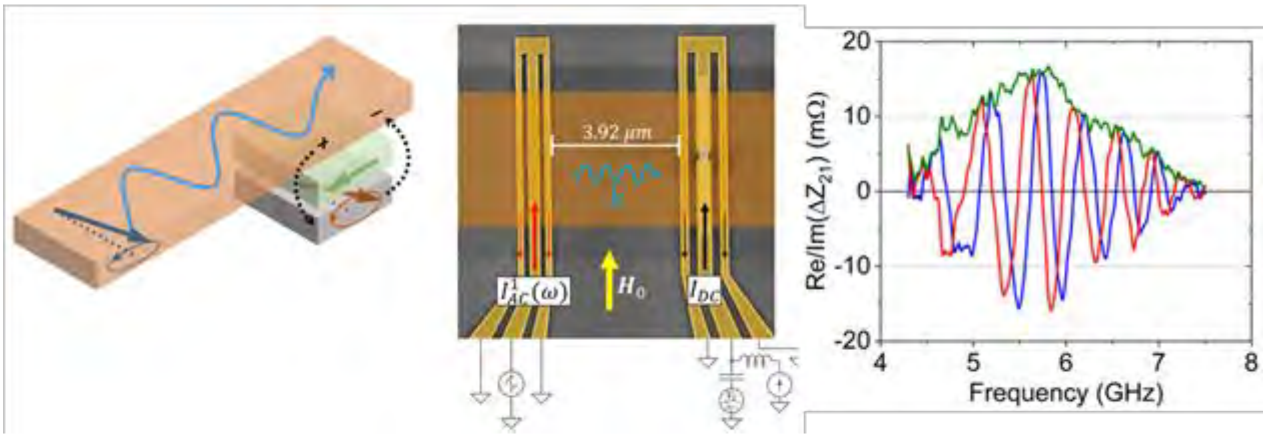
[3] Moulin et al. Appl. Phys. Lett. 115, 122406 (2019)
[4] Papp et al., Nature Comm. 12, 6422 (2021)

Figure. (left) Principle of the magnetoresistive detection of a spin-wave. (middle) Scanning electron microscope picture of the device. (right) GMR part of the microwave transmission signal, for an external magnetic field of 20mT and a bias current of 2.5mA.


3.92 μm
$I_{AC}(\omega)$
H_0
I_{DC}
Re/Im(ΔZ_{21}) (mΩ)
Frequency (GHz)

Low-energy, ultrafast anisotropy switching at competing hybrid interfaces

__Oscar Cespedes__[1], Servet Ozdemir[1], Matthew Rogers[1], Jaka Strohsack[2], Hari Babu Vasili[1], Manuel Valvidares[3], Parvathy Harikumar[4], David O'Regan[4], Gilberto Teobaldi[5], Timothy Moorsom[1], Mannan Ali[1], Gavin Burnell[1], B.J. Hickey[1], Tomaz Mertelj[3]

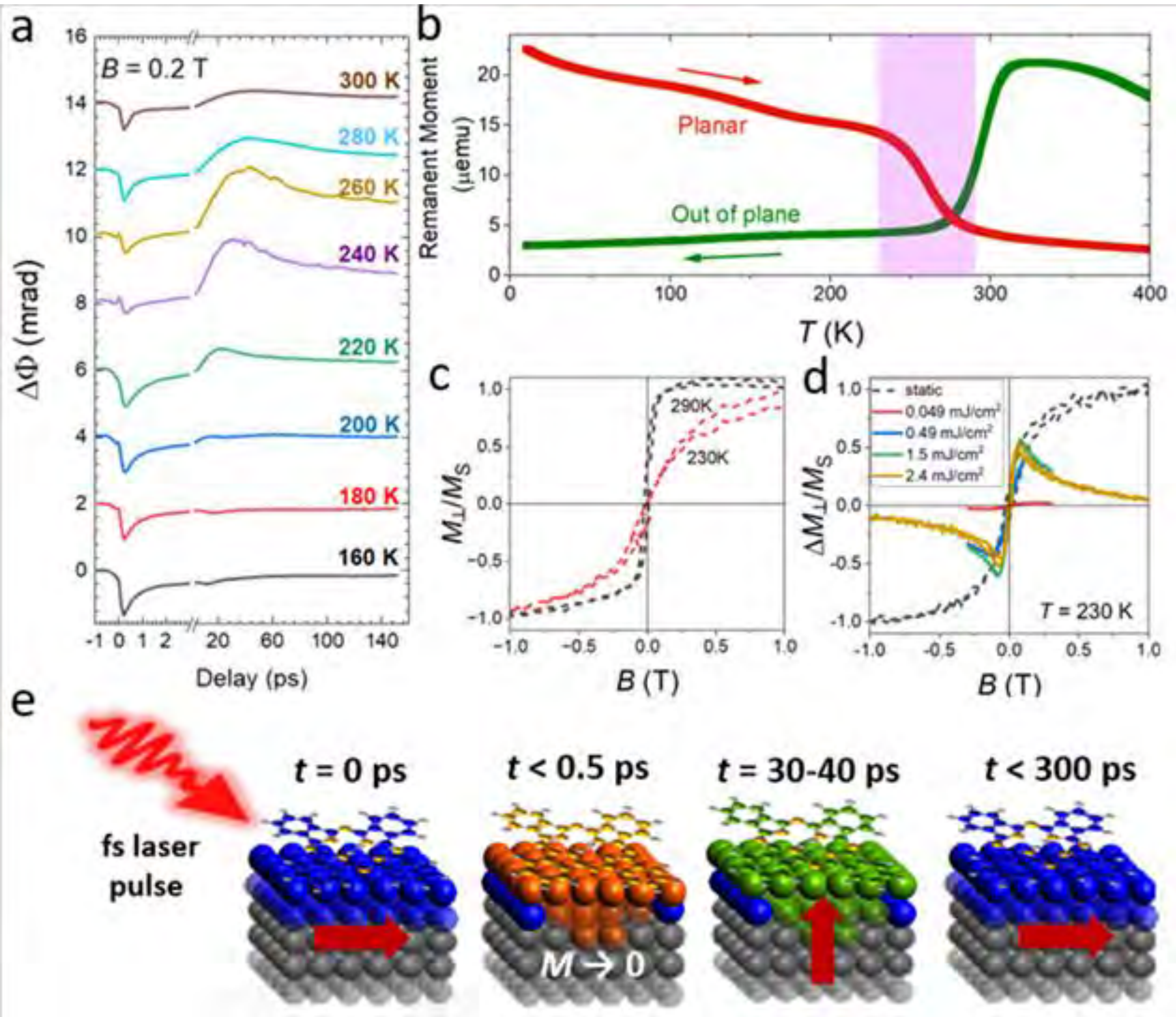
[1]University Of Leeds, United Kingdom, [2]Jozef Stefan Institute, Slovenia, [3]ALBA Synchrotron Light Source, Spain, [4]Trinity College Dublin, Ireland, [5]Science and Technology Facilities Council, United Kingdom

Contributed Talk: Oscar Cespedes, July 17, 2025, 11:45 - 12:00

Over the past decade, magnetic thin film applications in information processing and storage have been focussed on neuromorphic computing, Spin Transfer/Orbit Torque (STT/SOT) and Heat-Assisted Magnetic Recording (HAMR), where a fast, low power switching of the magnetisation direction is required. Here, we demonstrate a spin reorientation transition in conventional 3d ferromagnetic films due to a competition between perpendicular magnetic anisotropy induced by a heavy metal that dominates at high temperatures, and an in-plane anisotropy generated by molecular coupling at low temperatures. The transition can be tuned around room temperature by varying the ferromagnet thickness (~1.4 to 1.9 nm) or the choice of molecular overlayer, with the organic molecules being C_{60}, hydrogen and metal (Cu, Co) phthalocyanines. Near the switching temperature, the magnetisation easy axis can be reoriented with a small energy input, either optically by a fs laser pulse of fluence as low as 0.12 mJ/cm² or electrically with a current density of 10^5 A/cm². Xray magnetic dichroism measurements point toward a phase transition at the organic interface being responsible for the switching.

Fig. 1|THz magneto-optical Kerr effect (MOKE) spectroscopy of the spin-reorientation transition at Pt/Co(1.4 nm)/H_2Pc structure. a, Temperature dependent polar time-resolved Kerr angle transients corresponding to the out-of-plane magnetisation measured at an excitation fluence of 0.12 mJ/cm² showing an onset of optical-pulse-induced out-of-plane spin-reorientation transition between 220 and 280 K. b, Planar and perpendicular magnetic remanence curves measured on the metallo-molecular structure with the spin-reorientation transition temperature window (from 230 K to 290 K) highlighted in pink. c, The out-of-plane static polar MOKE hysteresis around the transition window at 230 K and 290 K, showing the easy axis emergence on the latter. d, The normalized field-dependent magnitude of the transient out-of-plane magnetisation, $\Delta M_\perp$, in comparison to the static out-of-plane magnetisation, $M_\perp$, at the optimal T = 250 K as a function of the excitation fluence specified in the legend. e, Schematic illustrating the picosecond spin-reorientation transition dynamics (suggested in a) with the planar magnet demagnetised after <0.5 ps, followed by the spin-reorientation transition after the laser-induced heating on a 30-40 ps timescale, and planar magnetisation re-emergence in less than 300 ps.

Fig. 2|Xray absorption spectroscopy and transport measurements. a, Circular polarisation dependent X-ray absorption spectrum and the corresponding magnetic dichroism measured at Co edge at 2 T in grazing incidence, showing Co to be in a valence 2+ state due to molecular chemisorption. b, Extracted total magnetic moment in grazing (GI) and normal incidences (NI) where a planar magnetisation onset below T = 200 K is evidenced as GI total moment overtakes NI. c, Temperature dependence of change in resistance on a Pt/Co(1.7nm)/CoPc structure measured during Anisotropic Magnetoresistance (AMR) field sweeps, with the field applied parallel to the electrical current, showing greater negative magnetoresistance as temperature is increased and spin reorientation transition takes place. d, AMR field sweeps measured at varying current densities on the Pt/Co(1.7nm)/CoPc structure at T = 150 K suggesting an induced spin reorientation transition at a switching current density of $\approx 1\times10^5$ A/cm².



a
b
c
d
e
B = 0.2 T
300 K
280 K
260 K
240 K
220 K
200 K
180 K
160 K
ΔΦ (mrad)
Delay (ps)
Remanent Moment (μemu)
Planar
Out of plane
T (K)
290K
230K
M⊥/MS
B (T)
static
0.049 mJ/cm²
0.49 mJ/cm²
1.5 mJ/cm²
2.4 mJ/cm²
ΔM⊥/MS
T = 230 K
B (T)
fs laser pulse
t = 0 ps
t < 0.5 ps
t = 30-40 ps
t < 300 ps
M → 0

Determination of exchange stiffness in Pt/Co/Ni multilayer system

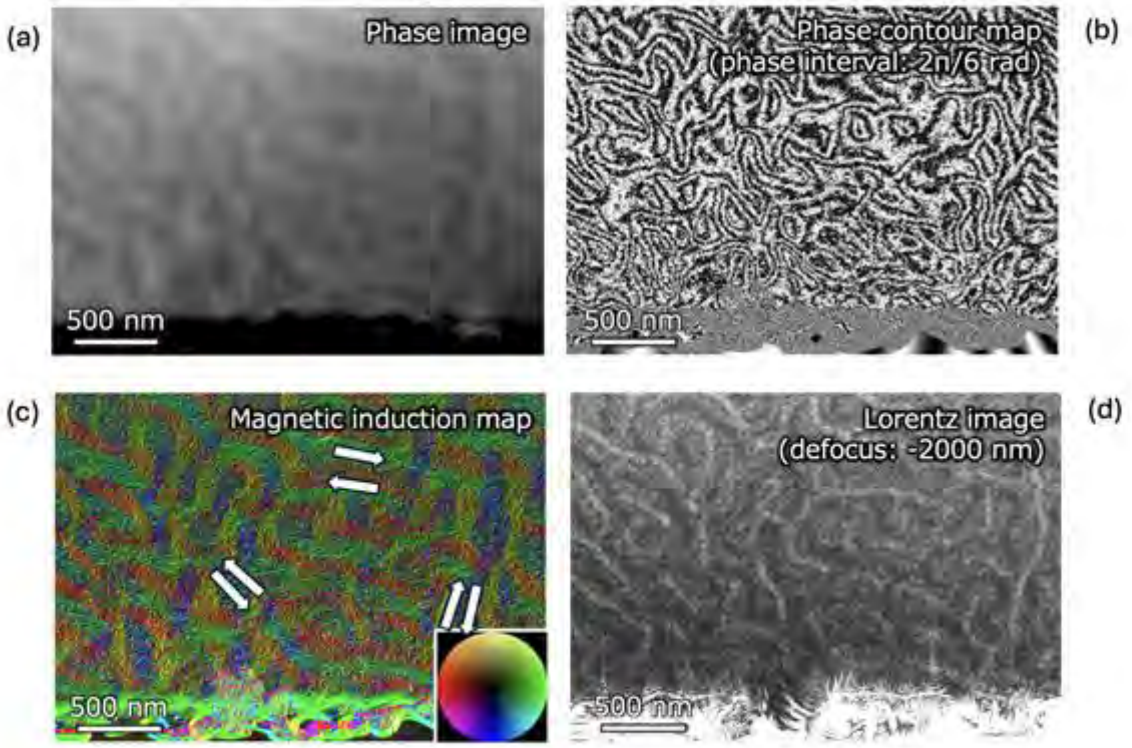
Tsz Chung Cheng[1], Lin Zhang[1], Yuto Tomita[2,3], Yuichiro Kurokawa[1], Yasakazu Murakami[2,3], Hiromi Yuasa[1]
[1]Graduate School of Information Science and Electrical Engineering, Kyushu University, Japan, [2]The Ultramicroscopy Research Center, Kyushu University, Japan, [3]Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University, Japan

Contributed Talk: Tsz Chung Cheng, July 14, 2025, 17:00 - 17:15

The domain wall dynamics of a multilayer system have been studied with electron holography. The sample is Ta(2)/Pt(5)/[Co(0.7)/Ni(0.5)/Pt(0.7)]$_{30}$/Ta(5 nm) multilayer that is known to show skyrmions at about 0.3 T. Although such cases are generally discussed by assuming that the exchange stiffness constant A_ex is the same as the bulk value, any detailed discussion of skyrmion stability requires an A_ex specific to the laminated film. In this study, the stiffness constant A_ex was estimated using the value of domain wall width obtained by the electron holography (Hitachi HF-3300X Electron Microscope) at zero field.

Figure 1a is the resultant phase profile reconstructed by aligning 50 images and Figure 1b is the phase counter image obtained by Fourier and inverse Fourier transforms. A magnetic induction map from the phase profile was reconstructed as shown in Figure 1c, where three pairs of 180-degree domain walls were identified as indicated by white arrows. The phase differential of the identified domain walls was then fitted with a tanh function profile. [1] The result suggested a 6 nm domain wall width. An additional set of defocused Lorentz Transmission Electron Microscope images for the same field of view was shown in Figure 1d, suggesting that there is not a significant discrepancy between the values of the domain wall width obtained from the electron holography and LTEM.

Micromagnetic simulations were then carried out to estimate A_ex. A mesh of (1024 x 256 x 54) nm with periodic boundary conditions was initialised in a three-domain state to model all 90 layers. By applying a temporary external field of 1 mT in all three directions, the system's equilibrium was disrupted and relaxed into two 180-degree domain wall pairs. A tanh profile fitting was then conducted on the average magnetisation in the z-direction to obtain the domain wall width. With an interfacial Dzyaloshinskii-Moriya Interaction (DMI) constant of D=0.45 mJ/m^2 as previously reported in a similar system [2], A_ex was determined to be 17 pJ/m. Comparing electron holography observation to simulated domain wall profiles is a promising method to estimate the exchange stiffness constant, which can enable an accurate estimation of the DMI constant in further experiments.



(a)
Phase image
500 nm
(b)
Phase contour map
(phase interval: 2π/6 rad)
500 nm
(c)
Magnetic induction map
500 nm
(d)
Lorentz image
(defocus: -2000 nm)
500 nm

Spin relaxation determined by ferromagnetic damping in large-area CVD monolayer MoS2/permalloy heterostructures

Henry De Libero[1], Evelyn Chalmers, Noel Natera Cordero, Andrew Strudwick, Ivan Jesus Vera-Marun, Thomas Thomson
[1]*University Of Manchester, United Kingdom*

Contributed Talk: Henry de Libero, July 18, 2025, 10:15 - 10:30

Spin-charge interconversion is the key mechanism behind next generation spintronic devices, namely magnetic RAM, conventionally achieved using heavy metal thin films such as platinum [1]. However, in recent years, 2D materials and transition metal dichalcogenides (TMDs) have received significant attention as an alternative spin-charge conversion layer due to high spin-orbit coupling and spin-charge interconversion [2]. Most of the work on TMDs has been done using flake-scale devices that are incompatible with industry processes. Here, we explore the large-area capabilities of TMDs for spin-charge interconversion by measuring the ferromagnetic damping. Damping is related to energy dissipation due to spin relaxation [3]. By measuring the damping, one can get an understanding for spin pumping and spin relaxation in heterostructures and thus, spin-charge interconversion [4]. While damping mechanisms in conventional NM/FM heterostructures are well-studied, those in 2D-material/FM heterostructures remain less understood.

Here, we report on ferromagnetic damping in large-area CVD-grown monolayer MoS2/permalloy heterostructures using broadband VNA-FMR spectroscopy. Permalloy (NiFe) was deposited on MoS2 via DC magnetron sputtering, with monolayer MoS2 confirmed through x-ray reflectometry and Raman spectroscopy. Large-area growth of the MoS2 was also confirmed by photoluminescence and Raman spectroscopy. By varying the NiFe thickness, we explored both bulk and surface contributions to Gilbert damping [2]. Notably, we observed no enhancement in effective damping due to spin pumping (Fig. 1). This was further confirmed by measuring the surface anisotropy using VNA-FMR, showing a reduction of a factor of 10. This indicates interfacial phenomena such as proximity-induced magnetism could be impeding spin pumping across the interface.

Furthermore, the bulk damping contribution to the effective damping in NiFe increased when interfaced with 1L MoS2 compared to SiO2 (Fig. 1). X-ray diffraction analysis indicated an increase in (220) and (111) crystallite grains in NiFe on MoS2 (Fig. 2), suggesting a link between crystallinity and bulk damping via spin-lattice scattering. Atomic force microscopy also revealed an increased surface roughness and large crystal grains on the MoS2/NiFe samples. Additionally, the reduced variation in Raman linewidth across the sample suggests fewer defects in our MoS2 samples compared to other studies, correlating with the lack of extrinsic spin-orbit coupling enhanced damping [5]. These findings highlight the importance of understanding interfacial phenomena in 2D/bulk heterostructures, specifically spin transport across an interface for spin-orbit torques.

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[5] R. Bansal, A. Kumar, N. Chowdhury et. al., J. Magn. Magn. Mater., vol. 476, pp. 337-341 (2018)

Fig. 1. Gilbert damping against permalloy thickness deposited on SiO2 and 1L MoS2.

Fig. 2: Grazing-incidence XRD for 8 nm of permalloy grown on SiO2 and 1L MoS2. Vertical lines indicate powder diffraction peaks for permalloy.

Figure 1:

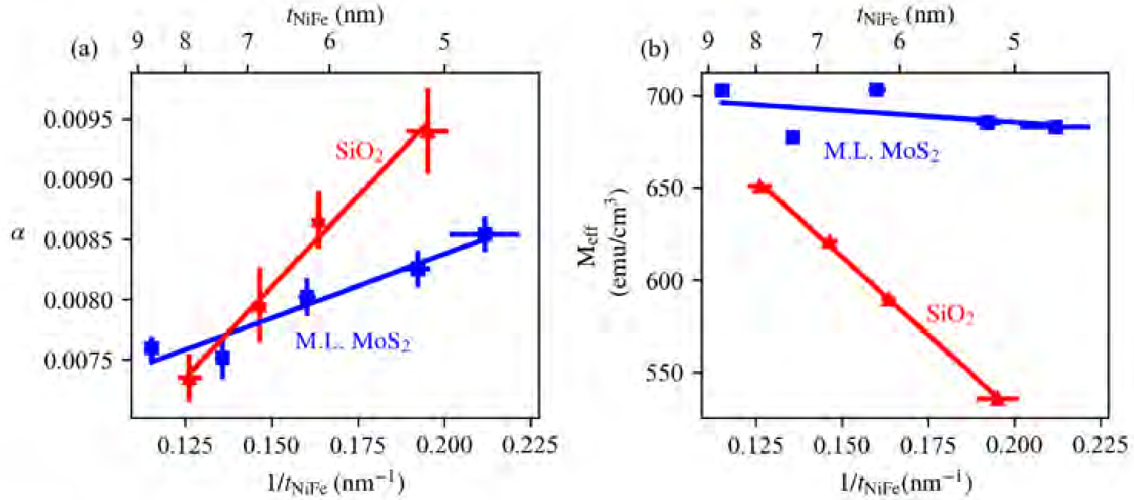
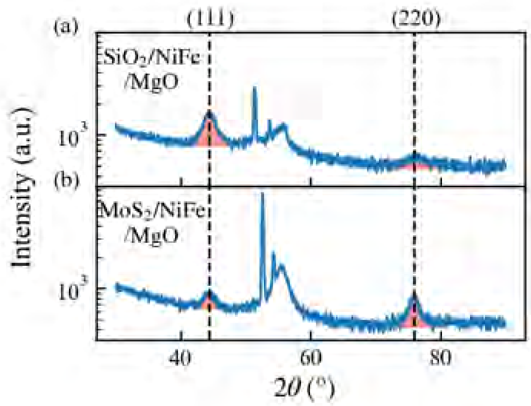


Figure 2:



Electrical, optical and mechanical tailoring of magnetic properties in an extrinsic multiferroic : a case study

Matthieu Liparo[1], Jean-Philippe Jay[1], Matthieu Dubreuil[1], Alain Fessant[1], Walaa Jahjah[1], Yann Le Grand[1], Charles J. Sheppard[2], Aletta R. E. Prinsloo[2], Benedicte Warot-Fonrose[5], Gaelle Simon[3], Vincent Vlaminck[4], Vincent Castel[4], Loic Temdie-Kom[4], Guillaume Bourcin[4], David Spenato[1], David Dekadjevi[1]

[1]Optimag / University Of Brest, France, [2]Cr Research Group / University of Johannesburg, South Africa, [3]Service RMN-RPE / University of Brest, France, [4]IMT-Atlantique, France, [5]CEMES / CNRS, France

Contributed Talk: David Dekadjevi, July 18, 2025, 14:00 - 14:15

Magnetostrictive thin films have attracted a large amount of interest. Indeed, using strain to control magnetism through anisotropy modifications is a method to create functional materials to be implemented in different devices. Here, we probe mechanisms at play in mechanical, electrical, and optical controls of the Galfenol magnetization through strain[1-4].

To achieve a mechanical control using multiaxial stress [3], 10nm $Fe_{81}Ga_{19}$ (Galfenol) thin films are grown on flexible Aluminium foils bought in a supermarket. Then, these flexible samples are pressed on different convex optical lenses to achieve multiaxial stress. Without multiaxial bending, it is shown that the Galfenol anisotropy character is a superposition of twofold and fourfold anisotropy. The multiaxial stress modifies magnetization reversals. It results in an irreversible development of a random anisotropy.

To achieve a strain-mediated electrical manipulation of magnetization[4], Galfenol thin films are grown on PMN-PZT ferroelectric substrates by RF sputtering. Magnetization reversals under electric fields (E-fields) of different magnitudes are then studied as shown in Figures 1(a) and 1(b). Under E-fields, magnetic anisotropy and magnetization reversals undergo drastic modifications as shown in Figures 1(c) and 1(d). An almost 90° rotation of the preferential anisotropy axis is observed. Coercivity as a function of E-fields exhibits a butterfly shape as shown in Figure 1(e). The converse magnetoelectric coupling coefficient is determined from MH loops. It is found to be quite large (ie. 2.7×10^{-6} $s.m^{-1}$).

To achieve an optical control with non-pulsed visible lights [5], Galfenol/PMN-PZT static and dynamic magnetic properties are probed under a 410nm Laser illumination and a 405nm LED illumination, as shown in Figure 2(a). Using strain gages, the strain under illumination is quantified as shown in Figure 2(b). Angular dependent magnetization reversals are modified under the 0.6 W/cm^2 laser illumination as shown in Figures 2(c) and 2(d).
We define a novel converse magneto-photostrictive coupling coefficient. The light-induced variation of the magnetic properties through photostriction is then quantified by this coefficient. It is found that azimutal dependencies of magneto-photostrictive and magneto-electric effects are similar in shape. It reveals that anisotropy modifications are similar under light and under E-fields as shown in Figure 2(e). Also, the maximum relative changes of magnetization obtained by light is similar in magnitude than the one obtained under electrical manipulation : a 76% change under illumination vs a 82% change under electrical manipulation).
About the optical control of spin dynamics, FMR measurements reveal that resonant fields are shifted under a $7W/cm^2$ LED illumination as shown in Figure 2(f). Linewidths are not modified by the illumination.
It should be noted that thermal measurements show that these optical controls of magnetic properties are not driven by thermal effects.

Perspectives on using a different multiferroic to enhance optical control of magnetization with non-pulsed visible lights will be discussed.

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FIGURE 1

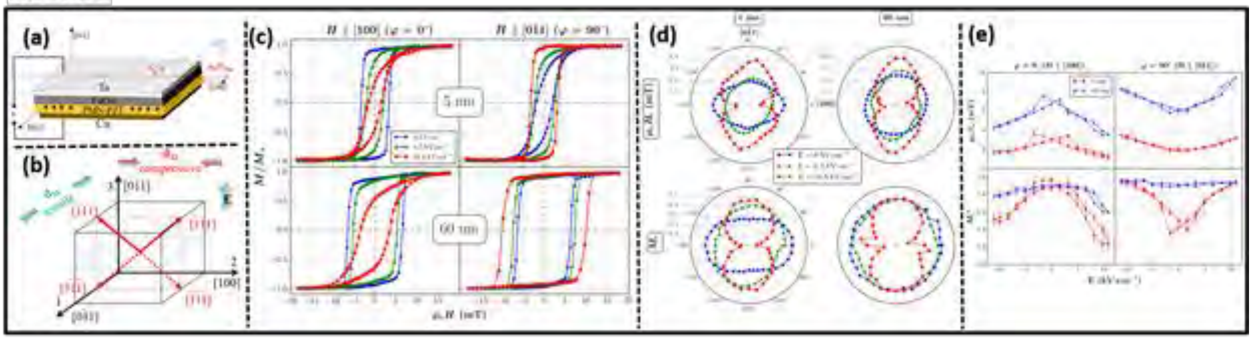
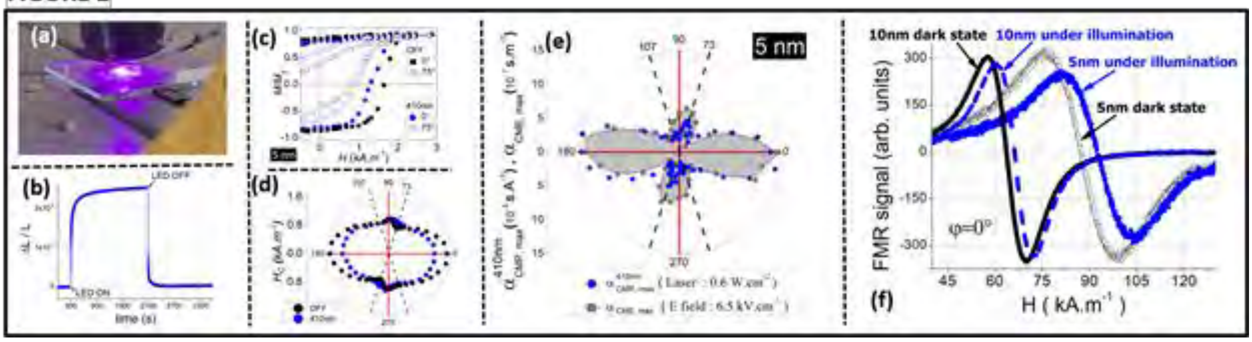


FIGURE 2



Magnon frequency combing in strongly dipolar coupled magnetic layers

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Contributed Talk: Troy Dion, July 14, 2025, 14:15 - 14:30

In the face of ever-growing energy demands from data processing, there is a need for the development of new technologies and tools that are energy efficient, parallelisable and operate in the GHz regime. Magnonics, the study and exploitation of coherent magnetic oscillations, offers fertile ground for such technologies, intrinsically operating at GHz frequencies with low power consumption, and already harnessed in neuromorphic computing schemes [1,2]. However, magnonic computing schemes often struggle to achieve crucial high data input dimensionalities.

A phenomenon which has demonstrated strong processing benefits & enhanced parallelisation in photonics is frequency combs, in which a central frequency mode is multiplexed into many equally frequency-spaced sideband modes - or "comb teeth". In recent decades, optical frequency combs have delivered broad success [3].

Following the success of optical frequency combs, the concept of magnonic frequency combs has recently attracted recent attention [4,5]. Current experimental demonstrations have shown magnon frequency combs within single magnetic vortex disks, a key breakthrough. It is now attractive to explore expanding experimental realisations into more flexible multi-layered and coupled systems.

Here, we present experimental realisation of a magnon frequency comb generated between multiple distinct magnetic textures driven by strong dipolar magnon coupling between free-space in a multi-layered system [6]. Here we use a trilayer structure of NiFe/Al/NiFe (Fig 1), capable of hosting stable vortex and macrospin states in the bottom and top NiFe layers respectively. Using experimental measurements supported by micromagnetic simulations (Fig 2), we probe ferromagnetic resonances in the structure at fixed DC magnetic fields across a range of input rf fields. Above a critical RF field threshold, we observe frequency combing generated in the macrospin layer by the gyrotropic vortex core mode in the vortex layer, with 'comb-teeth' frequency spacings matching the gyration mode frequency. Dipolar coupling between these states can be efficiently tuned by choice of the Al interlayer thickness, and we explore the effect of inter-nanoisland interactions, from isolated bars to dipolar-coupled artificial spin ice arrays.

This work demonstrates progress towards high-dimensional magnonic computation and information processing schemes, with potential application in next-generation neuromorphic computing systems.

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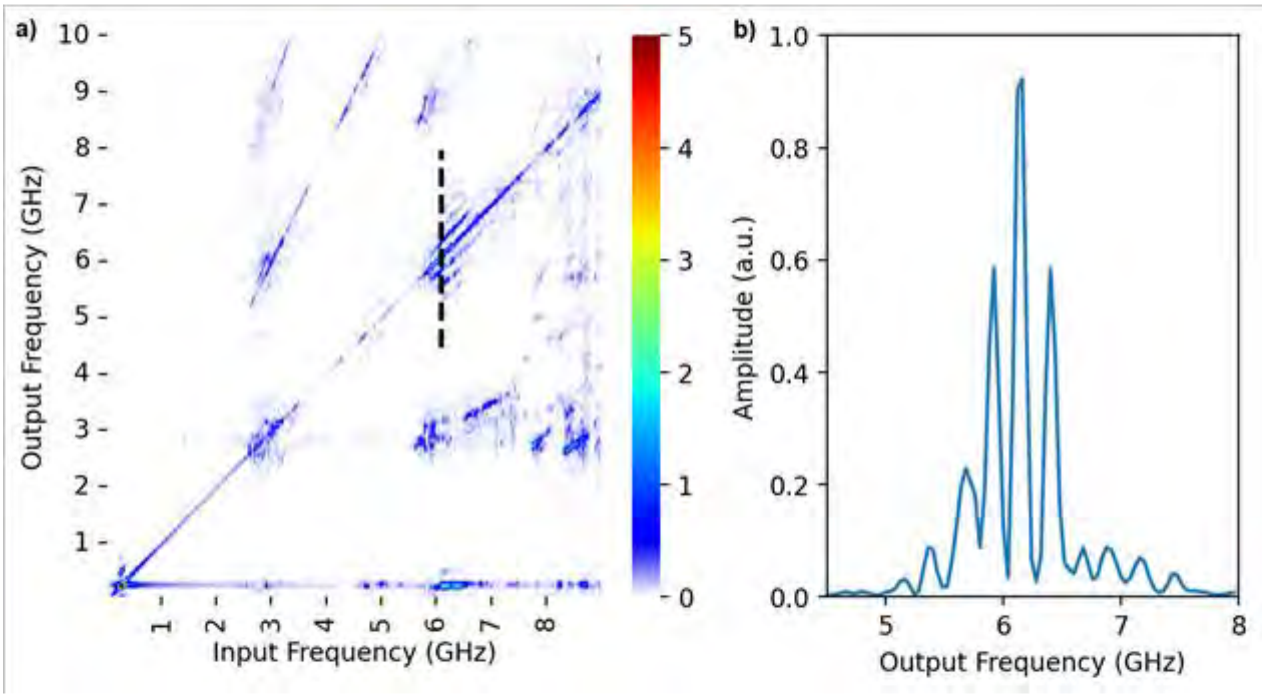
Figure 1: 3D schematic of the trilayer nanobars

Figure 2: (a) Heatmap of magnon resonances for given input rf excitations, demonstrating magnon frequency combing. (b) Line scan of spectra from dashed line in (a)



Artificial superlattices with abrupt interfaces by monolayer-controlled growth kinetics during magnetron sputter epitaxy

Samira Dorri[1,2], Olle Nyqvist[2], Justinas Palisaitis[2], Alexei Vorobiev[3,4], Anton Devishvili[3], Per Sandström[2], Per Persson[2], Naureen Ghafoor[2], Fredrik Eriksson[2], Jens Birch[2]
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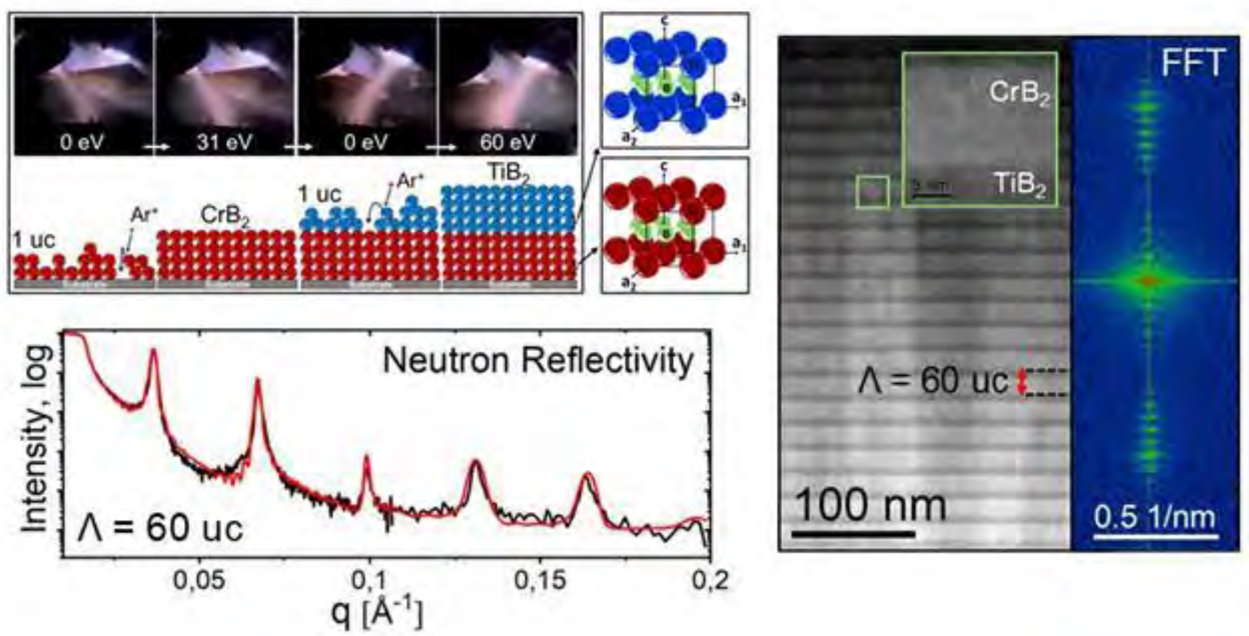
Contributed Talk: Samira Dorri, July 18, 2025, 11:30 - 11:45

Artificial superlattices exhibit exceptional electronic, magnetic, optical, and mechanical properties which make them unique candidates for new applications in a broad range of technologies. A common key feature of superlattices is the need for atomically abrupt interfaces. However, superlattices comprised of materials with different properties, such as melting points and diffusivities, pose large challenges for achieving high crystal quality of both constituents with abrupt interfaces. We present an innovative solution to this problem by utilizing a unique combination of thermal radiation and kinetic energy provided by ion flux during ion-assisted magnetron sputter epitaxy. The research has been implemented for the case of hexagonal α-type CrB2/TiB2 heteroepitaxial superlattices, as neutron interference mirrors, wherein the constituents' melting points differ by 1100 K. The strategy is to provide sufficient adatom mobility to enable epitaxial growth of both materials by utilizing the best balance between thermal energy and kinetic energy as provided by ion flux, for CrB2 and TiB2 individually. Ion-induced intermixing was avoided by commencing growth of each TiB2 and CrB2 layer by up to 3 unit cells (uc) without ion assistance, forming a buffer to protect the interface during the ion-assisted growth of the remainder of each layer. Heteroepitaxial superlattice growth with interface widths σCrB2 ~1 uc and σTiB2 ~2 uc was confirmed for different modulation periods. More than 3000 uc (~1 μm) thick superlattices with abrupt interfaces were successfully demonstrated for neutron mirror applications. These results show that utilizing the monolayer-controlled growth kinetics during ion-assisted magnetron sputter epitaxy allows for growth of superlattices with large number of periods with minimal accumulated roughness and layer intermixing. The method can be generalized for synthesizing high quality heterostructures and superlattices containing layers of materials with a large difference in melting temperatures.



Curvature induced spin textures in thin magnetic films deposited on nanowire networks

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Contributed Talk: Peter Fischer, July 14, 2025, 17:15 - 17:30

There is recent increased interest to explore 3D nanomagnetic systems as the expansion from systems with low dimensionality into the 3rd dimension will open up new opportunities to explore systems with higher complexity, new functionalities and enhanced properties. Significant advances in modelling and theory, synthesis and fabrication, and characterization and validation are rapidly emerging to address the challenges associated with it [1,2]. Topological spin textures, notably magnetic vortices and skyrmions are prototypical examples of interest, but have been experimentally studied mostly as 2D objects and on flat surfaces [3]. Of specific interest is the exploration of local curvature as a new design parameter, as it would change the local energy landscape and modify detailed configurations of spin textures in the system.

Here, we report investigations of a 56 nm thin Co/Pd metallic multilayer film with strong perpendicular magnetic anisotropy which was deposited onto an interconnected Cu nanowire network consisting of 1-5 µm long and 50 nm thick nanowires serving as 3D scaffolds for the synthesis of curved magnetic thin films, with a focus on understanding the stabilization and modification of topologically non-trivial spin textures.

Magnetic soft x-ray nanotomography using the MTXM beamline MISTRAL at ALBA/Spain was used to image the magnetic domain patterns at the Co L3 edge using XMCD as magnetic contrast. A series of angular scans was recorded and tomographic reconstruction methods were applied to obtain the 3D representation of the magnetic network. The data analysis focused on determining the local curvature with regard to principal curvatures as defined in differential geometry, notably Gaussian curvature $k1.k2$ and mean curvature $(k1+k2)/2$ [4]. We found that the curvature of the nanowires creates a preferential orientation of the domain walls and that this preferred orientation imprints into the flat region of the film. A three-dimensional reconstruction of the mesh reveals the non-flat structure of the nanowire network with nanowires extending into the out-of-plane direction.

Micromagnetic simulations confirm our experimental findings and provide guidance to future studies to understand the complex emergence of spin textures, e.g. at nanowire crossings, which might have future technological relevance towards 3D spintronic devices.
This work was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Materials Sciences and Engineering Division under Contract No. DE-AC02-05-CH11231 within the Non-equilibrium Magnetic Materials Program (MSMAG) and NSF grant DMR-2005108. The MTXM experiments were performed at the MISTRAL beamline at ALBA Synchrotron with the collaboration of ALBA staff. The ALBA Synchrotron is funded by the Ministry of Research and Innovation of Spain, by the Generalitat de Catalunya and by European FEDER funds.

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Equilibrium density of dipolar-stabilized Skyrmion lattices at zero field

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Contributed Talk: Robert Frömter, July 17, 2025, 14:00 - 14:15

Magnetic skyrmions stabilized by interfacial DMI are today regarded as well-understood two-dimensional topological spin textures. In particular, skyrmion lattices in magnetic multilayers have recently gained attention as a versatile model system to study ordering/disordering phenomena in two dimensions [1]. Surprisingly, little can be found about the mutual interactions of dipolar-stabilized skyrmions.

In this work, we use the number or repetitions of a multilayer unit cell to selectively control the strength of the dipolar interaction, while keeping the remaining magnetic properties constant. For a single, isolated skyrmion, the size is expected to increase on increasing the number of repetitions [2]. However, when investigating skyrmions arranged in a lattice we find exactly the opposite behavior.

By engineering a magnetic multilayer stack made from Ta/CoFeB/MgO layers we are able to stabilize skyrmion lattices at room temperature and zero field from 1 to 30 repetitions. Using Kerr microscopy and Magnetic Force Microscopy we observe a drastic decrease in skyrmion diameter from 40 µm down to 250 nm as the number of repetitions is increased [3].

We present an analytical model to describe the skyrmion radius and periodicity from the single-layer to the thick-film limit and complement this with micromagnetic simulations, explaining the observed behavior

Additionally, we identify the critical role of the nucleation process in forming the skyrmion lattice. Our work provides a comprehensive understanding of skyrmion-skyrmion interactions, which are driven by dipolar interactions as the multi-layer stack thickness increases.

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Magneto-ionic control of coupled spin-valve heterostructures

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Contributed Talk: Markus Goessler, July 17, 2025, 16:00 - 16:15

The voltage control of magnetic properties by electrochemical reactions, known as magneto-ionic effect, has become an important alternative to conventional magnetoelectric effects. The use of electrochemical reactions not only promises to reduce power consumption in magnetoelectric devices, but also enables the non-volatile control of magnetic properties, which is crucial for data storage applications. Over the past decade, ionic control has been demonstrated for a variety of magnetic phenomena in layered structures, including anisotropy,[1] interlayer coupling,[2] and exchange-bias.[3] Here, we show that the magneto-ionic effect can also be utilized to control spin-valve layer systems, which are technologically important structures in magnetic sensing devices exhibiting the giant magnetoresistance (GMR) effect.

In contrast to conventional spin-valves, where interactions between the two ferromagnetic layers are an undesired side effect, we make use of a strong ferromagnetic interlayer coupling to obtain full magneto-ionic control over a spin-valve structure. For our spin-valve structures we use coupled IrMn/Fe/Au/Fe layer systems, since Fe is known to show a magneto-ionic effect at low voltages. Our magneto-ionic mechanism is based on the electrochemical reduction of a native FeOx layer, which forms on the top Fe layer upon air exposure after sputtering.
We show that this electrochemical reduction of FeOx exclusively on the top Fe layer has a pronounced effect on the magnetic properties of the entire spin-valve structure. We not only observe a decrease of the offset field and coercivity of the top layer, but also a decrease in exchange-bias field and coercivity of the pinned layer, mediated by interlayer coupling. For the control of exchange-bias, we find a significant improvement in reversibility compared to an IrMn/Fe structure,[3] where the pinned Fe layer was in direct contact with the electrolyte solution.

After optimization of the interlayer coupling in our layer structure, we can also show a reversible toggling between single-step and double-step hysteresis loops in Figure 1, corresponding to the voltage controlled OFF- and ON- switching of spin-valve functionality. Modelling hysteresis loops in an extended Stoner-Wohlfarth approach allowed us to conclude that the magneto-ionic effect can be fully explained by an increase/decrease of the Fe top layer thickness upon electrochemical reduction/oxidation and a concomitant strengthening/weakening of the interlayer coupling.

A calculation of GMR highlights the application potential of our magneto-ionic spin-valves for magnetic field sensors with tunable sensitivity. The isolation of the active magneto-ionic layer from the underlayer by an interaction layer could also present a general strategy for the future magneto-ionic control of sensitive magnetic interfaces and spin textures, such as synthetic antiferromagnets or noncollinear magnetic layers.

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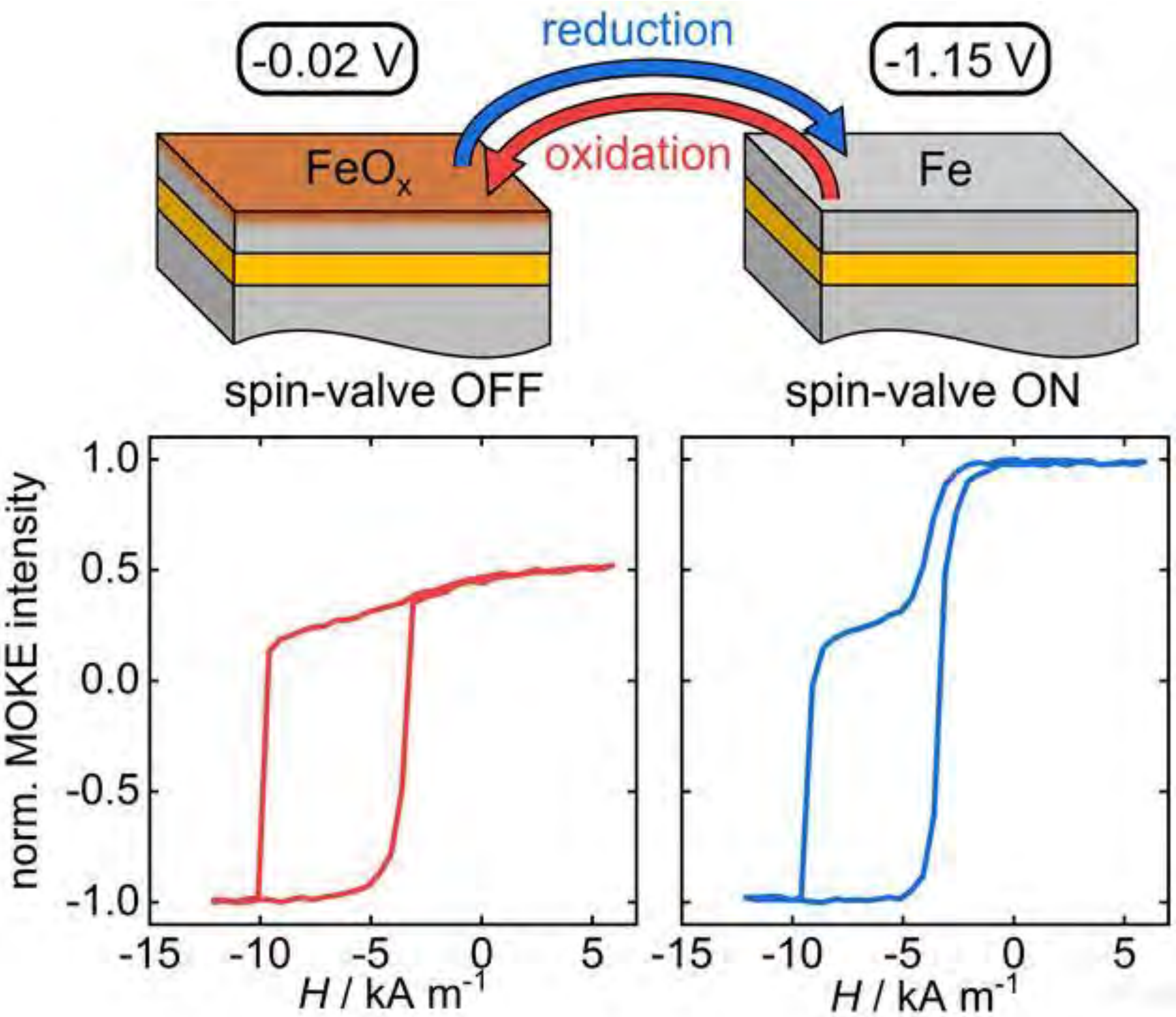
Figure 1: Magneto-ionic switching of an IrMn/Fe/Au/Fe spin-valve. In the oxidized state at -0.02 V a single-step hysteresis loop is observed, while a double-step spin-valve hysteresis loop is obtained in the reduced state at -1.15 V, corresponding to the OFF- and ON- switching of a spin-valve.



Magnon confinement in a nanomagnonic waveguide by a magnetic Moiré superlattice

Gianluca Gubbiotti[1], Marco Madami[2], Jilei Chen[3,4], Haiming Yu[5]
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Contributed Talk: Gianluca Gubbiotti, July 14, 2025, 15:45 - 16:00

The study of moiré superlattices has unveiled intriguing phenomena in electronic systems, including unconventional superconductivity and ferromagnetism observed in magic-angle bilayer graphene.[1,2] This concept has recently been extended to the field of magnonics. In this work, we numerically investigate the confinement of spin waves in a nanomagnonic waveguide integrated with a magnetic moiré superlattice, consisting of a stack of twisted YIG antidot lattices with a square unit cell and periodicity of a= 100 nm and circular holes with a diameter of 50 nm.[3] The thickness of the YIG layers and the waveguide is 2 nm. The YIG waveguide is atop of the moiré superlattice (Fig. 1(a)). Our numerical analysis reveals a magnonic flatband at the center of the Brillouin zone, around 8.2 GHz, induced by a 3.5° twist in the moiré superlattice (see Fig. 1(b)). This flatband, characterized by a high magnon density of states and zero group velocity, enables the confinement of magnons within the AB stacking region. The flatband extends over a wavevector range of about 40 rad/μm and emerges from mode anticrossing between several magnon bands. The flatband is imprinted into the magnonic waveguide, resulting in a high magnon density of states at the flatband and enabling magnon confinement with spatial confinement that extends to approximately 166 nm, as can be inferred from Fig. 1(c). This work introduces a promising approach for controlling spin waves in nanomagnonic waveguides. This approach could be leveraged to design advanced nanomagnonic architectures. It lays the foundation for nanomagnonic devices and circuits based on spin-wave trapping in magnon waveguides.

Fig. 1 (a) Side view of the magnetic moir_e superlattice based heterostructure. Two YIG magnetic layers with antidot lattices are twisted with an angle of θ=3.5°. (b) Magnonic band structure of the magnonic waveguide on top of the moirè superlattice. (c) The upper panel illustrates the internal field within the magnonic waveguide (unit in kA/m). The lower panel depicts the spatial distribution of the magnetization dynamics (unit in kA/m) mx at t=4 ns. (d) A line-cut of the magnetization amplitude at y=0. The red curve is a Lorentz fitting, which yields a linewidth of 166 nm.

Ackowledgment
G.G. acknowledges funding from the European Union – Next Generation EU – "PNRR – M4C2, investimento 1.1 – "Fondo PRIN 2022" – TEEPHANY– ThreEE-dimensional Processing tecHnique of mAgNetic crYstals for magnonics and nanomagnetism ID 2022P4485M CUP B53D23002820006.

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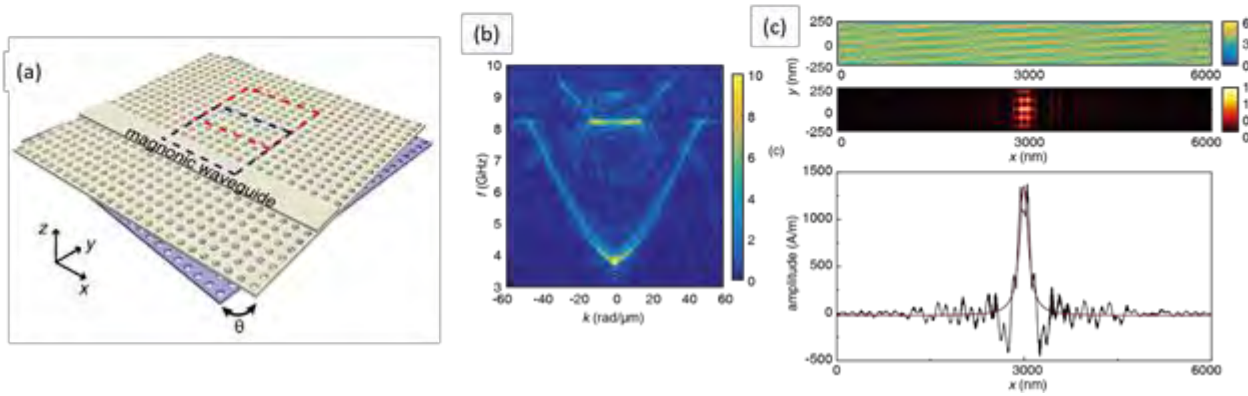

(a)
magnonic waveguide
z
y
x
θ
(b)
f (GHz)
k (rad/μm)
(c)
y (nm)
x (nm)
amplitude (A/m)
x (nm)

Search for proximity-induced magnetism in CrTe2/Bi2Te3 ferromagnet-topological insulator heterostructures

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Contributed Talk: Emily Heppell, July 15, 2025, 14:00 - 14:15

Topological electronics explores novel quantum properties, such as those encountered in topological insulators (TIs). Theoretically, TIs are characterised by an insulating bulk and topologically protected conducting surface states. When magnetically doped, TIs can display the quantum anomalous Hall effect. However, defects associated with the doping limit the useful temperature range to well below the magnetic ordering temperature. A promising alternative is to bring a magnetic material close to a TI such that the TI's surface states can acquire magnetic properties via the proximity-induced magnetism (PIM) effect [1]. As such, finding ferromagnetic materials with compatible crystal structures and deposition conditions has been an intense field of study in spintronics. However, the difficulty of obtaining clean interfaces free from the diffusion of magnetic constituents has made unambiguous confirmation of PIM elusive [2].

We examine the interfacial coupling between ferromagnetic CrTe2 and the TI Bi2Te3 using polarised neutron reflectometry (PNR) and magnetic x-ray spectroscopy. We have recently demonstrated their epitaxial growth over large (wafer-scale) areas by molecular beam epitaxy [3]. Importantly, we observe excellent lattice matching, high homogeneity, and atomically sharp, well-defined interfaces where diffusion and island growth are suppressed. PIM in Bi2Te3 manifests as a non-zero magnetic moment induced in Bi2Te3 within a few nanometres near the interface with CrTe2. We present first fitting results of PNR measurements of the CrTe2/Bi2Te3 heterostructure, hinting at a non-zero magnetic moment in the Bi2Te3 layer close to the interface. The direction of the magnetic moment is anti-aligned with respect to the magnetisation direction of the CrTe2. We also observe an enhancement of the magnetisation of the CrTe2 in the interfacial region. A more in-depth analysis is still essential to corroborate our findings. If confirmed, CrTe2/Bi2Te3 heterostructures have great potential for applications in energy-efficient devices and quantum computation.

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Real-time observation of VCMA-assisted magnetization switching

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Contributed Talk: Marco Hoffmann, July 18, 2025, 14:15 - 14:30

Voltage control of magnetic anisotropy (VCMA) [1,2] provides interesting options for low-power magnetization switching as required for magnetic random-access memories (MRAM). Specifically, VCMA allows for the reduction of magnetic fields and spin-torques, thus saving energy during the switching process. It is well known that VCMA can be the main driver of switching via precession or relaxation of the magnetization in the presence of magnetic fields [3]. However, the response of the magnetization does not need to be fast, and various factors can contribute to a delayed dynamics. Understanding and controlling these delays is crucial to achieve reliable and fast VCMA-assisted switching in technological applications. Here, we present real-time data of VCMA-assisted switching via relaxation in a magnetic field in magnetic tunnel junctions (MTJs) with a hybrid free layer comprising an MgO barrier with a CoFeB/W/[IrFeCoPt]3 hybrid free layer. We investigate the statistical distribution of single-shot switching events and show how the switching speed is determined by the applied voltage and magnetic field. In critical conditions, the reversal starts by the end of the applied voltage pulse and is completed only after pulse termination. Micromagnetic simulations incorporating the finite charging times of the tunnel junction and the granularity of the magnetic film reproduce the experimental switching traces. Our quantitative analysis of the switching is of interest for the exploitation of the VCMA effect, e.g., for the design of hybrid MRAM [4] or to control topologically protected magnetic textures for information storage in such hybrid free layer systems [5].

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Local reconfiguration of antiferromagnetic layer in magnetic tunnel junctions in the context of radio-frequency spintronic neuromorphics

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Contributed Talk: Alex Jenkins, July 16, 2025, 17:00 - 17:15

One of the key building blocks of spintronics is the magnetic tunnel junction (MTJ), which are versatile nano-devices capable of a range of functionalities, and have already attracted significant interest as sensors, non-volatile memories, energy harvesters, radiofrequency sources and rectifiers, and more recently for novel computing paradigms. To truly harness the analogue nature of spintronics, magnetic stacks need to be designed which are capable of being reprogrammed after device fabrication. A variety of properties can be reprogrammed, from the static resistance value to the dynamic properties of the devices, such as the oscillation frequency, linewidth and power.

By applying a current pulse to MTJs, the antiferromagnet which pins the reference layer can be heated above the Neel temperature and reset, depending upon the current and field conditions. This local reprogramming allows for individual devices to be modified, strongly impacting both the static resistance and dynamic properties of the MTJ in a non-volatile manner. By introducing additional antiferromagnets of differing thickness, different pinning layers can be reset with differing pulse amplitudes. Additionally, the resultant magnetic texture in the antiferromagnet can be non-homogeneous, leading to many complex and highly analogue possible reconfigurable states [1].

The reprogramming of the dynamic properties of MTJs is of particular significance in the context of emerging spintronics based neuromorphic architectures, where the generation and detection of radio-frequency signals is closely associated with the functionality of spintronics neurons and synapses, respectively [2]. A significant part of the power consumption is spent on modifying the frequency of the oscillators (i.e. weights) and a non-volatile reprogrammable solution is a requirement for any realistic implementation of such a radio-frequency spintronic neural network.

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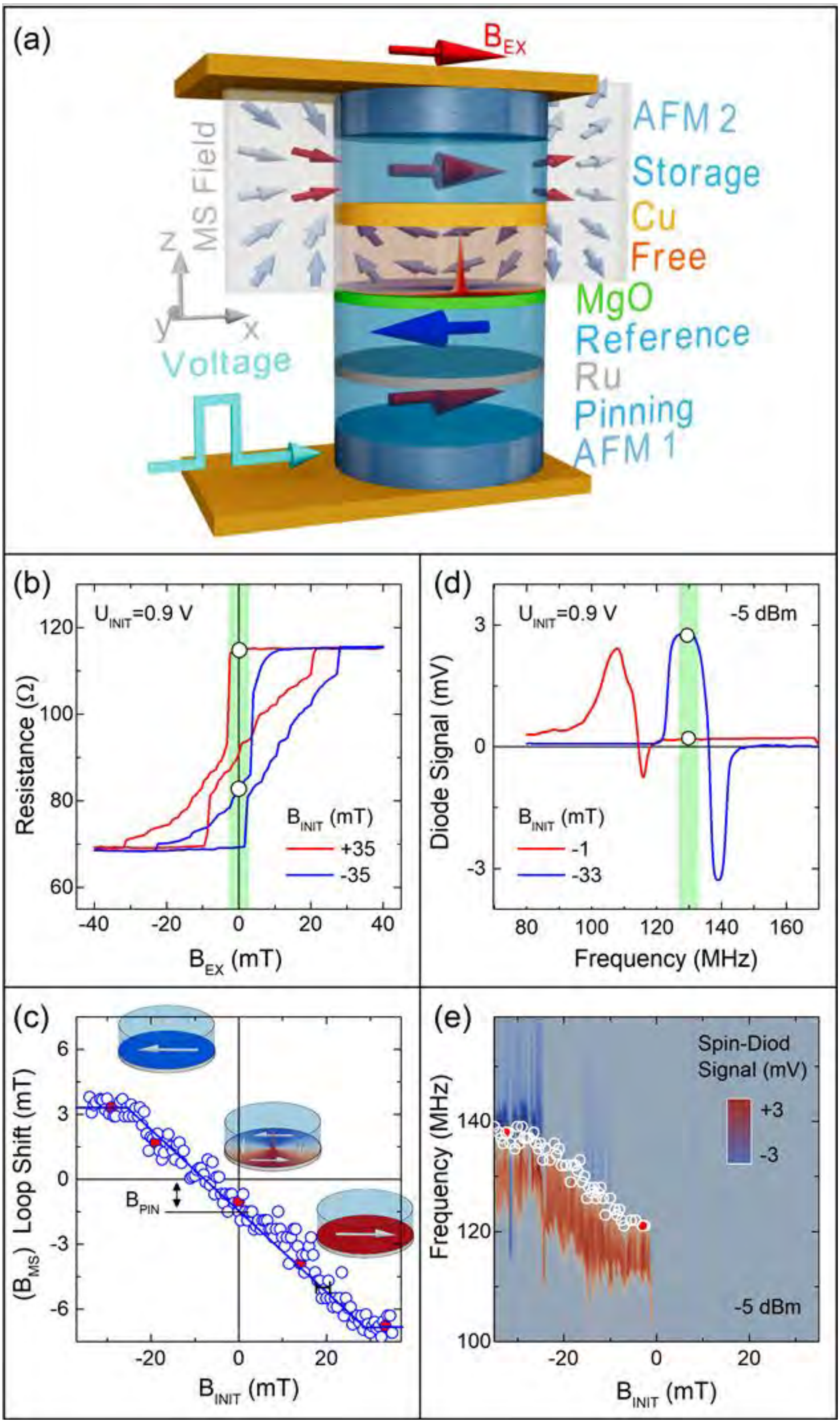
Fig. 1. (a) Schematic representation of the structure under study, which indicates the position of functional layers and external influences. The grey box shows a cross-section of the distribution of the magnetostatic field produced by the storage layer and acting on the free layer. Comparison of the hysteresis loop (b) and spin-torque diode effect curves (c) obtained after 1 ms pulse of 0.9 V in the presence of a different initializing field. Summarized dependences of the magnitude of the magnetostatic field (d) and the resonance frequency of the vortex precession (e) on the magnitude of the initializing field for the 0.9 V pulse.



(a)
B_EX
MS Field
AFM 2
Storage
Cu
Free
MgO
Reference
Ru
Pinning
AFM 1
Voltage
z
y
x
(b)
U_INIT=0.9 V
Resistance (Ω)
B_EX (mT)
B_INIT (mT)
+35
-35
(d)
U_INIT=0.9 V
-5 dBm
Diode Signal (mV)
Frequency (MHz)
B_INIT (mT)
-1
-33
(c)
(B_MS) Loop Shift (mT)
B_PIN
B_INIT (mT)
(e)
Spin-Diod
Signal (mV)
+3
-3
Frequency (MHz)
-5 dBm
B_INIT (mT)

Magnetization dynamics driven by displacement currents across a magnetic tunnel junction

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Contributed Talk: Paul Keatley, July 16, 2025, 17:15 - 17:30

Magnetic tunnel junctions (MTJs) are nanoscale magneto-electronic devices that underpin a variety of spintronic applications. MTJs typically comprise of magnetic metallic multilayers and a thin insulating tunnel barrier. They are highly efficient for reading and writing data due to their rapid response, making them ideal for high-speed memory technologies at GHz frequencies. At these frequencies, MTJs may also play a significant role in radio frequency (RF) spintronics, offering promising applications in signal processing, wireless communication, and neuromorphic technologies. Therefore, understanding the frequency-dependent characteristics of MTJ devices holds both practical and fundamental importance.

MTJs can be considered as leaky capacitors, where their transport properties can be influenced by frequency-dependent capacitance-related effects. In this work [1] specially designed W/CoFeB/MgO/CoFeB-based MTJ devices were used to investigate magnetization dynamics in the vicinity of the MTJ and its narrow, non-magnetic Pt top contact, but also far from the MTJ in the extended heavy metal-ferromagnetic metal (W/CoFeB) bottom contact. The MTJ fabrication was optimized to achieve large tunnel magnetoresistance, while time-resolved scanning Kerr microscopy with pulsed or RF current waveform excitation was used to directly probe and image the dynamic magnetization at ~2 GHz with a spatial resolution of ~400 nm (Figure 1). Images of the magnetization dynamics revealed that substantial displacement currents (~mA) flow through the MTJ circuit at GHz frequencies. The observed dynamics in the W/CoFeB bottom contact (wide horizontal tapered bar in Figure 2) were found to extend a significant distance (~10s μm) from both the MTJ and its narrow top contact (narrow vertical bar in Figure 2). The dynamics in the W/CoFeB bottom contact may be induced by a combination of spin orbit torque and Oersted magnetic field due to significant RF displacement currents across an MTJ capacitor. Images of magnetization dynamics when the current passed through either the top or bottom contact only, allowed the dynamics excited by each contact to be understood. Notably, for the MTJ current path, the displacement current does not cause charge to flow across the MgO barrier, allowing for low risk of barrier breakdown and a device longevity suitable for extensive observation of the resulting magnetization dynamics. These findings reveal the potential of MTJs for use in high-frequency, high-current conditions, paving the way for more durable and efficient MTJ devices.

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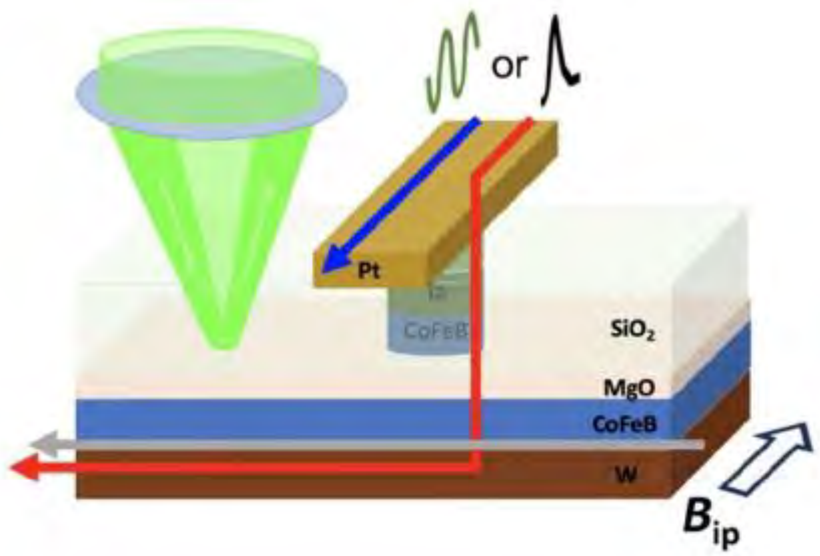
Figure 1. Schematic of time-resolved scanning Kerr microscopy of magnetization dynamics in the bottom contact for different current paths.
Figure 2. Reflectivity image of the device (top panel) and magnetization dynamics at antinodes (+/-AN) and node (N) of precession in the bottom contact when the current path is across the MTJ.



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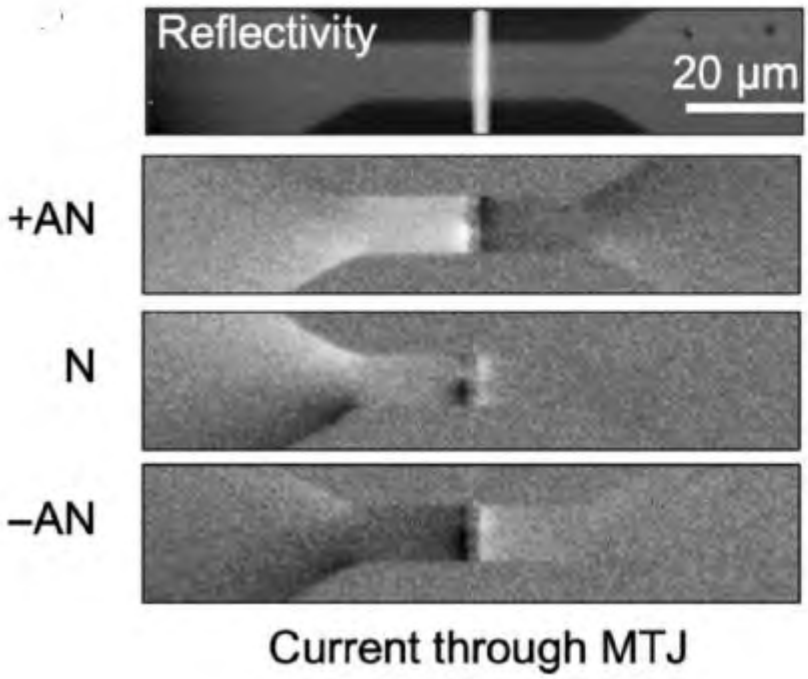

Spin-transfer torque in altermagnets with magnetic textures

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Contributed Talk: Alexey Kovalev, July 16, 2025, 10:15 - 10:30

We predict the existence of anisotropic spin-transfer torque effect in textured altermagnets [1]. To this end, we generalize the Zhang-Li torque to incorporate the symmetry associated with prototypical d-wave altermagnets and identify the spin-splitter adiabatic and nonadiabatic torques. Applying our results to domain wall dynamics induced by spin-transfer torque, we find that, in certain regimes, the spin-splitter adiabatic torque can induce domain wall precession, significantly slowing down domain wall motion. The response of the domain wall also becomes anisotropic, reflecting the d-wave symmetry of the altermagnet. Furthermore, we observe that the spin-splitter adiabatic torque modifies skyrmion dynamics see figure, inducing anisotropic skyrmion Hall effect. The above phenomena can serve as a hallmark of altermagnetism in textured magnets, distinguishing it from the behavior of ordinary antiferromagnets.

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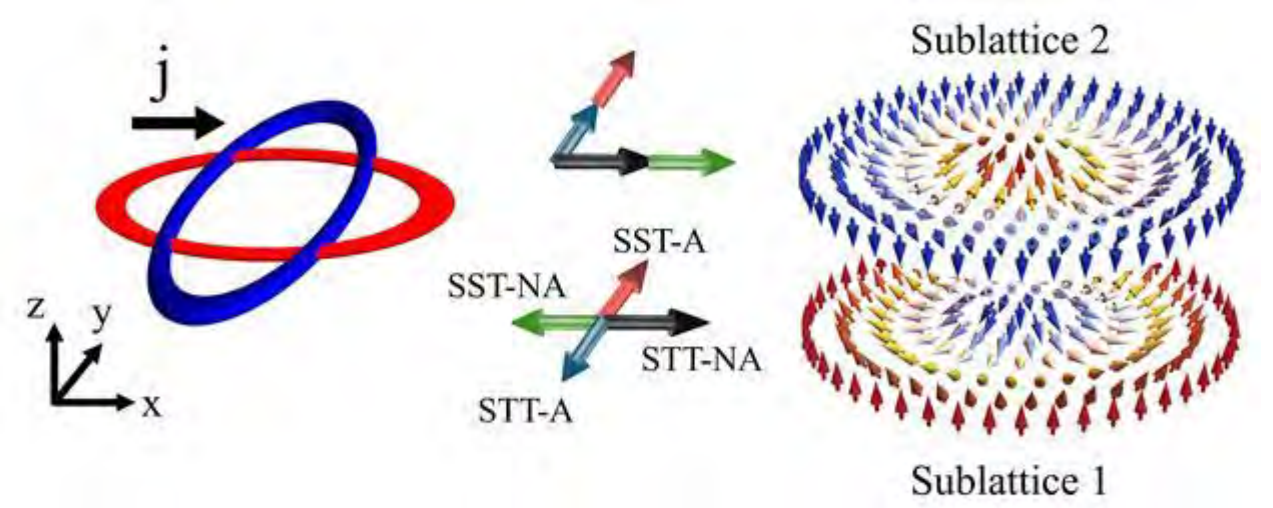
Figure caption: Schematics of the spin-transfer and spin-splitter effects in altermagnets, where the two sublattices are repre sented as two layers and the current direction is aligned with the altermagnetic order. The spin-transfer effect corresponds to spin currents flowing in the same direction in both layers, while the spin-splitter effect corresponds to spin currents flowing in opposite directions in the two layers. We illustrate the directions of the forces induced on a skyrmion in the two sublattices by the adiabatic and nonadi abatic spin-transfer torques (STT-A and STT-NA) as well as the adiabatic and nonadiabatic spin-splitter torques (SST-A and SST-NA), which result in the skyrmion Hall effect.



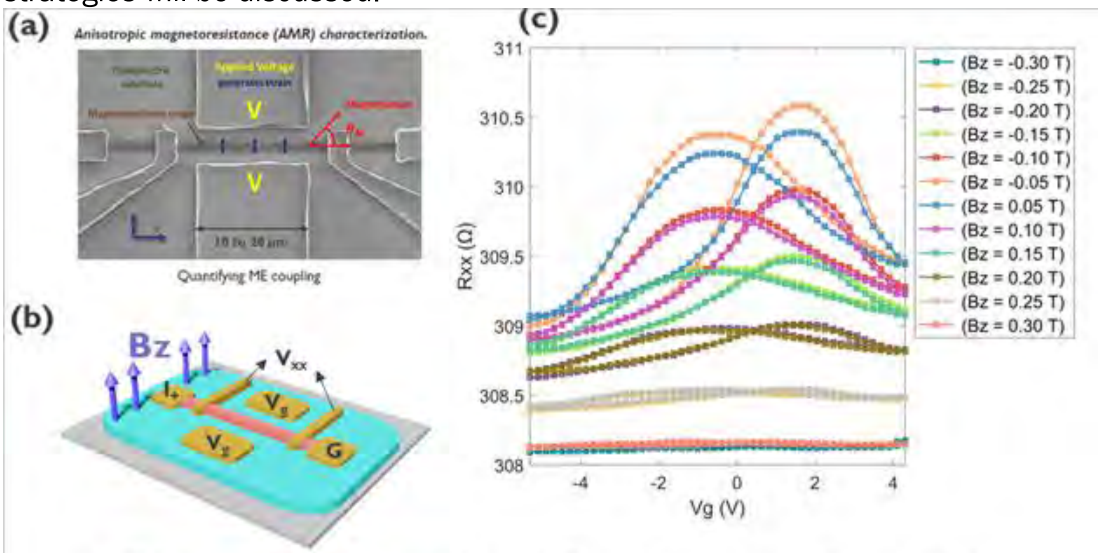
Strain-Mediated Magnetoelectric Coupling in Scaled Devices for Out-of-Plane Magnetization Switching

Fanfan Meng[1], Emma Van Meirvenne[2], Anais Guerenneur[2], Federica Luciano[2], Xiangyu Wu[1], Florin Ciubotaru[1], Christoph Adelmann[1]
[1]IMEC, Belgium, [2]KU Leuven, Belgium

Contributed Talk: Fanfan Meng, July 17, 2025, 17:15 - 17:30

Energy-efficient transducers for exchanging information between magnetic and electrical (CMOS) domains are crucial for enabling spintronic logic for large-scale computing applications. Magnetoelectric (ME) devices that combine piezoelectrics and magnetostrictive ferromagnets, are promising candidates for achieving voltage-driven ultra-low energy switching due to the significant ME coupling coefficient reported for bulk multiferroic heterostructures compared to single phase multiferroics [1]. Although this significant ME coupling enabled by extrinsic strain has been extensively studied macroscopically, its projection to sub-micron devices is challenging. At these scales, strain is no longer uniform, leading to a non-uniform effective magnetic field (HME), resulting in complex spatial behavior of nanomagnets. Additionally, the dependence of HME on the magnetization direction introduces further dynamic complexity. So far, most studies have focused on in-plane switching of nanomagnets under high voltages [2]. Here, we investigate the influence of geometries in scaled devices on strain-mediated ME coupling and how to exploit this for out-of-plane switching, which is desired for future low-voltage memory or logic devices.

We investigate magnetoelectric (ME) coupling via anisotropic magnetoresistance (AMR) in sub-micron Ni stripes (300 nm to 3 µm wide) deposited on a 500 nm-thick piezoelectric PZT layer. A voltage applied across gate electrodes induces strain in the PZT, generating a magnetoelastic field in the magnetostrictive Ni layer. AMR loops (Fig. 1), measured during gate voltage sweeps (-5 V to +5 V and back), exhibit a ferroelastic butterfly loop behavior, clearly demonstrating the coupling between the ferroelasticity and the magnetization. The loop sizes vary with the applied external bias field (perpendicular to the substrate), highlighting the influence of magnetization on the ME coupling strength. We quantify the ME coupling as a function of external field and stripe width, corroborating these experimental findings with Multiphysics and micromagnetic simulations. The effects of device geometry on ME coupling and potential optimization strategies will be discussed.



(a) SEM image of the device (1 µm wide Ni wire). (b) Device and measurement configuration, with the bias magnetic field applied perpendicular to the substrate. (c) Magnetoresistance loops measured during gate voltage sweeps (-5 V to +5 V and back) under different external out-of-plane bias fields

Strain induced reversible modulation of magnetism in transition-metal thin film near Curie temperature

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Contributed Talk: Toshiaki Morita, July 17, 2025, 16:15 - 16:30

The control of magnetism is crucial for spintronic devices. The electrical control of magnetism has been mainly studied [1-4]. Recently, flexible spintronics have attracted attention due to its high elasticity [5]. The concept of flexible spintronics is mainly based on the magnetostriction effect. However, the modulation of the magnetism by strain is not fully understood. Here, we observed the strain induced reversible modulation of magnetism in Co delta-doped Ni thin film near ferromagnetic phase transition temperature.

The samples were deposited by magnetron sputtering on flexible substrates at room temperature. The layer structure from substrate side is as follows: Ta(2.0 nm)/Pt(1.0)/Ni(0.3)/Co(delta-dope)/Ni(0.3)/Pt(1.0). The Hall measurement was conducted under various temperatures. A small tensile jig was used to apply a tensile strain. The results for Hall measurement at 200 K and 240 K are shown in Fig. 1. The blue and red plots represent the results without (w/o) and with (w/) strain, respectively. The strain dependent change in shape of the hysteresis was observed. At 200 K, the square hysteresis was observed independent of strain, but the coercivity increased with the application of the tensile strain. At 240 K, the result w/o strain shows no coercivity. In contrast, by applying the tensile strain, the hysteresis loop with small coercivity was observed. Moreover, this strain effect is reversible [see dashed line in Fig. 1]. There are two possible origins of the results. One is related to the ferromagnetic phase transition. The other is a change in the magnetic anisotropy due to inverse magnetostriction effect. However, from the temperature dependence of the magnetization per area (m/S) w/o strain [see Fig. 2], the easy axis is out-of-plane direction, and spin reorientation near 240 K is not observed. Thus, the results can be attributed to the strain induced reversible ferromagnetic phase transition. We will discuss the mechanism of the results in detail.

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Figure 1: The results of Hall measurement w/o (blue) and w/ strain (red) at 200 K and 240 K.
Figure 2: Temperature dependence of the magnetization per area with out-of-plane and in-plane magnetic field of −0.5 mT in the absence of the strain.

Figure 1

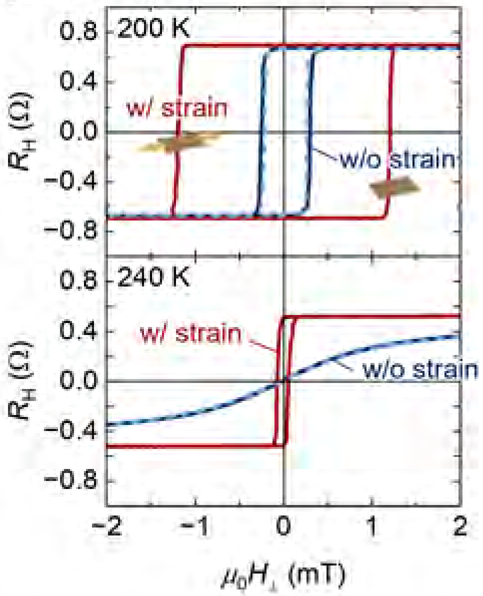
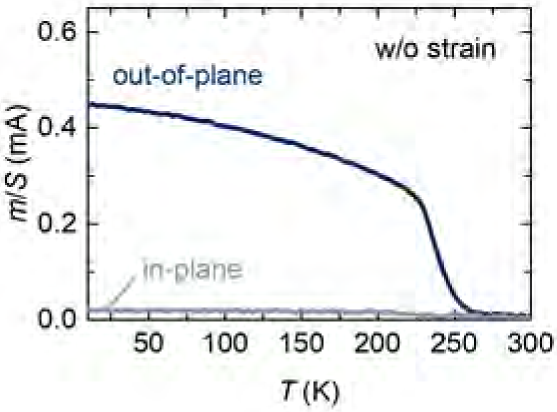


Figure 2



Investigating topological Hall effect using simultaneous soft x-ray scattering

Sophie A. Morley[1]
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Contributed Talk: Sophie A. Morley, July 15, 2025, 11:30 - 11:45

The Fe/Gd ferrimagnetic system shows non-collinear magnetic structures similar to the widely-studied skyrmion-hosting helimagnetic B20 crystals such as MnSi and FeGe [1,2]. The FeGd thin film multilayer system can be tuned to stabilise non-collinear spin structures at room temperature via careful tuning of the dipolar energy [3]. The nanomagnetic spin phase diagram and its level of ordering can be characterized using soft x-ray magnetic diffraction [4]. In addition, the topological Hall effect has been used as a way to prove the existence of skyrmions in materials. The possible extrinsic factors such as material properties and experimental difficulties can lead to misinterpretation [5]. Here we measure the nanomagentic spin texture and the Hall effect at the same time using soft x-ray diffraction to accurately connect various features in the transport data with the specific nanomagnetic phases. We found that the topological Hall effect (THE) shows peaks with opposite signs, suggesting the presence of different mechanisms. We observe the sign reversal in THE occurs during a transformation between the skyrmion lattice and isolated skyrmion phases, which we interpret as a change from a topology induced mechanism to a skew scattering mechanism.

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Investigating magnetic domain dynamics in an amorphous Fe-Ge thin film through X-ray Photon Correlation Spectroscopy with an MCP/TimePix3 detector

Ahmad Ikhwan Us Saleheen[1], Margaret McCarter[1], Zoey Tumbleson[2], Stephen Kevan[1], Anton Tremsin[3], Sophie Morley[1], Sujoy Roy[1]
[1]Advanced Light Source, Lawrence Berkeley National Laboratory, USA, [2]Dept. of Physics, University of California, USA, [3]Space Sciences Laboratory, University of California, USA

Contributed Talk: Sophie A Morley, July 17, 2025, 14:15 - 14:30

We report results from the X-ray Photon Correlation Spectroscopy (XPCS) measurements performed on an amorphous $Fe_{53}Ge_{47}$ thin film sample, conducted for the first time with a TimePix3 detector at the Advanced Light Source, Lawrence Berkeley National Laboratory. A competition between scalar and randomized vector interaction—known as the Dzyaloshinskii Moriya Interaction (DMI)—between spins leads to rich textures such as stripes in amorphous thin films, and skyrmions in single crystals[1]. In realizing and stabilizing these spin textures, thermally induced fluctuations play a critical role. Techniques such as XPCS and X-ray Speckle Visibility Spectroscopy (SVS) have been successfully employed to investigate domain fluctuations in magnetic systems. In order to explore faster dynamics, it is crucial to have fast detectors. Here, we employ a micro channel plate (MCP) based detector with a fast readout TimePix3 chip designed to detect single soft x-ray photons with high spatial and timing resolution even at substantially high rates[2]. In this experiment, the detector was operated in photon counting mode where each photon's spatial position and arrival time were recorded. The coherent X-ray light was tuned to Fe L3 edge, which resulted in speckled diffraction pattern from the helimagnetic order on the detector[3]. Our XPCS analysis reveals the characteristic time-scales of helical domain fluctuations at different temperatures during a magnetic phase transition. Our analysis attempts to connect the role of thermal fluctuations in stabilizing the different magnetic phases in this system. We also demonstrate that the unique ability of the MCP/TimePix3 detector to record photon position and arrival times, adds nanosecond resolution to experiments. From the same dataset, the photons can be binned and analyzed as images in a manner similar to commercial frame-based detectors. In addition, as the detector allows for photon counting, photon statistics or photon contrast methods such as the SVS technique can also be employed. This enables the investigation of fast dynamics down to micro-second regimes.

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Thickness dependent investigation of single target grown c-plane epitaxial Kagome crystal Mn3Ge films

Servet Ozdemir[1], Matthew Rogers[1], Philippa Shepley[1], Ahmet Yagmur[1], Ismet Gelen[1], Callum Brennan-Rich[1], Gavin Burnell[1], B J Hickey[1]
[1]*University of Leeds, United Kingdom*

Contributed Talk: Servet Ozdemir, July 15, 2025, 16:30 - 16:45

Mn3Ge has been demonstrated to be a non-collinear chiral antiferromagnet(1) accompanied with a large anomalous Hall effect(2,3) where the latter is attributed to a large Berry curvature. We present results of a systematic study of the structure, magnetisation and transport properties of epitaxial (0001) orientated Mn3Ge films of varying thicknesses. Fully epitaxial samples were grown by UHV sputtering utilising an Mn5Ge alloy target, as well as a Ru(0001) seed layer grown on c-plane sapphire. We achieved the correct stoichiometry through a temperature dependent growth study utilising RHEED, x-ray and STEM diffraction. Magnetisation experiments determined a thickness-dependent Néel temperature as well as a small remanent moment due to canting from the ideal 120 degree alignment. Transport experiments manifest the expected anomalous Hall effect. A thickness dependent study of Mn3Ge films is of fundamental importance in determining the origin of the Berry curvature, where alternative mechanisms of spin-orbit coupling induced band gaps(4) and Weyl points(5,6) are theoretically discussed.

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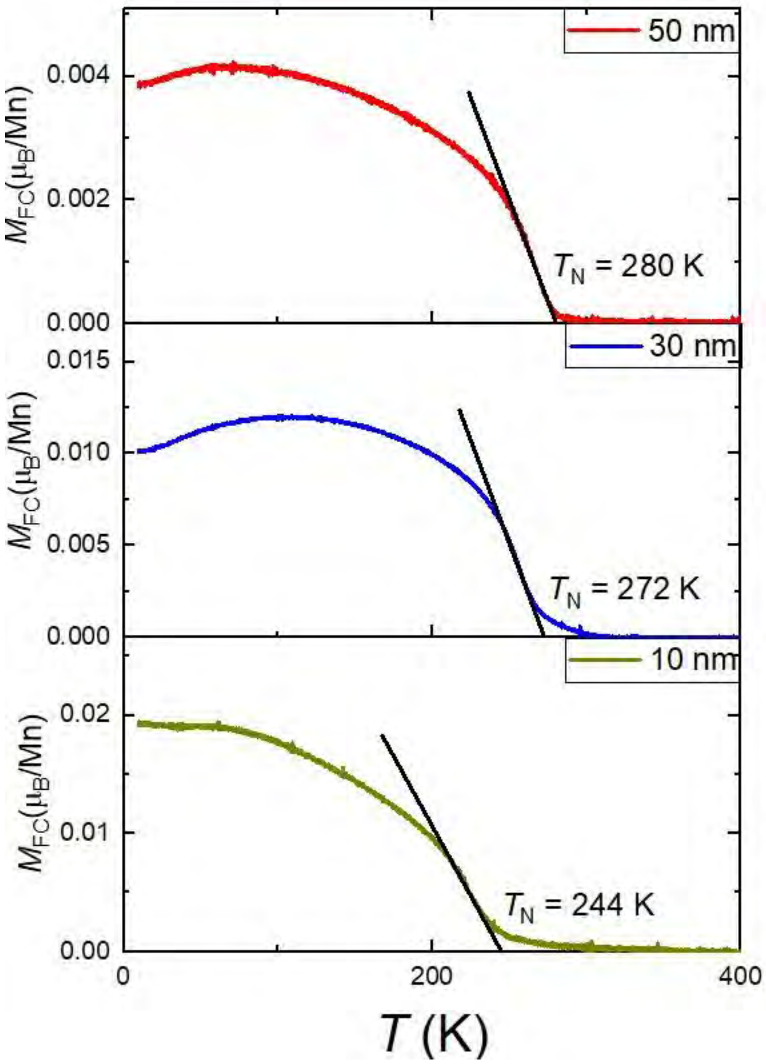

50 nm
30 nm
10 nm
T_N = 280 K
T_N = 272 K
T_N = 244 K
$M_{FC}(\mu_B/Mn)$
0.004
0.002
0.000
0.015
0.010
0.005
0.02
0.01
0.00
0
200
400
T (K)

Spin-to-charge current conversion and THz emission in graded tetragonal L1o-FePt alloyed interfaces

Evangelos Papaioannou[1]
[1]Department Of Physics, Aristotle University Of Thessaloniki, Greece, [2]National Institute of Materials Physics, Romania

Contributed Talk: Evangelos Papaioannou, July 17, 2025, 10:15 - 10:30

The fascinating field of ultrafast spin physics has recently opened a new research direction in THz physics, namely the field of THz spintronic emitters (STEs) [1,2,3]. The main concept deals with the generation and the transport of an ultrafast spin current after femtosecond laser pulse excitation. Usually, a STE is composed of magnetic (FM) and non-magnetic (NM) ultra-thin layers. The spin current generated in the FM layers diffuses to the NM layer where is then converted to an ultrafast charge current. This transient ultrafast current is able to emit THz radiation. Key factors that define the strength of the THz emission are the mechanism of the current generation and its efficient transport across the layers.

In this work, we address the interface transparency of spin current and the spin-to-charge conversion efficiency at structural and compositional gradient multilayers. In particular, we address Fe/Pt bilayers and their interfaces. We induce during growth process the tetragonal $L1_0$-FePt crystal phase at the interface. We show that the graded structure of Fe/$L1_0$-FePt/Pt boosts the THz emission. We present the dependence of the THz emission with respect to the thickness of the induced $L1_0$-phase. We further engineering the alloy-interface by changing the stoichiometry of the lattice without modifying the tetragonal $L1_0$ crystal symmetry. Practically, by maintaining the crystal structure we only modify the chemical composition achieving a compositional graded structure. We reveal that the graded interface has a large influence on the magnetization reversal that we attribute to the different values of exchange stiffness of Fe atoms. The stoichiometrically graded tetragonal structure modifies further the THz emission. Finally, interface transparency and subsequent Terahertz emission efficiency are correlated to investigations of the magnetization profile in the $L1_0$-phase and the Pt layers. The profile is determined using x-ray resonant magnetic reflectivity measurements (XRMS) performed with X-ray energy corresponding to the Pt L_3 edge at the ESRF synchrotron (XMaS beamline).
Our results quantify the ability of $L1_0$ phase to transfer spin current and emit THz radiation and reveals the potential of graded structures as efficient spintronic THz sources.

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The impact of hydrogen absorption on the magnetic properties of Pd/Co/Pd

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Contributed Talk: Sabine Pütter, July 18, 2025, 11:45 - 12:00

Pt/Co/Pt and Pd/Co/Pd heterostructures which exhibit perpendicular magnetic anisotropy (PMA) are typically used for magnetic recording. PMA can be tuned by e.g. thin film thickness, strain, ion bombardment or temperature. Recently, it has been shown that the absorption of hydrogen in the Pd can modify the PMA.[1-4] Reversible and non-destructive toggling of the easy axis of magnetisation between in-plane (IP) and out-of-plane (OOP) orientation was also achieved in a Co/GdOx thin film system at room temperature. [4] As a result, these solid-state devices based on the principle of easy axis switching are candidates for magnetic hydrogen sensing.

The impact of hydrogen on the magnetic properties of Pd/Co layered structures has been intensely studied in the past with varying results. [1-3] Changes of the coercivity, manipulation of the strength of PMA or changes in the saturation magnetisation are observed. The mechanisms for these property changes are still under discussion.

Polarised neutron reflectivity is an effective tool for studying the hydrogen uptake and its impact on the magnetic properties in PMA systems. [2,3] Resonance enhanced polarised neutron reflectometry (RNR) was shown to be particularly suited for studying the hydrogen uptake quantitatively and with time resolution of less than seconds.[5]

In this contribution we report on results of RNR experiments on hydrogen uptake in Nb/Pt/Co/Pt/Nb heterostructures fabricated by molecular beam epitaxy on MgO(001) substrates measured at D17 at ILL and the requirements for measuring the switching of the easy axis on hydrogen uptake in the trilayer system Pd/Co/Pd.

Prerequisite for full magnetization switching is the understanding of hydrogen absorption in Pd. The incorporation of hydrogen in bulk Pd depends on temperature and pressure. Pd thin films exhibit in addition a thickness and strain dependence. We investigated the hydrogen uptake of Pd thin films with in-situ X-ray reflectometry and X-ray diffraction during exposure to hydrogen. We observe two distinct channels for hydrogen absorption, namely via grain boundaries and in the crystal structure.

Furthermore, we study the changes of magnetic properties in Pd/Co/Pd layers with OOP and IP easy axis on hydrogen uptake by in-situ magnetoresistance measurements and relate them to the hydrogen absorption mechanisms.

Final aim is the measurement of the hydrogen uptake in Pd/Co/Pd trilayers by RNR with time resolution. This will enable a quantitative relation of the hydrogen content in the layers with the change of the magnetic properties. The combination of various in-situ characterization techniques will shed light on the exact mechanism at the basis of hydrogen-induced modification of the PMA in thin layers, opening the way for further optimization and device implementation.

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Giant Nonreciprocity in Surface Acoustic Wave Transmission Using Simple SiO2/Ni/SiO2 Multilayer Structure

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Contributed Talk: Shunsuke Sakai, July 17, 2025, 17:00 - 17:15

Surface acoustic waves (SAWs) are mechanical waves that propagate along the surface of materials. With their suitable velocity (typically 2–4 km/s on piezoelectric substrates) for micrometer-scale wavelengths, SAWs are widely utilized in various wireless communication devices, including filters, resonators, and oscillators. In applications where SAW devices are actively used, the development of acoustic isolators for SAWs is critical and remains an area of active research. To achieve acoustic isolation of SAWs, several approaches leveraging nonreciprocal SAW transmission via phonon-to-magnon energy conversion in magnetic thin films have been proposed. Some methods rely on the helicity difference between phonons and magnons, while others utilize shifts in magnon dispersion in synthetic antiferromagnets [1-2]. However, these approaches often suffer from either insufficient nonreciprocity or require complex and precise device architectures.

In this study, we demonstrate a giant nonreciprocity in SAW transmission using a simple SiO_2/Ni/SiO_2 multilayer structure, enabled by surface acoustic wave spin-wave resonance (SAW-SWR). A 128° Y-cut $LiNbO_3$ substrate equipped with sputtered interdigital transducers (IDTs) for SAW generation and detection was prepared. Between the IDTs, a SiO_2(20 nm)/Ni(30 nm)/SiO_2(20 nm) multilayer was deposited via sputtering, as illustrated in Fig. 1. SAWs were generated by applying microwave signals to one IDT, which propagated along the substrate and interacted with the multilayer. An external magnetic field, varied in orientation and magnitude, was applied to the system. When SAWs entered the multilayer, their high-frequency AC strains induced a spatially non-uniform effective magnetic field in the Ni layer through the magnetoelastic effect, leading to spin-wave resonance (SWR) observable as a reduction in transmitted SAW amplitude. Importantly, reversing the SAW propagation direction did not reverse the helicity of the phonons, whereas the helicity of the magnons flipped due to the fixed clockwise chirality of magnetization precession governed by the Landau–Lifshitz–Gilbert equation. This helicity mismatch created an asymmetry in shear-strain-induced SWR.
The shear strain component of SAWs, which is antisymmetric under wave vector inversion, reaches its maximum at a specific depth in the substrate. As all strain components of SAWs are distributed over a depth approximately equal to their wavelengths, shorter wavelength results in the shear strain maximum occurring closer to the surface. By sputtering a SiO_2 layer onto the Ni layer and using high-order harmonic SAWs with shorter wavelengths, we enhanced the shear strain intensity within the Ni layer, thereby maximized the asymmetry in SAW attenuation. Consequently, we achieved a giant nonreciprocity in SAW transmission at an external field angle of 35° and an SAW frequency of 5.7 GHz, as shown in Fig. 2.

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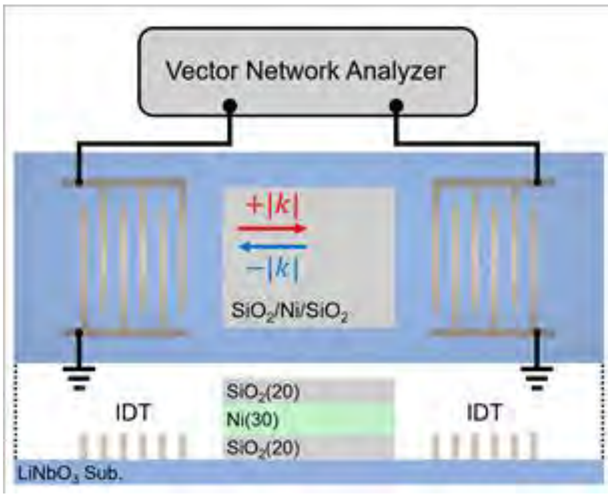
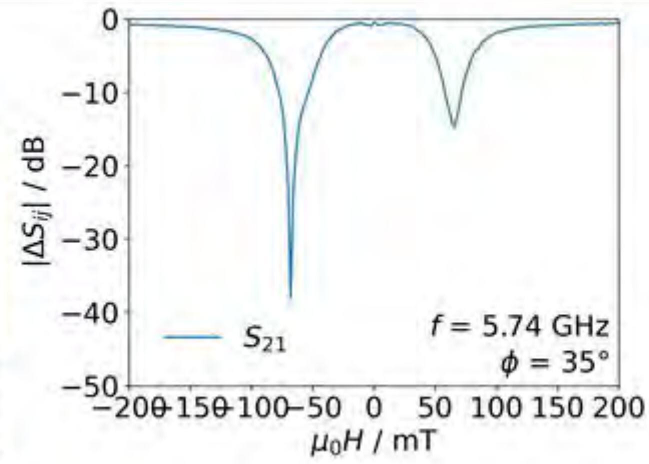
Captions

Fig. 1. Schematic depiction of the experimental arrangement.

Fig. 2. Nonreciprocal SAW transmission at an external field angle of 35 ° and SAW frequency of 5.7 GHz.





Correlating ultrafast demagnetization with terahertz radiation using spintronic bilayer heterostructures

Shreya Shrestha[1], Laura Scheuer[1], Weipeng Wu[1], Nawsher J. Parvez[1], John Q. Xiao[1], Branislav Nikolic[1], Lars Gundlach[2], Benjamin Jungfleisch[1]

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Contributed Talk: Shreya Shrestha, July 17, 2025, 11:30 - 11:45

The terahertz gap has experienced significant technological advancements over the past decade, driven by its applications in medicine, industrial processes, and potential for quantum transduction. Combined with its ultrafast time scale, interest also arises in its application in spectroscopy. Additionally, the magnetization of thin films drops in the first picosecond following the absorption of a femtosecond laser pulse [Phys. Rev. Lett. 76, 4250 (1996)], which contributes to the ultrafast optical-magnetic memory.

Spintronic THz emitters (STEs), magnetic heterostructures consisting of a ferromagnetic (FM) and heavy metal (HM) bilayer, have emerged as broadband and polarization tunable THz sources. STEs offer advantages over conventional THz sources like photoconductive antennas and nonlinear crystals [J. Appl. Phys. 130, 091101 (2021)]. Besides its efficiency and functionality as a THz emitter, STEs are a fascinating system for fundamental research, encompassing a diverse range of spin and charge transport dynamics. The phenomenological explanation of the THz emission from STE is the ultrafast demagnetization (UDM) of the FM layer triggered by a highly non-equilibrium state initiated by ultrafast laser pulse excitation [Nat. Nano. 8, 256-260 (2013)]. This process leads to the generation of an ultrafast spin current that diffuses from the FM into the HM layer where it is converted into a charge current by means of the inverse spin Hall effect, resulting in THz emission. However, this conceptually simple explanation has recently been scrutinized as the microscopic origin of such interlayer spin current remains vague [arXiv:2410.07360]. One way to experimentally untangle the different processes leading to THz emission is to temporally correlate the UDM with the resulting THz emission upon femtosecond laser excitation of the STEs.

We present time-resolved magneto-optic Kerr effect (TR-MOKE) measurements correlated with time-domain terahertz spectroscopy (TDTS), allowing us to probe the ultrafast spin dynamics and THz emission simultaneously. TR-MOKE investigates the magnetization dynamics due to laser excitation, while TDTS measures the emitted THz radiation. Synchronizing these probing techniques provides information about the demagnetization dynamics and allows us to correlate their temporal fingerprint with the resulting THz signal. Following the henomenological explanation, the expectation is to detect the THz radiation after some time delay from the start of the demagnetization in the FM, as the spin current requires some time to diffuse from FM to the HM layer. However, our preliminary results for 5nm of CoFeB|Pt bilayer suggest that the THz emission occurs at an earlier time than one expects from this universally accepted model. We observe the demagnetization after the start of the THz pulse. Additionally, we present results in the comparison of demagnetization dynamics of the STE by adding a Cu spacer layer between the FM and HM layer and the signal variation due to the thickness of the spacer. Our results offer unprecedented insights into the ultrafast demagnetization process. We hope our results will aid in validating and refining microscopic models of ultrafast spin dynamics and the THz generation mechanisms.

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Spin-dependent transport in ferromagnetic high-entropy-alloy thin films

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Contributed Talk: Koki Takanashi, July 15, 2025, 10:15 - 10:30

High-entropy alloys (HEAs) have attracted considerable attention for their applications as structural materials owing to their excellent mechanical properties, heat resistance, corrosion resistance, and irradiation resistance. In recent studies, the benefit on the concept of HEAs has been expanded to include functional electronic materials such as magnetic, thermoelectric, and superconducting materials. For magnetic materials, however, most of studies have been conducted using bulk magnets [1], and the spin-dependent transport in ferromagnetic HEA thin films have not been well investigated. One of the interesting aspects of ferromagnetic HEAs is the dependence of spin-dependent transport on the type and composition of constituent elements. Particularly, it is important to investigate how spin-dependent transport changes for heavy elements with large spin-orbit interaction. In this study, we focus on FeCoNiCuPd HEAs, which exhibit a Curie temperature higher than room temperature [2] and contain a heavy element (Pd) with relatively large spin-orbit interaction.

The thin-film samples with different composition ratios of Cu and Pd under the same amount of FeCoNi, Fe20Ni20Co20CuXPdY (30 nm, X:Y=30:8, 25:12, 20:16, 15:21, 10:25), were prepared on thermally oxidized Si substrates at an ambient temperature by an ultrahigh vacuum sputtering system (base pressure of ~10-7 Pa) using a co-sputtering technique with three targets: Fe33Co33Ni33 alloy, Cu, and Pd. X-ray diffraction profiles and transmission electron microscopy images of the prepared samples confirmed the formation of homogeneous face-centered cubic structure without significant phase separation. All the films exhibited ferromagnetic hysteresis curves with soft magnetic behavior at room temperature. The saturation magnetization increased linearly with the Pd concentration, which might be attributed mainly to the induced Pd moment.

Anisotropic magnetoresistance (AMR) and anomalous Hall effect (AHE) were measured for Hall-bar devices fabricated by conventional photolithography and Ar milling process. Fig. 1 shows the Pd concentration dependence of the AMR ratio and anomalous Hall resistivity (ρyxAHE) at 300 K. The AMR effect showed a smooth, simple increase with the Pd concentration, suggesting that the spin-orbit interaction of constituent elements plays a significant role on the AMR effect in ferromagnetic HEAs. On the other hand, the AHE decreased monotonically with the Pd concentration, showing a opposite trend to that of the AMR effect. Although consistent explanation for the Pd concentration dependence of AMR and AHE requires further investigation, particularly an understanding of the electric structure of FeCoNiCuPd HEAs, we may say that the spin-dependent transport in HEAs can be tuned by the content of heavy atoms with large spin-orbit interaction, which provides important insights into the application of HEAs as future spintronics materials.

In the presentation, the results on anomalous Nernst effect will also be shown and discussed.
This research was partly supported by the JSPS Grants-in-Aid for Scientific Research 21K18180.
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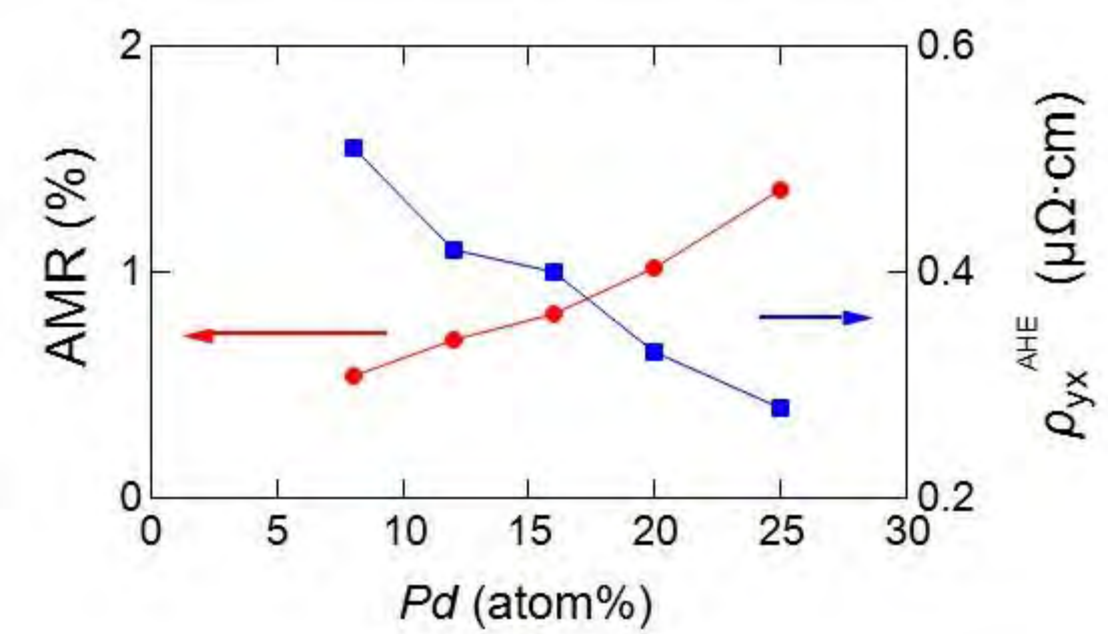
Fig. 1 Pd concentration dependence of AMR ratio and anomalous Hall resistivity (ρyxAHE) at 300 K.



Entropy-Assisted Nanosecond Stochastic Operation in Perpendicular Superparamagnetic Tunnel Junctions

Louise Desplat[1], Lucile Soumah[1], Nhat-Tan Phan[1], Ahmed Sidi El Valli[1], Advait Madhavan[3], Florian Disdier[1], Stéphane Auffret[1], Ricardo Sousa[1], Ursula Ebels[1], Philippe Talatchian[1]
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Contributed Talk: Philippe Talatchian, July 16, 2025, 14:15 - 14:30

Magnetic tunnel junctions (MTJs) are now well established building blocks for nonvolatile magnetic memory, for which information retention at the scale of years is required. More recently, superparamagnetic MTJs, in which thermal noise induces the magnetization to fluctuate rapidly between two metastable states--parallel (P) and antiparallel (AP) (Fig. 1(a)), have emerged as highly appealing for numerous low-energy, unconventional and bioinspired computing applications [1,2]. For the latter, reducing the mean dwell times between reversals is a way to increase efficiency.

In this work [3], we demonstrate a good agreement between mean dwell times measured in 50 nm diameter, perpendicularly magnetized superparamagnetic tunnel junctions, and theoretical predictions based on Langer's theory [4]. Due to a large entropic contribution, the theory yields Arrhenius prefactors in the femtosecond range for the measured junctions, in stark contrast to the typically assumed value of 1 ns. Thanks to the low prefactors, and fine-tuning of the perpendicular magnetic anisotropy, we report measured mean dwell times as low as 2.7 ns under an in-plane magnetic field at negligible bias voltage (Fig. 1(c)) - a timescale thus far only reported in junctions magnetized in plane [5]. Under a perpendicular magnetic field, we predict a case of the Meyer-Neldel compensation rule, whereby the prefactor scales like an exponential of the activation energy [6], in line with the exponential dependence of the measured dwell time on the field (Fig. 1(d)). We further predict the occurrence of (sub)nanosecond dwell times as a function of effective anisotropy and junction diameter at zero bias voltage.

These findings pave the way towards the development of ultrafast, low-power, unconventional computing schemes operating by leveraging thermal noise in perpendicular SMTJs, which can be scaled down below 20 nm.

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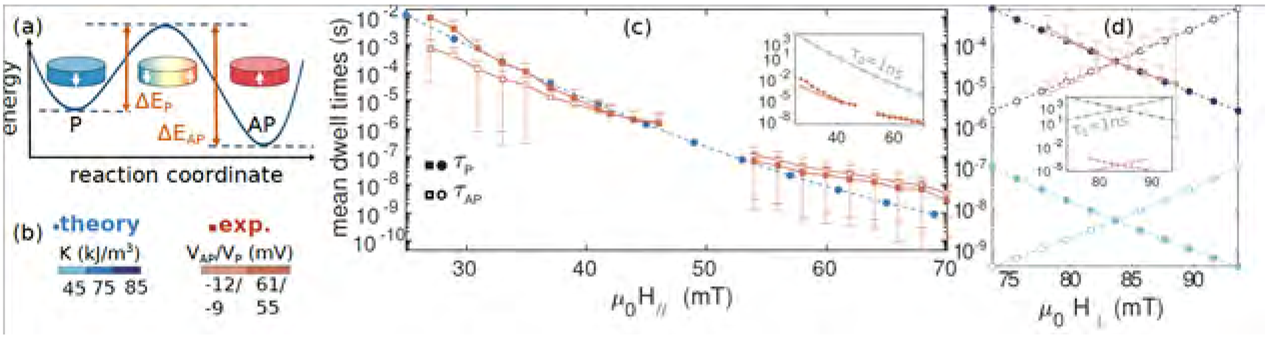

(a)
energy
P
AP
ΔE_P
ΔE_AP
reaction coordinate
(b)
theory
K (kJ/m³)
45 75 85
exp.
V_AP/V_P (mV)
-12/ -9
61/ 55
(c)
mean dwell times (s)
τ_P
τ_AP
τ_0 = 1ns
μ_0 H_// (mT)
(d)
τ_0 = 1ns
μ_0 H_⊥ (mT)

Tunable Spin Blocking and Unidirectional magnetoresistance in YIG/PtMn/C60

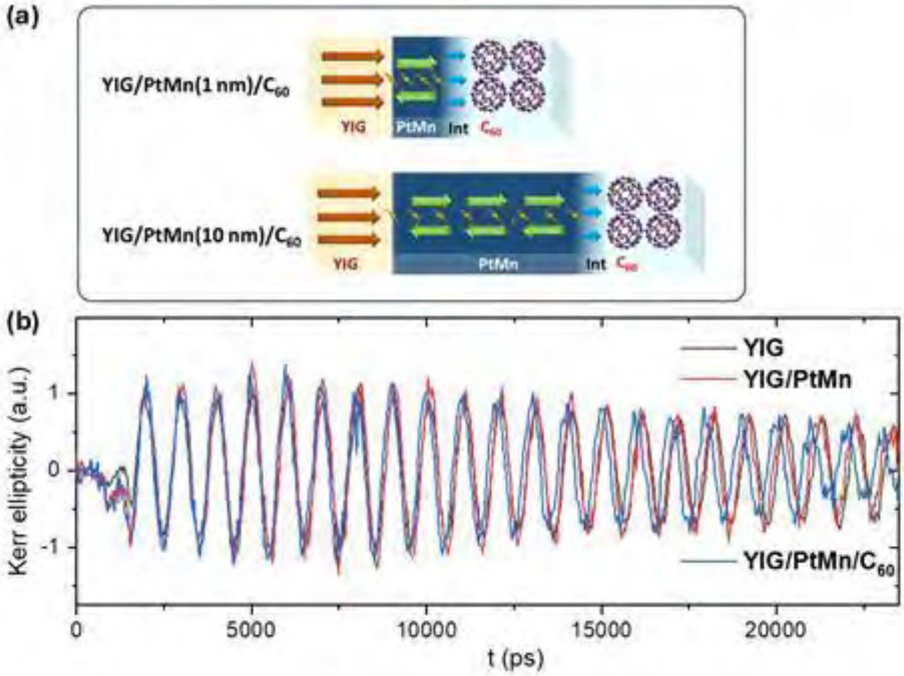
HARI BABU VASILI[1], Satam Alotibi[1], Mairi McCauley[2], Paul S. Keatley[3], Matthew Rogers[1], Manuel Valvidares[4], Pierluigi Gargiani[4], Timothy Moorsom[1], Donald A. MacLaren[2], Mannan Ali[1], Gavin Burnell[1], Robert J. Hicken[3], Bryan J. Hickey[1], Oscar Cespedes[1]
[1]School of Physics and Astronomy, University of Leeds, United Kingdom, [2]School of Physics and Astronomy, University of Glasgow, United Kingdom, [3]Department of Physics and Astronomy, University of Exeter, United Kingdom, [4]ALBA Synchrotron Light Source, Spain

Contributed Talk: Hari Babu Vasili, July 15, 2025, 11:45 - 12:00

Metallic antiferromagnets (AFs) have gained significant interest in spintronics due to their potential for high frequency (~THz) applications, strong inverse spin Hall effect and the absence of stray magnetic fields [1]. Of particular interest in spintronics is transport of pure spin currents, achieved in ferrimagnetic insulator/normal metal bilayers [e.g. $Y_3Fe_5O_{12}$(YIG)/Pt) with strong spin-orbit coupling (SOC) [2]. Molecules, such as C_{60}, are known to enhance SOC when interfaced with heavy metals (e.g. Pt/C_{60}) [3,4]. This interfacial engineering allows for the manipulation of spin transport properties through charge transfer and hybridization effects. However, tuning the properties of antiferromagnetic materials with molecules remains largely unexplored. This work investigates spin transport in YIG/PtMn(t)/C_{60}(15 nm) samples (t = 1-10 nm), where PtMn is a metallic AF material with strong SOC interfaced with C_{60}. The study aimed to achieve enhanced and tunable spin transport, explore transient spin current dynamics, and discover other emergent properties.

Electron microscopy and x-ray absorption experiments revealed charge transfer from PtMn to C_{60}, inducing a metallic, canted magnetic state at the PtMn/C_{60} interface (denoted as Mn-'Int' spins, see Figure 1(a)). Time-resolved magneto-optic Kerr effect (TRMOKE) measurements show a YIG spin momentum loss that we attribute to spin pumping into PtMn and PtMn/C_{60}. This is manifested by precession time delays and changes in the damping constant (Figure 1(b)). The Mn-'Int' state counteracts the exchange bias from the PtMn layer, leading to a tunable magnetic blocking of the underlying YIG spins, shifting their Blocking temperature, evident in Spin Hall magnetoresistance (SHMR), ferromagnetic resonance (FMR), and SQUID magnetometry measurements. Importantly, the competition between the magnetoresistance contributions from the Mn-'Int' spins and PtMn's Néel vector orientation allows to the explicit isolation of a unidirectional magnetoresistance (UMR) in YIG/PtMn(2)/C_{60} at 30 K (Figure 2(b,c)). The magnitude and sign reversal of the UMR with the magnetic field direction can be attributed to the Rashba spin-orbit coupling, significantly enhanced by the field-induced spin canting of the interfacial Mn-'Int' spins.

The thickness-dependent FMR linewidth ratio of 10 K to 50 K shows a reduced value for low thicknesses, suggesting a reduced spin blocking due to the Mn-'Int' spins (Figure 2d). The blocking of the YIG magnetisation direction remains constant for higher PtMn thicknesses, consistent with transport and magnetization data. Furthermore, differences in the FMR resonant field were observed for positive to negative polarities, indicating the unidirectional exchange bias at low temperatures (Figure 2f). This shows that reversing the magnetic field polarity does not recover the spin transport or resonant fields, respectively, but remains unidirectional. Our findings demonstrate the potential for engineering novel spintronic functionalities by manipulating interfacial interactions in antiferromagnet-molecules heterostructures. The observation of UMR paves the way for exploring non-reciprocal spin transport phenomena and developing novel applications in rectification and low-power electronics.



(a)
YIG/PtMn(1 nm)/C_{60}
YIG
PtMn
Int
C_{60}
YIG/PtMn(10 nm)/C_{60}
YIG
PtMn
Int
C_{60}
(b)
YIG
YIG/PtMn
YIG/PtMn/C_{60}
Kerr ellipticity (a.u.)
1
0
-1
0
5000
10000
15000
20000
t (ps)

Interplay of spin waves and surface plasmons in hybrid magnet/2D material structures

<u>Huaiyang Yuan</u>[1], Yaroslav Blanter[2], Haiqing Lin[1]
[1]Zhejiang University, China, [2]Delft University of Science and Technology, The Netherlands

Contributed Talk: Huaiyang Yuan, July 14, 2025, 14:00 - 14:15

Understanding the interaction of light and condensed matter is an important topic in modern physics. Light can induce electronic oscillations on metal surfaces, known as surface plasmons, which have important applications in electromagnetic wave amplification and sensing. Although surface plasmons in the visible and infrared regions have been widely studied, how to generate low-frequency plasmons with desirable polarity is still an outstanding challenge. Here, by exploring the transport properties of electromagnetic waves in a two-dimensional (2D) material/magnetic film composite system, we found that the surface spin waves excited in the magnet can break the excitation bottleneck of transverse electric surface plasmons in the 2D materials [1]. The joint excitation of spin waves and surface plasmons will take away part of the electromagnetic energy, thus showing an obvious valley in the reflection spectrum of the system, which may be feasible to detect in experiments. Furthermore, we found that spin waves and surface plasmons in 2D materials will hybridize to form an anticrossing dispersion near the resonance frequency. Thanks to the tunability of the 2D system, the coupling strength can be effectively controlled through electric gating technology and reaches a strong coupling regime. Our series of results extend the current research horizon of magnon spintronics, and also provide new ideas for the development of the interdisciplinary fields of spintronics, nanophotonics, and low-dimensional physics.

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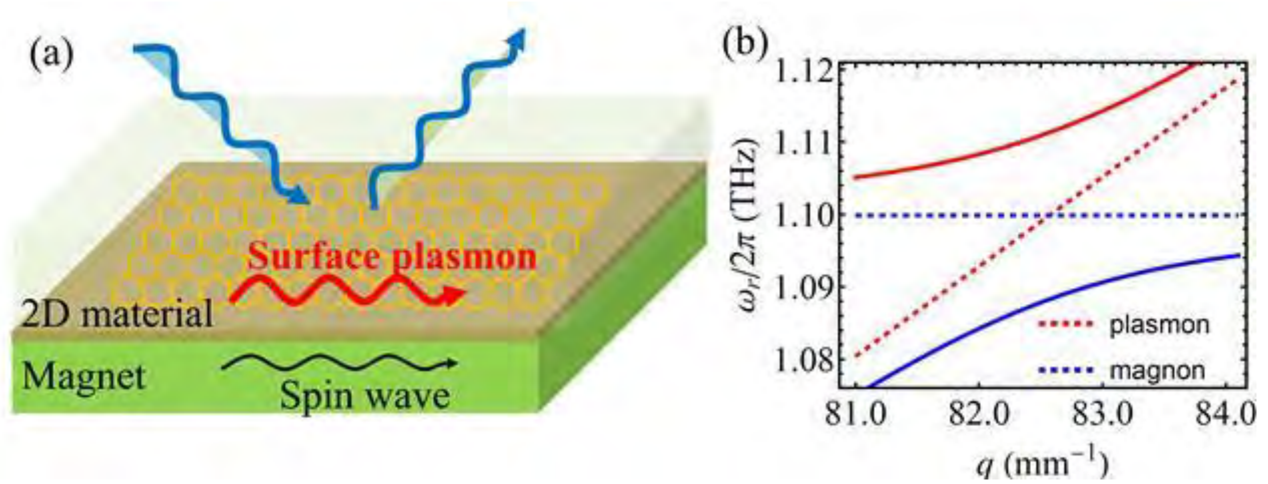
Figure caption

Figure (a) Scheme of the hybrid 2D material/magnet structure that allows for the excitation of surface plasmons and spin waves. (b) Dispersion relation of the hybrid system with an anticrossing structure, characterizing the strong coupling between magnons and surface plasmons.



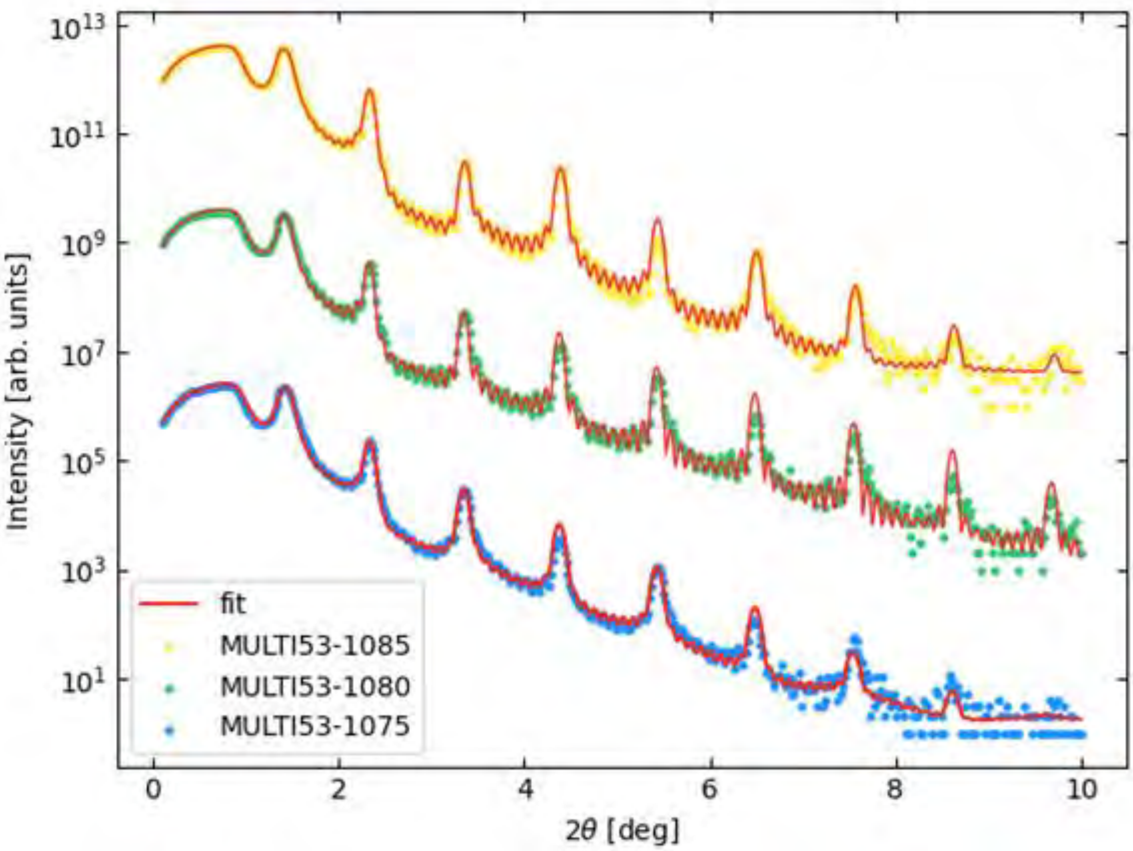
Spin Polarization Profile and Terahertz Emission in Pt/(Amorphous CoAlZr) Bilayers and Multilayers Deposited via Magnetron Sputtering

Unnar Arnalds[1], Evangelos Papaioannou[2], Kristina Ignatova[1], Stefan Arnalds[1], Dimitrios Karfaridis[2], Thomas Hase[3], Vassilios Kapaklis[4]
[1]University Of Iceland, Iceland, [2]Aristotle University of Thessaloniki, Greece, [3]University of Warwick, United Kingdom, [4]Uppsala University, Sweden

Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

This study explores the terahertz (THz) electromagnetic emission from ferromagnetic/non-magnetic bilayers and multilayers consisting of amorphous CoAlZr and Pt, deposited via magnetron sputtering. THz radiation is generated through femtosecond laser excitation, which induces a spin current in the ferromagnetic CoAlZr layer. This spin current is transported and converted into an ultrafast transient charge current in the Pt layer via the inverse spin Hall effect, emitting THz radiation. Such spintronic materials show great potential for ultrafast optoelectronic applications in the THz regime, where the interplay of spin dynamics and THz radiation is an area of growing interest.
The CoAlZr layers were co-deposited using pure Co and $Al_{70}Zr_{30}$ targets, with films of varying Co content ($Co_{75}(Al_{70}Zr_{30})_{25}$, $Co_{80}(Al_{70}Zr_{30})_{20}$, and $Co_{85}(Al_{70}Zr_{30})_{15}$) achieved by adjusting the magnetron power. These compositions were verified via x-ray photoelectron spectroscopy and exhibited significant variability in magnetization and Curie temperature. The bilayer and multilayer structures were fabricated with Pt layer thicknesses of 2 and 3 nm, and CoAlZr layer thicknesses of 3 and 5 nm.
X-ray reflectivity measurements revealed highly flat interfaces and distinct multilayer peaks (see Figure), while x-ray diffraction confirmed a highly textured (111) growth of Pt, even in multilayers with 10 repetitions. Vibrating sample magnetometry demonstrated that the films were magnetically isotropic, lacking discernible easy or hard axes.
The THz emission spectra were correlated with the magnetization profile within the Pt layer, determined via x-ray resonant magnetic reflectivity at the Pt L_3 edge using the XMaS beamline at the ESRF synchrotron. Fitting the resonant magnetic scattering curves with GenX revealed a well-defined spin polarization layer extending approximately 1 nm into the Pt.
These findings highlight the potential of amorphous magnetic materials in bilayers and multilayers for THz emitters with sharp interfaces. The study underscores their promise for efficient spintronic THz emitters and advances in understanding of ultrafast spin-dependent phenomena in layered structures.

Figure: X-ray reflectivity curves for multilayers with 10 repetitions of 5 nm CoAlZr and 3 nm Pt layers at varying Co content (85%, 80%, 75%). Distinct multilayer peaks illustrate well-defined structures and sharp CoAlZr/Pt interfaces. Solid red lines represent GenX fits to the data.



10^{13}
10^{11}
10^{9}
10^{7}
10^{5}
10^{3}
10^{1}
Intensity [arb. units]
0
2
4
6
8
10
2θ [deg]
fit
MULTI53-1085
MULTI53-1080
MULTI53-1075

Magnon-Magnon Coupling in a Pinned Synthetic Antiferromagnet

<u>Dirk Backes</u>[1]
[1]*Diamond Light Source, United Kingdom*

Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Magnon-magnon coupling garnered considerable interest lately because of the novel spin-wave states that can be observed, coherently overlapping over a large volume. A synthetic antiferromagnet (SAF) is the ideal model system to study such coupling effects, as it can harbor both optical and acoustic magnon modes. Under certain circumstances, these modes can mix or hybridize into magnon bands exhibiting a band gap, a measure for the coupling strength.

We demonstrate magnon-magnon coupling in a SAF using a home-built, VNA-based ferromagnetic resonance spectroscopy setup. Exciting both modes at the same time can be tedious, posing special requirements at the waveguide [1] or cavity design [2]. Our method is compatible with any given FMR setup and relies on pinning the SAF to an antiferromagnet. We show that, even in the weak pinning case, a magnon band gap of several GHz can be produced. This band gap is independent of the sample orientation with respect to the waveguide, requires no cooling and just a moderate magnetic field of <0.5T. A coupling rate η of 0.5 has been achieved, very close to the maximum of 1 for ultrastrong coupling.

Highly coherent magnon-magnon coupling states have the potential to be integrated and entangled with quantum platforms including superconducting qubits, nitrogen-vacancy centers, cavity photons, and phonons for coherent information transfer and collaborative information processing [3]. Our work thus paths the way towards applications in quantum computing, quantum memories and high-precision measurements.

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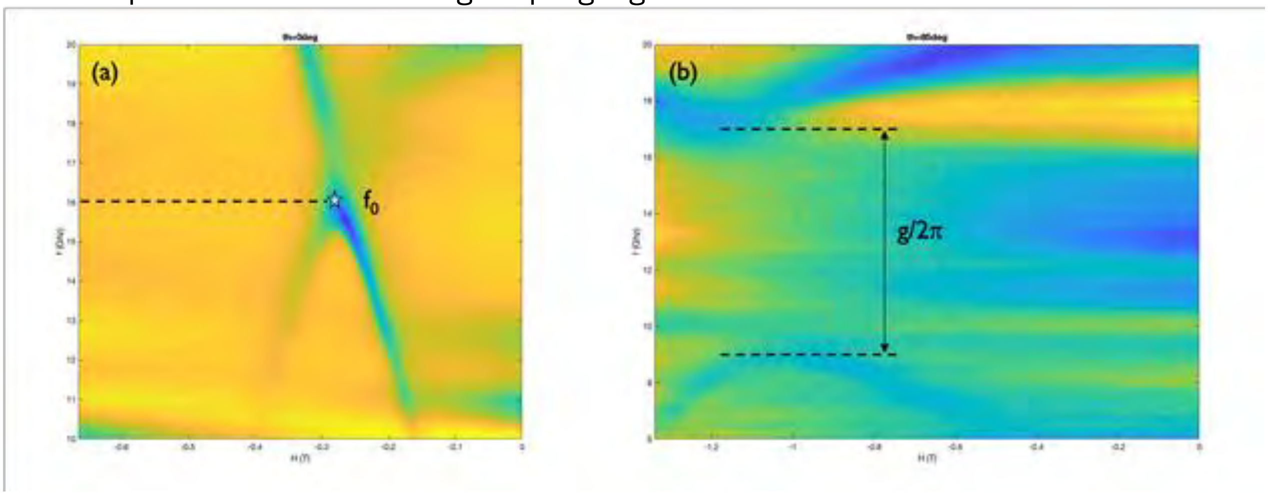
Figure caption:
Spectral map of a coupled optical and acoustic mode for a rotation angle θ of (a) 0° and (b) 85°. The hybridization of the two modes leads to the opening of a band gap. The coupling rate η, the ratio between band gap and intrinsic excitation frequency, as measured in (b) is 0.5. A value of η=1 marks the ultrastrong coupling regime.



Skyrmion motion in a synthetic antiferromagnet by asymmetric spin wave emission

Christopher Elliot Alexander Barker[1], Charles Parton-Barr[2], Christopher H Marrows[2], Olga Kazakova[1,3], Craig Barton[1]
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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Skyrmions—topologically protected vortex-like spin structures—have been proposed as the new information carriers in racetrack memory devices [1]. To realise such devices, a small size; high speed of propagation; and minimal deflection angle are required. Modelling has shown that synthetic antiferromagnets (SAFs) present the ideal materials system to realise these aims [2]. However, their magnetic compensation makes observation of skyrmions difficult and indeed this was only recently achieved [3].

In this work, we use micromagnetic simulations to propose a new method for manipulating them using exclusively global magnetic fields. An out-of-plane microwave field induces oscillations in the skyrmions radius which in turn emits spin waves. When a static in-plane field is added, this breaks the symmetry of the skyrmions and causes asymmetric spin wave emission. This in turn drives motion of the skyrmions, with the fastest velocities observed at the frequency of the intrinsic out-of-phase breathing mode of the pair of skyrmions.

This behaviour is investigated over a range of experimentally realistic antiferromagnetic interlayer exchange coupling strengths, and the results compared to previous works studying similar motion driven with an oscillating electric field [4]. Through this the true effect of varying the exchange coupling strength is determined, and greater insight is gained into the mechanism of skyrmion motion. These results will help to inform the design of future novel computing architectures based on the dynamics of skyrmions in synthetic antiferromagnets.

Figure shows: (a) Illustration of synthetic antiferromagnet stack which hosts a pair of coupled skyrmions and field components along with skyrmion velocity. (b) Skyrmion velocity as a function of microwave field frequency, matched with the breathing mode intensity of the two coupled skyrmions (measured without an in-plane field). The blue and black lines overlap for all measurements.

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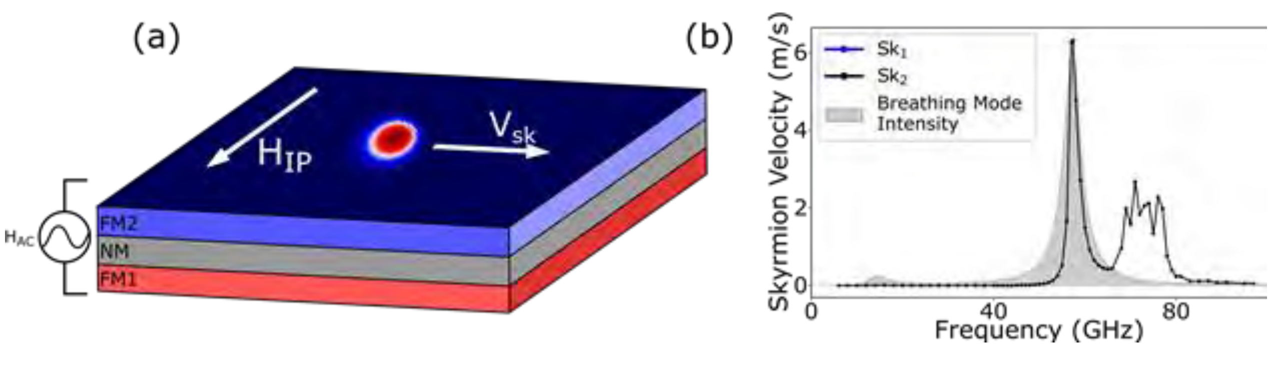

Phase mapping of Magnetic FexSn1-x Thin Films

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The Fe-Sn intermetallic alloys form layered structures that have distinct magnetic properties. FeSn is an antiferromagnet [1] while Fe_3Sn_2 is a frustrated ferromagnet [2]: these differ only in the stacking sequence of their layers. Fe_3Sn_2 has also been identified as a candidate material for hosting magnetic skyrmions stabilised by frustration [3]. Such stabilisation allows for a free chirality that can be manipulated with current pulses [4,5] and therefore could act as a candidate for the storing of bits in a spintronic device [6].
Here we report epitaxial growth of Fe-Sn thin films on sapphire using co-sputtering with an intermediate layer of Pt. Phase content is adjusted by controlling the relative Fe and Sn fluxes. Characterisation of these films was achieved through Cu K-α X-ray diffraction (XRD) and Scanning Transmission Electron Microscopy (STEM). Sample quality is comparable to films in the literature grown by MBE techniques [7].

In Fig. 1 (a) a low-angle annular dark field image gathered through STEM is shown. The layers of the material are evident and labelled. Using template matching, each pixel can then be assigned to a phase based on the Scanning Precession Electron Diffraction (SPED) image gathered at each point. The mapping for the Fe-Sn region is shown in Fig. 1 (b) and an example SPED image with matching simulation is shown in Fig. 1 (c).

This mapping opens up the opportunity for further quantitative characterisation through differential phase contrast and Lorentz Transmission Electron Microscopy (LTEM) to offer the ability to observe the skyrmion magnetic texture and potential interaction with the antiferromagnetic-ferromagnetic boundary.

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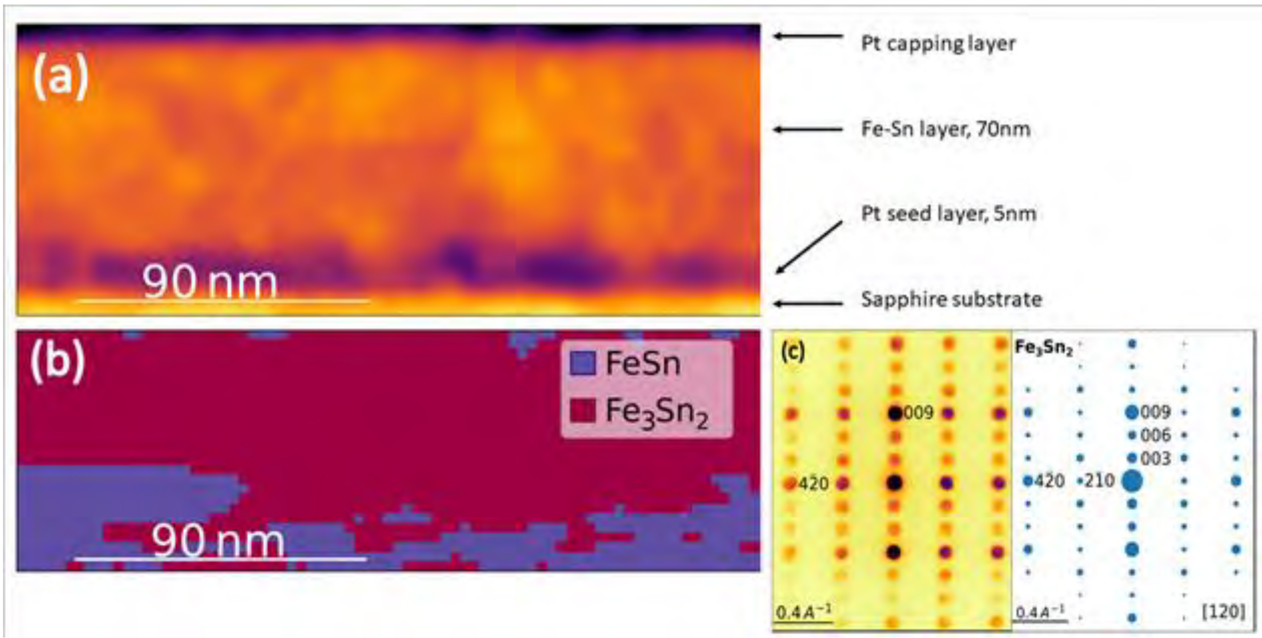
Figure Caption:
(a) - Low Angular Annular Dark field image through cross of section of thin film gathered using STEM.
(b) - Phase map of the cross section shown in (a), in which each pixel has been assigned either Fe3Sn2 or FeSn based on a template matching approach.
(c) - An example of a SPED pattern and a simulated spot template which is compared in the cross correlation process.



Growth of chiral magnetic multilayers on topological insulator Bi2Se3 epilayers and observation of hosted spin textures

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

It is now well established that magnetic skyrmions can be transported through spin-orbit torque (SOT) mechanisms originating from the spin Hall effect in heavy metals [1,2]. Topological insulators (TIs) are known for their larger charge to spin conversion through their spin momentum locked surface states that can give rise to highly efficient magnetic switching [3,4]. Whilst direct skyrmion / TI surface state interactions have gone largely unexplored, other ferromagnet / TI devices have shown the interface to be critical. Nevertheless, the perpendicular magnetic anisotropy (PMA) needed for hosting skyrmions in magnetic multilayers has consistently shown to be reliant on the insertion of a thin buffer layer [5,6].

Using conjoined UHV molecular beam epitaxy (MBE) and sputtering chambers, we have grown highly epitaxial Bi_2Se_3 on c-plane sapphire upon which a [Pt/CoB/Ru]x6 based skyrmion multilayer was sputtered. The unbroken vacuum leaves minimal opportunity for the degradation of the TI/metal interface.

In fig 1a we show the effective anisotropy Keff, as averaged across multiple ferromagnetic layers, is dependent on the thickness of an inserted Ta buffer - plateauing above 2nm. At this thickness we confirm we have full PMA through polarised neutron reflectometry (PNR) displaying a vanishing in-plane spin asymmetry at zero field (fig 1b). The complete removal of the buffer is shown to produce a non-zero remanent signal attributable by modelling to solely the CoB layer at the TI interface being magnetised in-plane.

The resultant spin textures have been observed using magneto-optical Kerr effect (MOKE) microscopy and x-ray photoelectric electron microscopy (X-PEEM) with recent samples showing potential chiral domains (fig 2a). These textures appear to be affected by terracing effects from the underlying TI as shown by AFM (fig 2b) which can limit skyrmion nucleation compared to similar multilayers grown on natively oxidised silicon (fig 2c). Potential solutions to this problem are proposed for future skyrmion dynamics experiments.

Figure 1a: PMA and IP remanent fraction as a function of Ta buffer layer thickness, 1b: in-plane spin asymmetry of neutron reflection at remanence.

Figure 2a: Polar MOKE images of magnetic domains of multilayer grown on Bi_2Se_3, 2b: AFM image of multilayer surface grown on Bi_2Se_3 showing underlying terracing effect from the TI surface, 2c: X-PEEM image of a skyrmion / bubble state of an identical multilayer grown on natively oxidised silicon under a 8 mT out-of-plane applied field.

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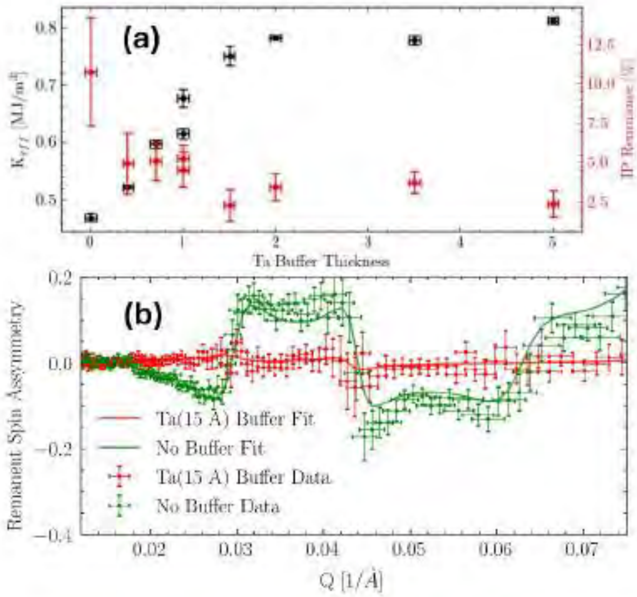
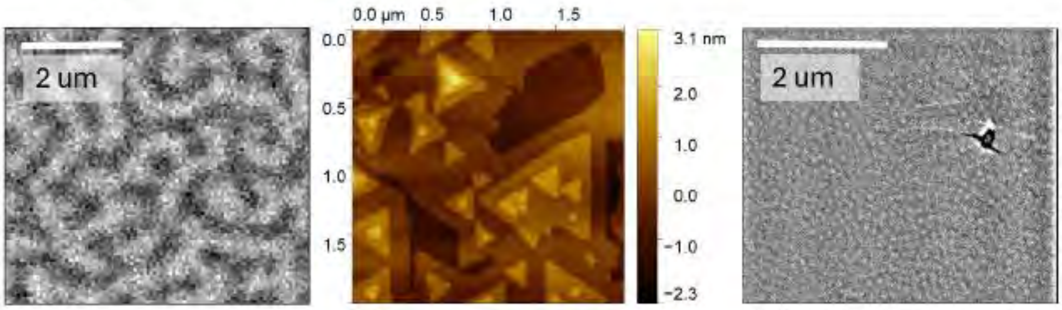


Figure 1a: PMA and IP remanent fraction as a function of Ta buffer layer thickness, 1b: in-plane spin asymmetry of neutron reflection at remanence.



(a) (b) (c)

Figure 2a: Polar MOKE images of magnetic domains of multilayer grown on Bi2Se3, 2b: AFM image of multilayer surface grown on Bi2Se3 showing underlying terracing effect from the TI surface, 2c: X-PEEM image of a skyrmion / bubble state of an identical multilayer grown on natively oxidised silicon under an 8 mT out-of-plane applied field.

Enhancement of spin signal via spin-dependent electron optics in graphene

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Combining the favourable spin transport properties of graphene with long range ballistic transport could prove key to realising future generation spintronic devices. At present, the methods used to evaluate spin transport in graphene are based on the 1D Bloch equation, which describes diffusive motion and relaxation of spin carriers propagating along a 1D channel. Here, we exploit the high-quality of hexagonal boron nitride (h-BN) encapsulated graphene devices with effective magnetic point contacts [1,2] to investigate spin transport in the ballistic regime, motivated by a desire to reduce momentum scattering of spin carriers. Quantised conductance through the point-like contacts implies the ballistic injection of spin polarised carriers [3], while the measurement of transverse magnetic focusing confirms end-to-end, spin-dependent ballistic transport over μm length scales. Focusing signals are sensitive to the relative magnetisation directions of adjacent contacts and show evidence of an enhanced spin signal for ballistic spin carriers, when compared to diffusive spin transport experiments. This is explained, in part, by the suppression of momentum scattering in the ballistic regime and the THz dynamics of focusing, both of which contribute to a reduction in spin relaxation. We observe structure in the focusing peaks consistent with spin-dependent quantum electron optics arising from the ferromagnetic nanowire contacts. Furthermore, the observation of quasi-ballistic transport at room temperature paves the way for future applications of such devices. These experimental results constitute the first realisation of a ballistic spin valve transistor in 2d materials, achieved through innovative device design and employing unconventional measurement techniques, which we hope will inspire future efforts towards building a comprehensive picture of ballistic spin transport in graphene.

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The effects of magnetic field annealing on the magnetic properties of Co thin films

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

The Pt/Co structure is of significant interest in the field of spintronics due to its robust perpendicular magnetic anisotropy (PMA), and interfacial Dzyaloshinskii-Moriya interaction(iDMI) which are crucial for the development of next-generation magnetic storage devices and spintronic applications such as domain wall devices and spin-orbit torque (SOT) devices [1, 2]. The magnetic properties of these thin films are susceptible to their microstructural characteristics, which can be modulated through post-deposition thermal treatments, such as annealing. Annealing can influence factors such as interfacial quality, strain relaxation, crystallographic texture, and atomic diffusion, all of which play a pivotal role in determining the magnetic behavior of the films. Furthermore, excessive annealing may lead to interdiffusion and degradation of the magnetic properties. Therefore, understanding the optimal annealing conditions is crucial for tailoring the magnetic properties of Pt/Co/Ta thin films to meet specific application requirements.

In this study, we systematically investigate the effects of different annealing temperatures on the Pt/Co/Ta structure. The structures are Ta(5)/Pt(3)/Co(0.5 – 2.5)/Ta (5) (thickness in nm). After deposition, the samples were annealed at 80, 100, 125, and 150 °C. The polar magneto-optic Kerr effect (MOKE) measurements and Brillouin light scattering were employed to measure the Co thickness dependent magnetic properties. Fig. 1 shows the normalized remanence values as a function of Co thickness for as-deposited and those annealing at 125 °C samples measured by MOKE. It is demonstrated that PMA increases after annealing at the whole Co thickness region. The detailed magnetic properties including PMA energy, iDMI energy density, and saturation magnetization as a function of annealing temperature will be discussed. The findings will provide valuable insights into the thermal stability and tunability of these thin films, contributing to the advancement of spintronic technology.

Fig. 1. The normalized remanence values as a function of Cobalt thickness.

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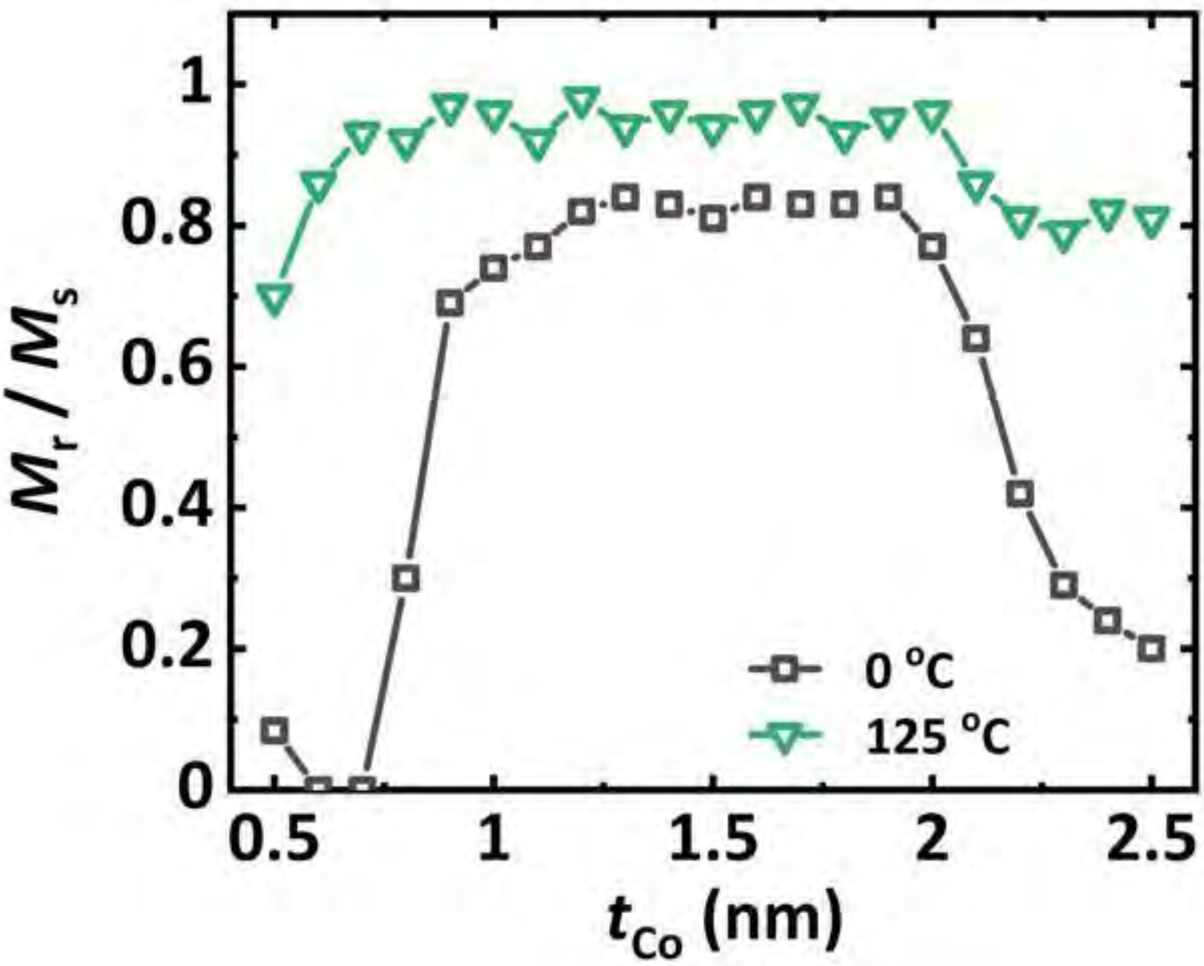

1
0.8
0.6
0.4
0.2
0
0.5
1
1.5
2
2.5
M_r / M_s
t_{Co} (nm)
0 °C
125 °C

Exploring the Magnetic and Topological Properties of Mn_3Ga Films

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

The noncollinear antiferromagnet systems such as D019-Mn3X (X= Sn, Ge, Ga) have attractive attention in spintronics due to their exotic properties such as the anomalous Hall effect (AHE), large intrinsic spin Hall effect (SHE), anomalous Nernst effect, and magneto-optic Kerr effect caused by breaking the time-reversal symmetry, despite having nearly zero magnetization [1]. Among the Mn_3X family, Mn_3Ga has been rarely studied, although theoretical study exhibits large intrinsic SHE compared to others [2] owing to the complexity of the MnxGay phase [3]. In this study, we successfully grew Mn_3Ga films on a MgO(110) substrate with a W seed layer under optimized deposition conditions. The temperature-dependent magnetic and electrical properties reveal that the AHE is observed despite exhibiting nearly zero magnetization. These results demonstrate the successful establishment of the non-collinear spin structure, which ensures the existence of a nonzero Berry curvature.

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Keywords: Non-collinear antiferromagnet; Mn3Ga thin film; Anomalous Hall effect

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Field-Free Spin-Orbit Torque Switching in Janus Chromium Dichalcogenides

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Spin-orbit torques (SOT) offer an efficient mean to switch magnetization via electrical currents, providing higher switching speed and endurance to spintronic devices [1]. 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) [2], 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 dichalcogenides (TMD) offer alternative paths to overcome these issues providing attractive magnetic properties demonstrated theoretically and experimentally [3-5].

Here, we combine ab initio and quantum transport methodologies to predict an exceptional SOT performance of chromium-based Janus TMD monolayers CrXTe (X=S,Se), allowing for field-free switching of the perpendicular magnetization [6]. We employed a robust methodology comprising first-principles calculations, Wannier tight-binding models fully capturing reciprocal space spin textures, quantum transport and critical field-free PMA switching current calculations. First, the ground state of CrXY monolayers for a range of magnetization directions were calculated using density-functional theory (DFT) where the metallic 1T phase (Fig. 1(a)) is found more stable than the semiconducting 1H phase. Next, based on maximally localized Wannier functions, multiple orbital tight-binding models (including Cr d-orbitals and chalcogen p-orbitals) with high-controlled accuracy were derived from DFT results. The real space Hamiltonian allowed to reproduce the DFT band structure with an impressive sub-1 meV accuracy in a large window around the Fermi level. Carefully deriving real-space spin operator, intriguing Fermi-surface spin textures were revealed with a clear Rashba spin-orbit coupling in the case of asymmetrical CrXY, X≠Y (Fig. 1(b)). Using the Wannier models, SOTs were then calculated via the linear response tensor χ within the Kubo formalism where different types of torques were disentangled with a symmetry-derived analytical expression of spin-density response in C3v systems. The obtained results including the estimated critical switching currents (Fig. 2(c)) show that the inversion-symmetry breaking in CrXY asymmetrical Janus monolayers produces ≃10-100x larger torques generated by giant Rashba splitting, equivalent to that obtained by applying a transverse electric field of ∼100 V/nm in non-Janus $CrTe_2$, completely out of experimental reach. Thus, magnetic chromium-based Janus TMDs offer a remarkable SOT performance yielding a competitive switching current with the additional advantage offered by 3m SOT component of neither requiring assistance of external fields nor the transmission of spin current through an imperfect interface.

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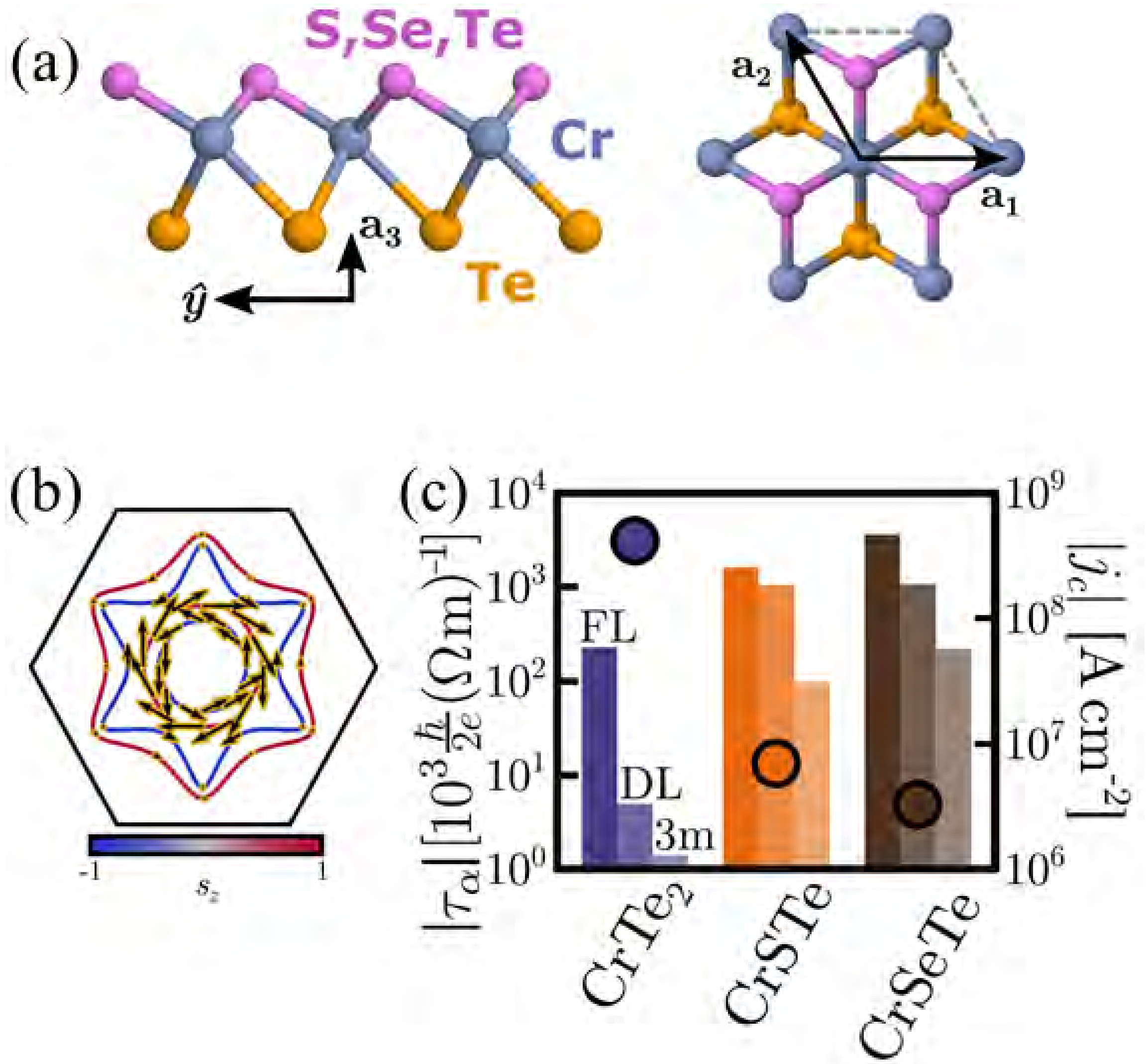
Fig. 1 (a) CrXTe Janus structure and lattice vectors. (b) Spin textures of CrSeTe. (c) Optimal switching current (right y-axis; filled circles) and the corresponding spin-torque conductivities (left y-axis; bars) for each system.



Homochiral antiferromagnetic merons, antimerons and bimerons realized in synthetic antiferromagnets

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Meronic spin structures have so far only been observed in native antiferromagnets where they are difficult to observe and manipulate. A more flexible platform to explore and manipulate both static and dynamic properties of such in-plane topological solitons are synthetic antiferromagnets (SyAFM), which combine the benefits of both FM and AFM scenarios: negligible stray fields, ultrafast spin dynamics, and detection of the absolute direction of the Néel order via imaging techniques that are typically suited for FM layers.

The stabilization of merons in an easy-plane-anisotropy thin-film system is primarily determined by the competition between the interfacial DMI (iDMI), the perpendicular magnetic anisotropy (PMA), and the demagnetizing field. Our micromagnetic model and the simulations show [1] that the vanishing demagnetizing field in the easy-plane SyAFM multilayer reduces the iDMI required to stabilize (anti)merons significantly and these spin textures can be stabilized in such systems even at iDMI values one order of magnitude lower than for of a conventional single FM system.

We have optimized multilayer SyAFM stacks with two different heavy metals Pt and Ir with opposite signs of DMI at the FM interface to break inversion symmetry and provide a finite DMI. The thickness of Ir has been optimized for the first AFM coupling maximum between the FM layers. By exploiting the high surface sensitivity of in-plane sensitive scanning electron microscopy with polarization analysis (SEMPA) and combining it with the out-of-plane sensitivity of magnetic force microscopy (MFM) we obtain access to the full Néel-order vector of the solitons. Fig. 1) shows such images from a SyAFM stack with 95% magnetic compensation, together with a topological analysis of the observed meronic spin structures.

Figure 1: Combined SEMPA a) and MFM b) datasets from the very same area on the multilayer surface yielding the full local 3D magnetization vector [1]. They allow to unambiguously identify the spin structures of merons with different helicities and topological charges, as sketched in panels c) and d) and antimerons in e) for the two antiferromagnetically coupled magnetic sublayer stacks. Bimerons are marked by ellipses on panel b).

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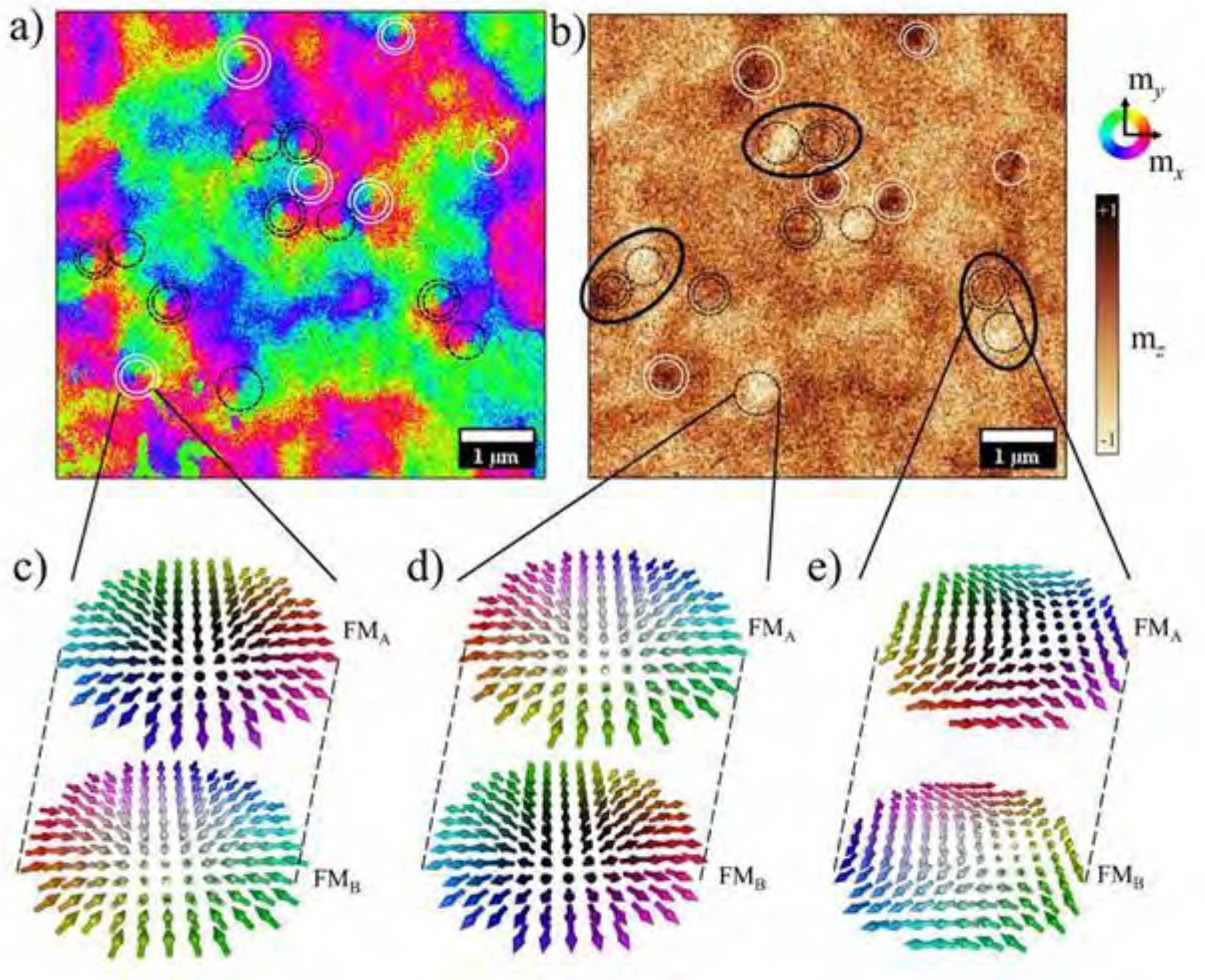

a)
b)
1 μm
1 μm
m_y
m_x
+1
m_z
-1
c)
d)
e)
FM_A
FM_B
FM_A
FM_B
FM_A
FM_B

MBE growth of high-quality Bi2Se3 topological insulators on [0001] oriented sapphire substrate and with (Bi, In)2Se3 buffer layer

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

In recent years, topological insulators, insulating in their bulk but conductive on surfaces due to a distinctive band structure, have attracted significant attention in spintronics and terahertz research [1]. The surface has a linear energy dispersion that features exotic, topologically protected, gapless states. Moreover, the surface charge carriers can be considered quasi-relativistic particles, which have extremely high mobilities and spin-locked transport. Topological insulators hold promises for advancing future technology, with thin films crucial for device development.

Molecular beam epitaxy (MBE) is a crucial growth technique to obtain very high-quality epitaxial topological insulator films. However, achieving high-quality growth requires careful consideration of parameters such as substrate preference, growth temperature, and the use of buffer layers [2]. Our study focuses on cultivating a high-quality topological insulator Bi2Se3 on sapphire [0001] substrate, employing a two-step growth method, initially growing in a low temperature of ~130 °C and increasing temperature to 330 °C. A trivial insulator (Bi, In)2Se3 (when the indium concentration is over ~6% [3]) was used as a buffer layer following the growth recipe of Koirala et al. [4]. A larger bismuth concentration in (Bi, In)2Se3 helps reduce lattice mismatch between Bi2Se3 and the buffer layer. We conducted a comprehensive analysis of surface morphology, crystalline structure, and magnetotransport properties at low temperatures.

In summary, the two-step growth method enhanced surface conditions, leading to large triangular terraces of high-quality Bi2Se3. Additionally, the (Bi, In)2Se3 buffer layer proved to be effective in preventing interfacial oxidisation, potentially enhancing the surface conductivity. Finally, we optimised the growth of Bi2Se3 with X-ray reflectivity & diffraction, atomic force microscopy, Raman spectroscopy, and magnetotransport properties by measuring standard Hall-bar type devices.

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Magnetic imaging of thermally switchable antiferromagnetic/ferromagnetic modulated thin films

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

The patterning of magnetic structures at the nanoscale using light ion irradiation has recently emerged as a powerful tool for developing thin film and multilayer systems with embedded magnetic variations. This has led to proposals for new functional devices across a wide range of applications, such as in patterned media [1], spin-orbit torque switching [2], skyrmionics [3], and magnonics [4]. Equiatomic FeRh is particularly suitable for patterning via ion-irradiated, owing to its thermally-driven magnetic phase transition (MPT) from antiferromagnetic (AF) to ferromagnetic (FM) ordering, the onset of which is highly sensitive to local damage [5]. In our previous work [6], we showed that it is possible to exploit this sensitivity to tailor the depth-dependent magnetism in 40 nm FeRh films. We furthermore demonstrated that by careful choice of the irradiating fluence it is possible to induce the MPT uniformly throughout the film depth at room temperature.

Here we report on the spin textures formed in AF/FM thin film stripes of width 100 nm formed via ion irradiation nanopatterning [7]. We exploit the sensitivity of the temperature-induced AF to FM phase transition to local damage in 40 nm FeRh thin films, thereby creating a series of thermally switchable AF/FM stripes which are embedded in an otherwise uniformly FM lattice (Fig. 1). A combination of X-ray magnetic circular dichroism photoemission electron microscopy (XMCD-PEEM), magnetic force microscopy (MFM), and vibrating sample magnetometry (VSM) measurements allow direct nanoscale observations of the stray fields emergent from the nanopattern as well as the underlying magnetization.

Our measurements demonstrate that the film microstructure has a significant effect on the underlying domain pattern. The MFM measurements reveal domain pinning centres which are resistant to thermal cycling, such that specific, nanometre-scale variations in the out-of-plane component of the local magnetisation can be destroyed and subsequently recovered via the sample temperature. The XMCD-PEEM data and micromagnetic simulations further reveal that the predominantly in-plane magnetisation forms micrometre-scale domains of collinearly oriented stripes, which are separated by vortex domain walls. Signatures of exchange bias are not observed, likely due to the fact that the interfaces between the damaged and undamaged regions are highly diffuse owing to the lateral scattering of incoming ions. These results show that temperature-controllable spin textures can be created in FeRh thin films which could find application in domain wall, microwave, or magnonic devices.

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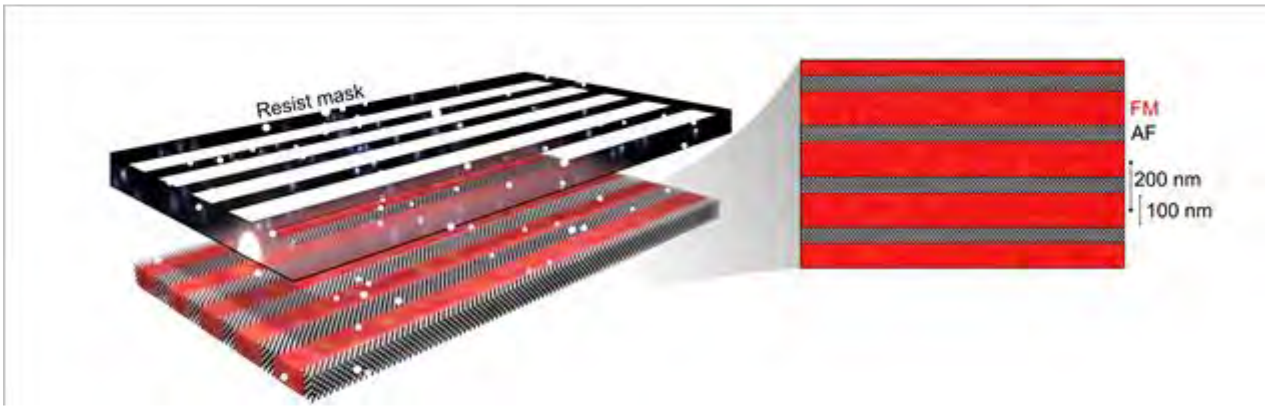
Fig. 1. Three-dimensional representation of the irradiation of an FeRh thin film through a patterned resist mask, with complementary plan view. At room temperature the irradiated regions (width 100 nm) are uniformly FM throughout the film depth, while the unirradiated regions remain AF.



Nonlinear electric generation of magnetization in time-reversal-even centrosymmetric metals

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Electric field generation of transverse spin current and spin-polarization in nonmagnetic materials are two central topics in all-electric spintronics. In contrast to spin current that can be driven by spin Hall effect in all systems, the electric field (current) induced spin polarization is limited to noncentrosymmetric metals (known as spin Edelstein effect). On the other hand, nonlinear responses of solids have been attracting increasing interest. This is because they dominate in materials where linear responses are symmetry-forbidden, probe quantum geometric quantities and provide novel methods to control materials. In particular, DC electric field induced nonlinear anomalous Hall effect in noncentrosymmetric crystals are connected with Berry curvature dipole and quantum metric dipole, while optical field induced nonlinear photocurrent currents are manifestations of Hermitian connection and Riemannian curvature [1-2]. In this talk, I will present our recent proposal of a time-reversal-even spin generation in centrosymmetric solids in second order of electric field [3] (nonlinear spin Edelstein effect), which would dominate the electric field generation of spin-polarization in a wide class of centrosymmetric nonmagnetic materials and lead to a novel nonlinear spin-orbit torque. We found that this effect is caused by the anomalous spin polarizability dipole. Furthermore, our first-principles calculations predicted significant spin generation in hcp metals and also in transition metal dichalcogenide monolayers. Finally, given the current enormous interest in orbtroinics, I will also report unpublished results of our first-principles calculations of nonlinear electric field generation of orbital magnetization (nonlinear orbital Edelstein effect) as well as linear electric field induced orbital Hall effect.

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Electrically Switchable Ferromagnetic Josephson Junctions for Cyrogenic Memory

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Superconducting computers operating at 4.2K have been proposed as a solution to the energy consumption issues faced by large-scale data processing systems, as well as to facilitate the interconnection between classical computers and their quantum counterparts. An ideal architecture for memory in such a system would be a superconducting memory bit that combines the quantum properties of superconductivity and magnetism.
A possible design would take the form of a CPP (current-perpendicular-to-plane) pseudo-spin valve ferromagnetic Josephson junction, utilising the 0-pi transition for information storage and a DC-SQUID readout (Figure 1). A prototype "Josephson MRAM" architecture has been established, along with read-out and write mechanisms[1] [2]. However, write mechanisms thus far have relied on globally applied fields or local fields generated from adjacent write lines.
To realise a more efficient electrical switching we are implementing junctions with perpendicular magnetic anisotropy(PMA) with the aim of exploiting spin transfer-torque or spin-orbit torque to reverse the magnetisation of one perpendicularly magnetised layer, analogous to a magnetic RAM device.
The perpendicular magnetisation brings further benefits in reducing stray fields and ensuring the maximum critical current is obtained at zero applied magnetic field[Figure 2] [3], although the additional interfaces due to the presence of a Pt layers to ensure the PMA and optimising a layer that can be switched easily at liquid He temperatures are challenges. Here we focus on our recent efforts characterising the interplay of the magnetic and superconducting proximity effects within the Pt layer and the use CoFeB alloys as candidate materials for the switchable layer in our prototype devices.

[Figure 1] - Schematic Pseudo-spin valve ferromagnetic Josephson junction with PMA layers.

[Figure 2] - Exemplary "Airy pattern" obtained from a Josephson junction measurement.

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Py17sg figures

Figure 1 – Pseudo-spin valve Ferromagnetic Josephson junction schematic

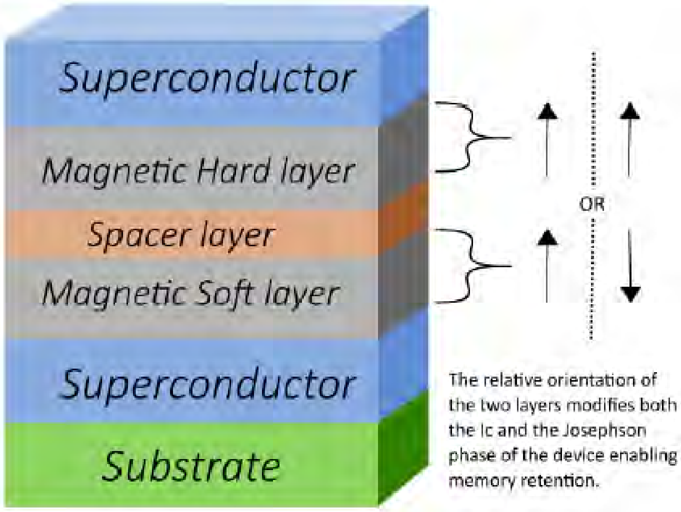
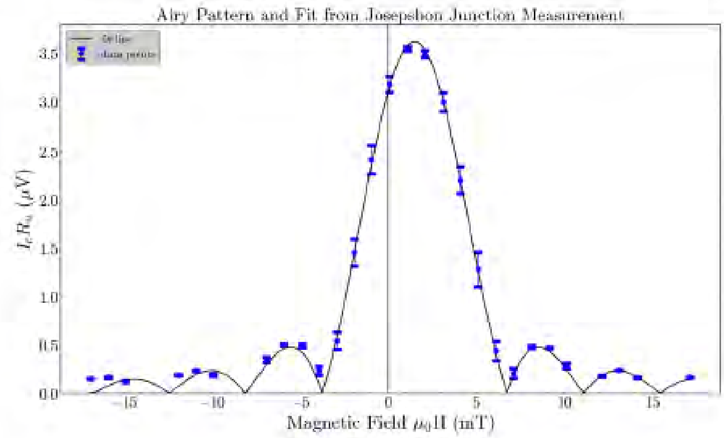


Figure 2 – Airy pattern obtained from Josephson junction measurement.



Impact of the spin-orbit torque source and buffer layer on driving skyrmion dynamics in ultrathin magnetic multilayers

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Skyrmions are topologically protected particle-like magnetic structures with significant potential for spintronic memory and logic devices [1][2]. In this regard, efficient and optimized skyrmions formation and their controlled, efficient motion under applied forces are very crucial for the practical realization of such skyrmionic devices [1][2]. Conventional spin-orbit torque (SOT) from heavy metals can drive skyrmion motion but suffers from low charge-to-spin conversion (CSC) efficiency. Topological materials (TM) characterized by spin-momentum-locked surface states and high CSC efficiency offer promising alternatives [3]. Ultrathin magnetic multilayers (UMM), where a ferromagnet is sandwiched between two heavy metals, are currently regarded as an excellent platform for hosting skyrmions [1]. However, achieving robust skyrmion formation in UMM structures is not straightforward and depends heavily on the structural quality of the TM layer and the buffer layer between the TM and UMM.

Here, we investigated skyrmion formation in an optimized MM ([Pt/CoB/Ru]x6) and over two TMs (Bi2Se3 and WTe2) exhibiting distinct SOT capabilities. Additionally, buffer layers (Ta, Ti, Mo, and Nb) with different Spin-orbit Coupling (SOC) strengths and spin-diffusion lengths are explored. The buffer layers are expected to induce some unwanted spin relaxation from the TM layer and self-induced subtractive SOTs, necessitating careful optimization.

Figure 1(a) shows the effect of buffer layer thickness on the effective anisotropy (Keff) of the UMM, and it is found to saturate nearly 2nm of the buffer layer thickness and hence can be considered as the critical buffer layer thickness. While looking for skyrmions in these optimized UMMs with Ta buffer layer on SiO2, a maze domain was observed without any magnetic field, which eventually collapsed into skyrmions under the applied magnetic field (Figure 1(d, e and f)). However, UMM on Bi2Se3 with 1.5 nm Ta buffer layer displays worm domains (even with an applied magnetic field (figure 1(g, h, and i))), possibly due to the terracing effects from the rough underlying TI surface with large roughness (~0.8 nm) (Figure1(b)). Increasing the buffer thickness reduced the roughness (~0.6 nm), but the effect still persists.

A straightforward solution is to explore a different TM, for example, WTe2, which also allows one to study the effects of unconventional torques [4][5]. The atomic force microscopy images of the MM on WTe2, even without any buffers, revealed smoother interfaces (~0.5 nm), addressing the roughness challenges (Figure 1(c)), and potentially could help to host skyrmion. This work underscores the need to optimize the structural and spintronic properties of TM and buffer layers to achieve efficient skyrmion formation and motion. These findings provide valuable insights for advancing skyrmion-based memory and logic technologies.

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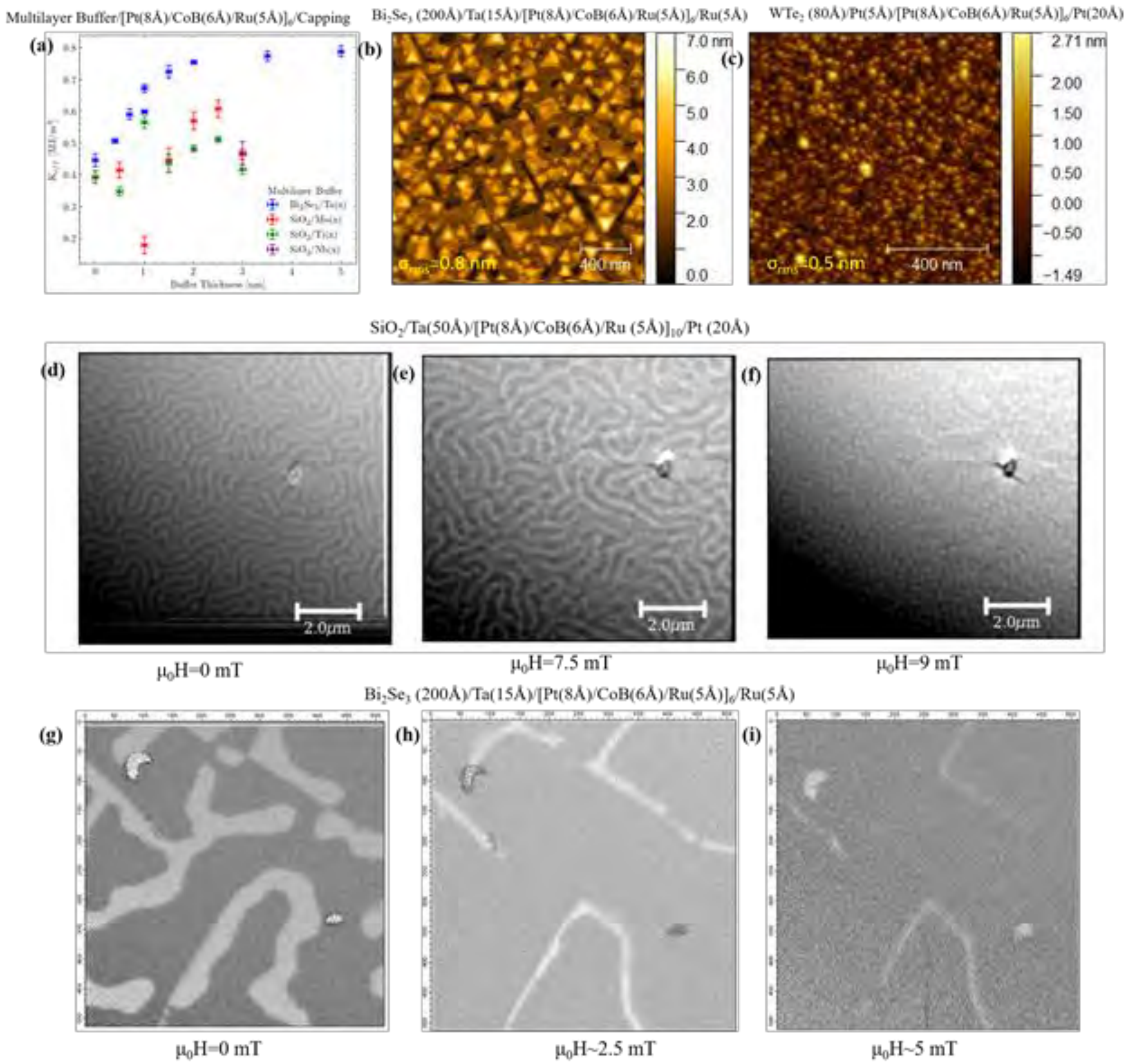
Multilayer Buffer/[Pt(8Å)/CoB(6Å)/Ru(5Å)]$_6$/Capping
(a)
Multilayer Buffer
Buffer Thickness [nm]
Bi_2Se_3 (200Å)/Ta(15Å)/[Pt(8Å)/CoB(6Å)/Ru(5Å)]$_6$/Ru(5Å)
(b)
σ_{rms}=0.8 nm
400 nm
7.0 nm
6.0
5.0
4.0
3.0
2.0
0.0
WTe_2 (80Å)/Pt(5Å)/[Pt(8Å)/CoB(6Å)/Ru(5Å)]$_6$/Pt(20Å)
(c)
σ_{rms}=0.5 nm
400 nm
2.71 nm
2.00
1.50
1.00
0.50
0.00
−0.50
−1.49
SiO_2/Ta(50Å)/[Pt(8Å)/CoB(6Å)/Ru (5Å)]$_{10}$/Pt (20Å)
(d)
2.0μm
(e)
2.0μm
(f)
2.0μm
μ_0H=0 mT
μ_0H=7.5 mT
μ_0H=9 mT
Bi_2Se_3 (200Å)/Ta(15Å)/[Pt(8Å)/CoB(6Å)/Ru(5Å)]$_6$/Ru(5Å)
(g)
(h)
(i)
μ_0H=0 mT
μ_0H~2.5 mT
μ_0H~5 mT

The first and second-order magnetic anisotropy in multilayer Co/h-BN heterostructure

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Magnetic anisotropy (MA) is a key factor in the development of spintronic devices, influencing their efficiency, stability, and miniaturization. By tuning the first and second-order MA constants, K1 and K2, the equilibrium states of magnetization such as perpendicular MA, in-plane MA, and cone state can be controlled. There are studies on the K_1 and K_2 for free layer in magnetic thin films [1] and magnetic layer on MgO substrates [2]. On the other hand, it is necessary to consider the two-dimensional (2D) materials with hexagonal symmetry due to future demand for magnetic materials that will be converted from three-dimensional to 2D materials. However, there are only few studies on the first and second-order MA constants of the magnetic layer on 2D material with hexagonal symmetry.

Here, we conduct a theoretical investigation into the first and second-order magnetic anisotropy dependence on the number of cobalt (Co) layers in Co/h-BN heterostructures (Fig. 1 (a)) using first-principles calculations. The results show that the Co monolayer on the h-BN has the perpendicular MA (PMA), whereas the Co 2-5 layers have in-plane MA (IMA). This is due to the contribution of IMA based on the dipolar anisotropy energy being larger than the contribution of PMA based on the magnetocrystalline anisotropy. We calculated the total energy difference between two different magnetization directions, θ and $0°$ by including spin-orbit coupling, and the first and second-order MA constants, K_1 and K_2, are evaluated by fitting the θ-dependence of MA energy as shown in Fig. 1 (b) and (c). The K_1 and K_2 in Co monolayer are 1.36 and 0.32 mJ/m^2, which indicate the equilibrium state is the PMA. On the other hand, the K_1 and K_2 in Co 2 layer are -0.06 and 0.02 mJ/m^2, which indicate the equilibrium state is IMA close to the cone state. We found that the magnetization equilibrium states (K_1 and K_2) can be controlled by the number of Co layers on h-BN. In the presentation, we will also discuss the first and second-order MA constants for other Co layers on h-BN and the application for magnetic field sensors.

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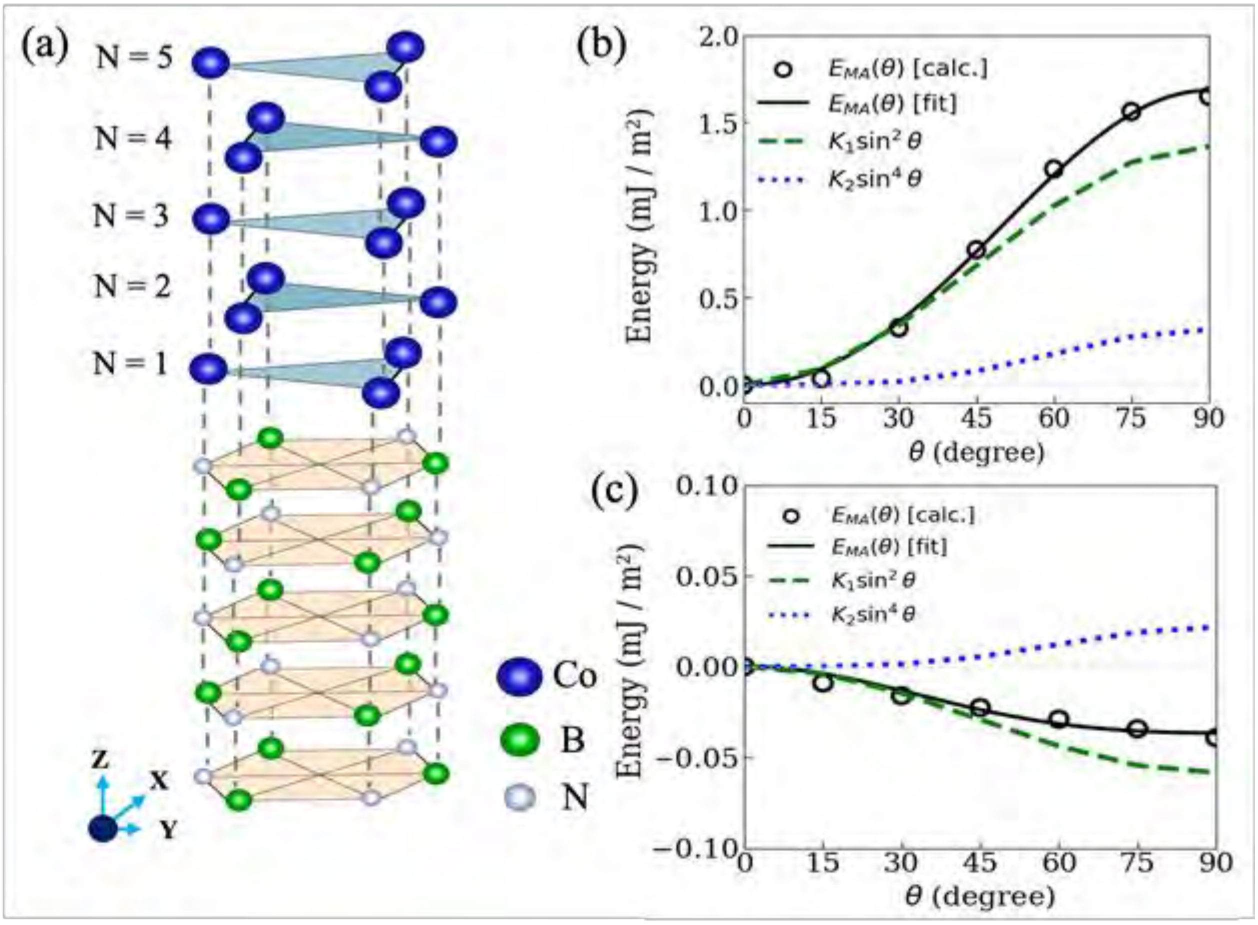
Fig. 1 (a) Schematic illustration of Co/h-BN heterostructure where N represents the number of Co layer. The magnetic anisotropy energies for (b) Co 1 monolayer and (c) Co 2 layer on h-BN as a function of the polar angle, θ.



Morphology and dynamics of domains and domain walls through asymmetric hole density-graduated 2D-arrays

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

The manipulation of magnetic domain walls (DW) opens novel strategies to design spintronic devices with potential high impact in data storage, nonvolatile logic, and magnonic applications, which may include reservoir/neuromorphic computing, data storage, and sensors among others. For the implementation of several of those applications, asymmetric DW motion controlled by electrical voltages or currents and magnetic fields is needed. The prototypical asymmetric DW motion mechanism is the so-called ratchet effect, which consists of an easier propagation of domain walls in one direction than in the other thanks to an asymmetric pinning potential.

Different mechanisms have been demonstrated to favour ratchet effect, being patterning into an asymmetric configuration one of the preferred options. 2D micropatterned arrays of asymmetric holes (2D-AAH) on magnetic thin films have been reported to show ratchet effect. In the large size regime, the DWs have been approximated as elastic lines of zero width that can distort (i.e., bend) throughout their length when pushed by a magnetic field. This bending was attributed to be the main factor determining DW propagation. However, in 2D-AAH, the optimum hole size for the occurrence of ratchet effects is twice the DW width. Therefore, when matching the hole size to the DW width of the particular magnetic thin film used, the DWs cannot be considered 1D objects and their morphologies play a very important role. Additionally, in regular arrays of asymmetric holes the very fine control of the ratchet effect can be challenging.

In order to tackle these two issues, we have fabricated 2D-AAH on Co86Zr14 with different hole shapes (triangles and arrows), sizes (from 2.5 to 6 μm), and pattern structure (regular and with different gradients in density of holes in the array) and study them combining Kerr microscopy and X-Ray PhotoEmission Electron Microscopy [1, 2]. The gradient strategy has allowed us superior control over the movement of the DWs along the array, enabling us to write various and specific magnetization states, which can be observed as a whole in the Kerr microscope due to the large field of view of this technique. On the other hand, high resolution images taken with the PEEM at ALBA synchrotron have revealed a much more complex magnetization structures and DW configuration than predicted. Specifically, cross-tie DWs have been experimentally observed. Micromagnetic simulations show that the total DW energy not only depends on the length of the wall as in the Néel case, but also on the density of vortex/anti-vortex textures forming the wall, hence, the inner DW magnetization structure could add an additional layer of control for the Ratchet phenomena allowing to fine tune the interaction between the DW and the holes pattern.

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Nonlinearly excited magnetization fluctuation in a nanoscale magnetic tunnel junction

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

In quantum science, a variety of physical systems have been proposed as quantum systems capable of carrying information. In such systems, realization of nonlinear interactions is crucial for uncovering the quantum mechanical properties. In magnetic materials, nonlinear interactions such as magnetic dipole interaction or exchange interaction are inherent. Due to this reason, magnons, quasiparticles of spin waves (the wave-like propagation of magnetization precession), have attracted attention as candidate quantum systems. Another distinguishing feature of magnon systems is the integrability of magnetic materials, a technology that has been fostered through the development and manufacturing of memory and sensor devices in the field of spintronics. Consequently, realizing a magnon-based quantum system would make it possible to integrate an extremely large number of these nanoscale systems into a device, thereby enabling a wide variety of information-processing applications. For this reason, acquiring physical states of magnons excited nonlinearly in nanoscale magnetic materials is an essential step toward realizing magnon-based quantum systems. However, the lack of suitable experimental principles and systems has left this stage unexplored.

In this presentation, we report experimental results of magnon fluctuations, which reflect physical states of magnons, obtained in a nanoscale magnetic tunnel junction (MTJ) connected to a microwave measurement system at room temperature. The MTJ was composed of a magnesium oxide insulating layer, sandwiched by cobalt–iron based alloy magnetic layers. In the MTJ, magnons are generated through parametric excitation, a nonlinear process whereby periodic modulation of the oscillator’s parameter generates an oscillation at half the frequency. In our experiment, applying an AC microwave electric field to the MTJ periodically modulated the electron occupation states at the magnet/insulator interface and thus the magnetic anisotropy. This in turn led to periodic modulation of magnetic anisotropy by spin-orbit interaction, which parametrically excited magnons at half the frequency of the applied field. The excited magnons can be electrically detected as an AC voltage through the magnetoresistance effect, where the electrical resistance of the MTJ depends on the relative magnetization orientation of the two magnetic layers. By splitting this AC signal and multiplying one portion with a reference signal and the other with a reference signal shifted by 90 degrees, the cosine and sine components of the voltage were extracted. Simultaneous and repeated measurements of these two components enabled us to acquire the probability density function of magnon fluctuations represented on a two-dimensional quadrature space.

Development and Characterization of RuO2 and Mn5Si3 Altermagnetic Heterointerfaces for Applications in Josephson Junctions

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Solids with intrinsic magnetic phase are traditionally classed as having either ferromagnetic or antiferromagnetic ordering. Recently, there has been great interest in the fundamental study and potential applications of an emerging third class of magnetic solid, altermagnets (AMs). AMs have properties which blur the lines between the traditional ferromagnetic and antiferromagnetic orderings. On the one hand, these materials have electronic properties consistent with ferromagnetism, they show an anomalous Hall effect and have spin polarized conduction bands. On the other hand, AM materials have antiparallel magnetic crystal order and zero net magnetization, consistent with antiferromagnetism. AMs are expected to be abundant in nature[1].

The presence of a spin polarized conduction band suggests that much of the rich physics present in superconductor–ferromagnet (SF) hybrid systems are also present when the ferromagnet is replaced by an AM[2], along with additional unique physics in the new AM system[3]. In SF systems where pair correlations proximitized the F layer, the splitting of opposite spins, leads to a finite momentum of the pairs. In the S–AM system, the finite momentum exhibits a strong anisotropy with respect to the direction of pair propagation.

AM properties are driven by the crystal structure of the material, the group of the spin sublattices, and the transformation operation between the opposite spin sublattices. In the example of ruthenium oxide (RuO_2), when an electric field is applied along the [110] axis, the spin-up and spin-down charge currents are parallel but of differing magnitudes due to the band anisotropy. Therefore, the longitudinal charge current is spin polarized. Conversely, along either the [010] or [100] axes, the spin-up and spin-down charge currents are equal in magnitude but are along opposite directions which combine to form an unpolarized charge current.

To date, there are no experimental studies of S–AM hybrid systems. In this work, we focus on the epitaxial growth of thin films of RuO_2 and manganese silicide (Mn_5Si_3) to determine whether the novel electronic properties displayed by these AMs can be maintained as their thickness decreases. Additionally, two orientations of RuO_2 and Mn_5Si_3 will be deposited to maximize the direction of spin polarization in-plane and out-of-plane. Developing the epitaxial growth of these materials in is key to maximizing the spin polarization for electrical characterization (in-plane) and would allow for the development of high-performance Josephson junctions (out-of-plane). We will present evidence that the orientation of these AM films can be controlled via the careful selection of heteroepitaxial partnerships, that the novel electromagnetic properties of AMs are maintained even when deposited as thin films, and that these epitaxial stacks can be utilized to create functioning Josephson junctions.

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Device Width Dependence of Critical Current Density and Superconducting Diode Effect in Nb/V/Ta Artificial Superlattice

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

The superconducting diode effect is a phenomenon in which the electrical resistance becomes zero in the forward direction but remains finite in the reverse direction. When an external magnetic field is applied, this effect has been observed in various superconducting materials, including the artificial superlattice Nb/V/Ta [1].

A prominent discussion on the mechanism of the superconducting diode effect emphasizes the contribution of finite-momentum Cooper pairs arising in systems where spatial and time-reversal symmetries are broken [2]. On the other hand, the emergence of non-reciprocal superconducting currents has been discussed in relation to "extrinsic" mechanisms, such as magnetic flux (quantum vortices) penetrating the superconductor and the combined effects of the Meissner screening effect and edge asymmetry introduced during fabrication [3]. In this study, we performed critical current measurements by varying the device width of the artificial superlattice Nb/V/Ta to investigate the effect of quantum vortices on the superconducting diode effect.

We fabricated thin films of [Nb(1 nn)/V(1 nm)/Ta(1 nm)]n superconducting superlattice on MgO(100) substrate by DC magnetron sputtering, and the films were fabricated into narrow wire devices using electron beam lithography and Ar milling. The width of the devices varied from 50 μm to 300 nm, and the critical current was measured using four-terminal measurements.

Figure 1 shows the critical current density at 2.0 K as a function of device width. The critical current density increases with decreasing device width and shows saturation to the constant value below 1 μm. The reduction of the critical current with device width can be attributed to the contribution of quantum vortex penetration and its de-pinning [4]. Therefore, narrowing the device width is useful to suppress the contribution of quantum vortex penetration into the superconductor. The intrinsic superconducting diode effect is expected to be observed in the region of the narrowest devices, where the critical current reaches its saturation. In the presentation, we will examine these results in detail and discuss the contribution of quantum vortices to the superconducting diode effect.

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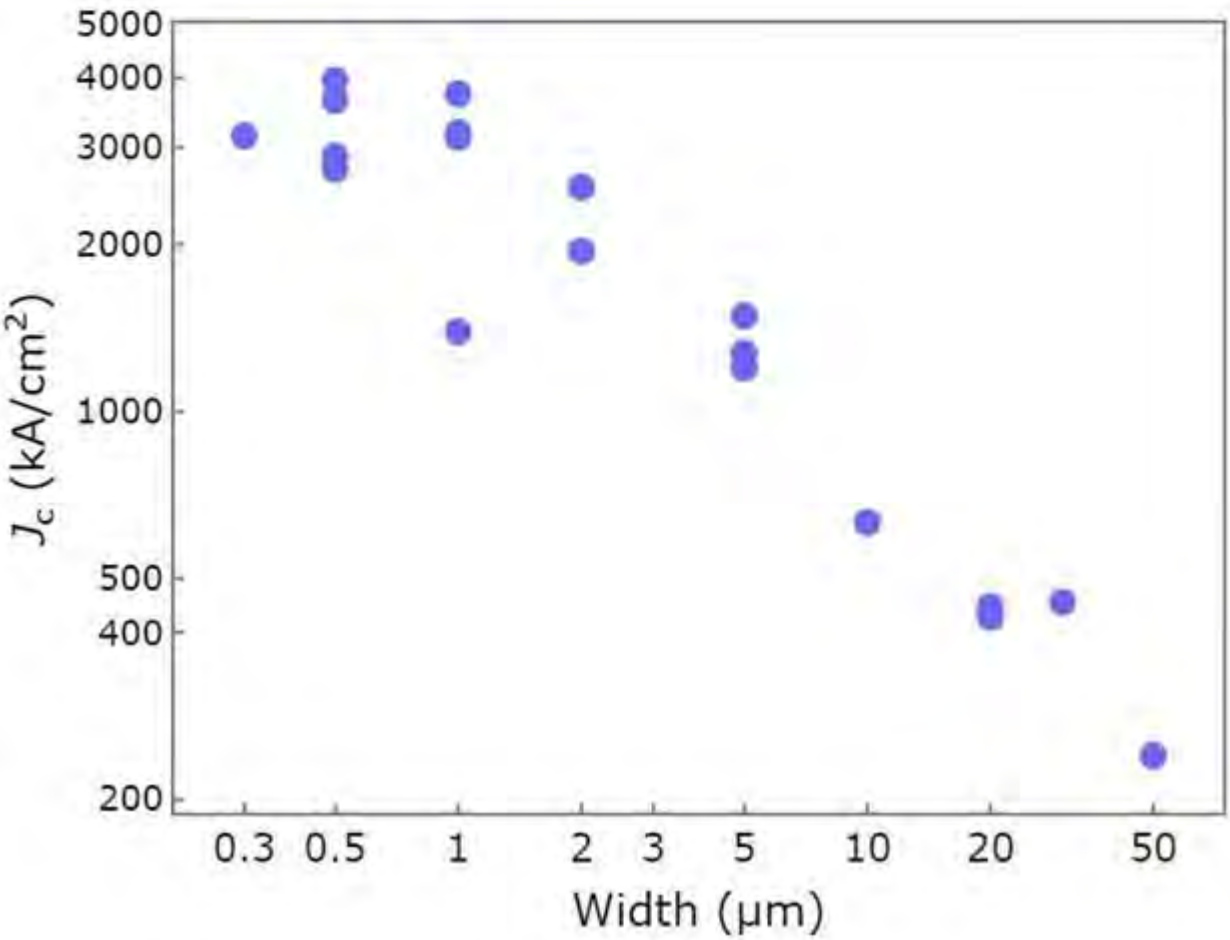

5000
4000
3000
2000
1000
500
400
200
J_c (kA/cm^2)
0.3
0.5
1
2
3
5
10
20
50
Width (μm)

Bismuth ferrite-lead titanate thin films for an investigation of the effects of the morphotropic phase transition on magnetic properties

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

$xBiFeO_3$-$(1\text{-}x)PbTiO_3$ (BFPT) is a ferroelectric perovskite for all values of x, and antiferromagnetic at certain values of x. The material properties depend on the crystal symmetry, which in turn depends on the ratio of $BiFeO_3$ to $PbTiO_3$ [1]. For x > 0.7 the crystal structure is rhombohedral (R), with the ferroelectric saturation polarisation (Ps) // [111], while for x < 0.7 it is tetragonal (T), with Ps // [001]. At room temperature, the R phase is G-type antiferromagnetic while the T phase is paramagnetic [2]. At x=0.7 BFPT exhibits a morphotropic phase boundary (MPB) between T and R structures [3], accompanied by an enhancement in the ferroelectric and piezoelectric properties. There's the potential to manipulate the phase transition by applied stress or electric field, and hence switch between antiferromagnetic and paramagnetic behaviour [4].

Here we deposit BFPT films for an investigation of the effect of the phase transition on the magnetism. Figure 1 demonstrates the effect of changing the chamber temperature during deposition. The splitting of the diffraction peak seen at 22° is synonymous with the (100) lattice plane splitting into (001) and (100), indicating the T crystal symmetry. This is useful for controlling whether BFPT is R or T without changing the composition. An optimum deposition temperature was investigated regarding thin film topography.

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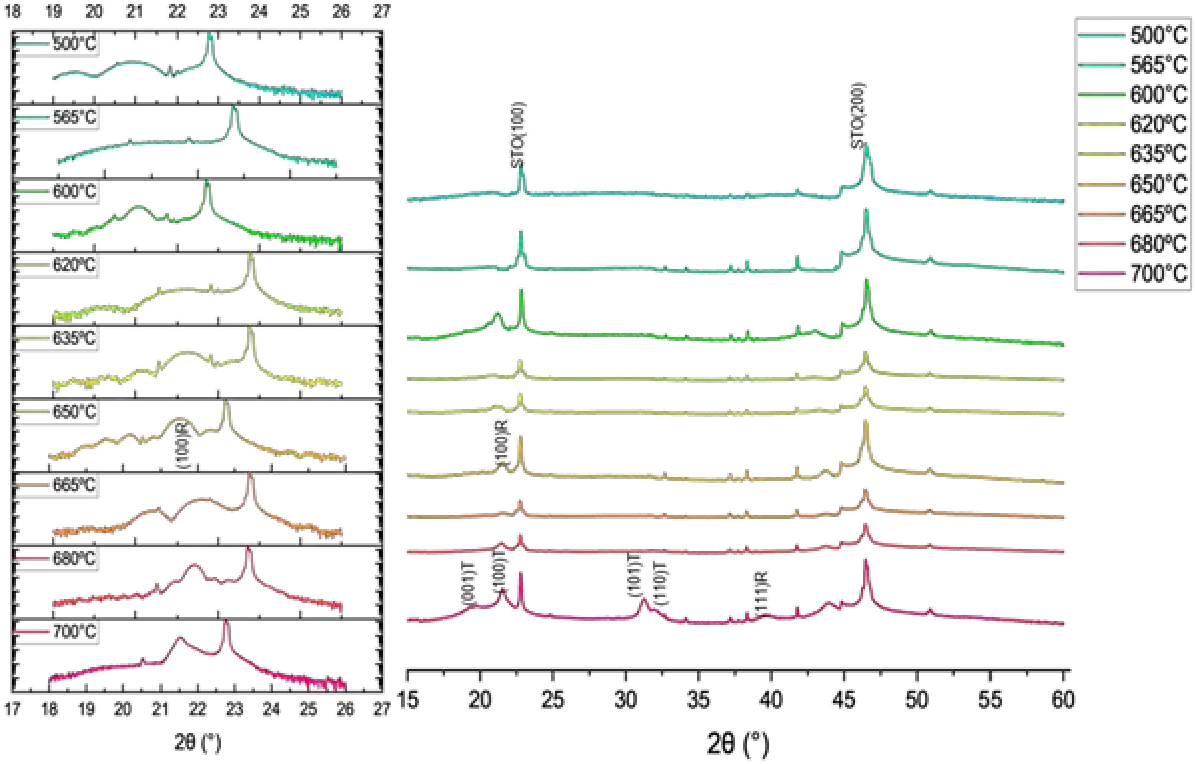

Figure 1: XRD data collected for x=0.65 (x)BF-(x-1)PT where deposition chamber temperature varied. a) shows the 2θ range of 15° to 60° and b) narrowed 2θ range, across the (100) peak, 18° to 26°

Strong spin-to-charge conversion driven by interfacial spin orbit coupling at full oxide ferromagnetic / quasi-2-dimensional structures

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Functional oxides and hybrid structures with interfacial spin orbit coupling such as the Rashba-Edelstein effect (REE) and spin Galvanic effect (SGE) are fascinating for future spintronic device applications. Here, we show strong spin-to-charge conversion through enhanced interfacial spin orbit coupling at the full-oxide interface of La0.7Ca0.3MnO3 with artificially controlled quasi-two-dimensional (quasi-2D) SrTiO3 (LCMO/STO). The quasi-2D interface is generated via oxygen vacancies at the STO surface. We obtain a strong spin-to-charge conversion with efficiency of θ_‖ ≈ 2.32 ± 1.3 nm, most likely originated from the inverse REE, which is relatively large value compared with all-metallic based spin-to-charge conversion materials systems. The results highlight that the LCMO/STO quasi-2D interface is a potential platform for spin-based memory and spin-transistor applications.

Current-driven domain wall motion in ferrimagnetic nanowires

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

This study explains the motion of domain walls (DWs) in ferrimagnetic (FiM) nanowires driven by spin transfer torques (STTs) using the energy-work principle. An adiabatic STT (a-STT) can be incorporated in the Lagrangian as an energy functional, causing DW planes to twist. In uniform FiM nanowires, DWs can resist movement induced by an a-STT below a critical value related to the maximum transverse anisotropic field. In contrast, a nonadiabatic STT (na-STT) cannot be included in the Lagrangian and affects spin dynamics through the Rayleigh functional, meaning that a static DW cannot exist under a na-STT, necessitating DW propagation under an arbitrarily small na-STT. STTs perform overall positive work on a DW, which must be balanced by energy dissipation through damping when the spins within the DW are moving. Below the Walker breakdown current, na-STT does positive work while a-STT does none. Above this threshold, the DW begins to precess around the wire axis during propagation. The work done by a-STT varies based on the direction of precession, while na-STT consistently does positive work. We derive a DW velocity formula that aligns with simulations both below and above the Walker breakdown current (See Fig, 1(a) for a comparison). Near the angular momentum compensation point, the precession frequency of the DW peaks, leading to distortion in the DW structure and spin wave emission, which alters DW motion and deviates from a simple linear relationship with current density. Our generalized theory effectively captures this nonlinearity, as illustrated in the attached Fig. 1(b,c). In summary, our theory successfully explains the observed DW mobility near the angular momentum compensation point in FiM nanowires and addresses the issue of the unphysical negative na-STT observed in experiments.

Refs.

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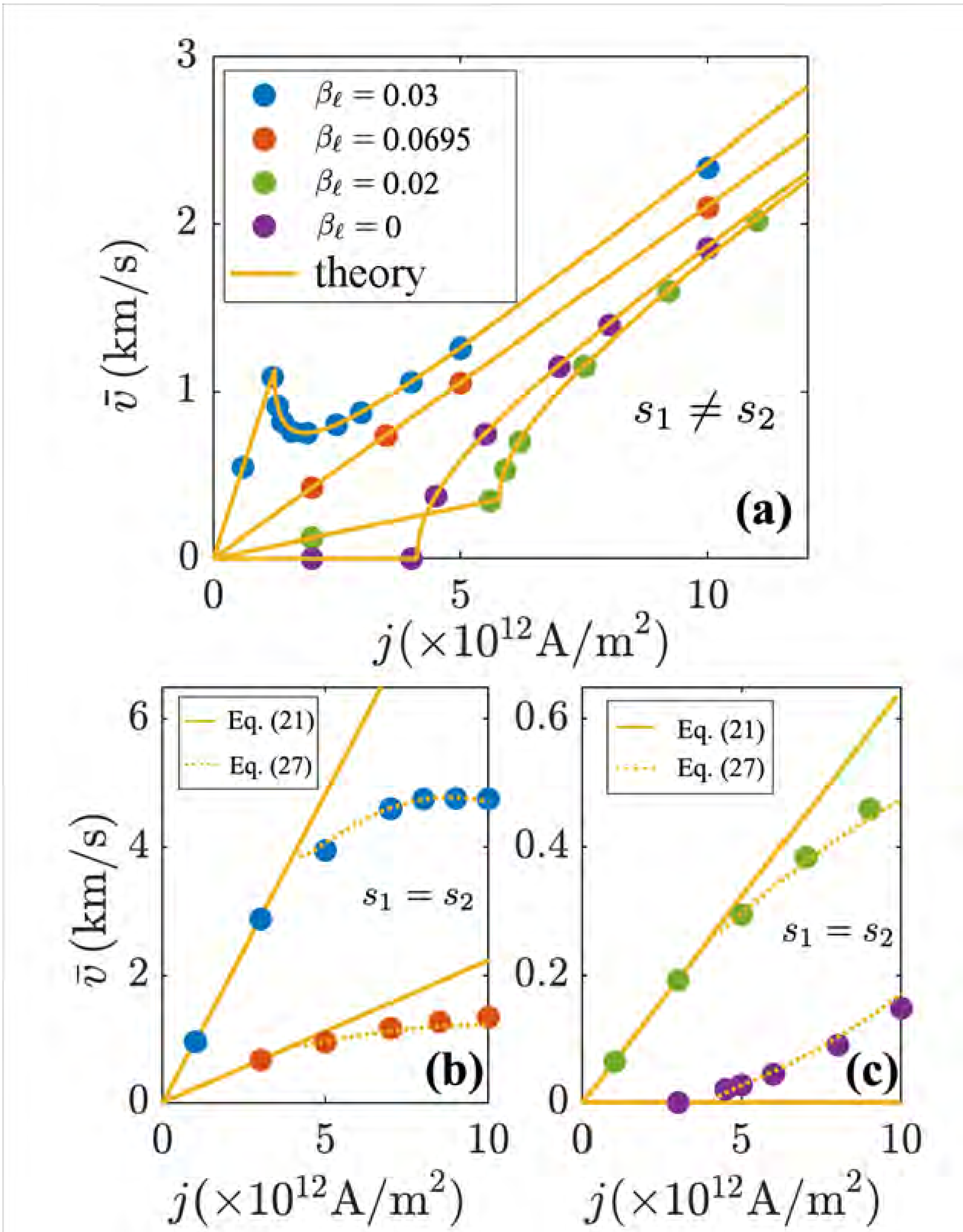
Figure caption:
Current-density dependencies of averaged DW velocity for a nanowire away from the angular momentum compensation point (a) and at angular momentum compensation point (b), (c).



Effect of Interfacial Exchange on Anisotropy and Magnetization Dynamics of Permalloy/L10-FePt Bilayers

Kapil Dev[1], Ankit Kadian[1], Vishnu Kumar[1], Ashish Gupta[2], Mukul Gupta[2], S. Annapoorni[1]
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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Magnetic hard/soft bilayers exhibiting exchange spring behavior have got considerable research interest for the development of advanced spintronics and high-density magnetic storage devices. Permalloy/FePt bilayers are a suitable choice of magnetic hard/soft layers where the permalloy exhibits high permeably, negligible anisotropy and low gilbert damping whereas FePt in L10 phase exhibit highest anisotropy [1]. The switching field of the hard layer can be manipulated by spin injection using microwave excitation through the soft layer, promising for next generation microwave assisted magnetic recording (MAMR) devices [2]. The investigation of anisotropy control and magnetization switching in such hard soft system is crucial for further development of such ultra-fast high density storage devices.

In the present work Permalloy/FePt bilayers have been deposited on SiO2/Si substrate using DC magnetron sputtering techniques with varying thickness of individual layers. The deposited bilayer films were annealed at different temperatures ranging from 300 ˚C to 600 ˚C in reducing (95%Ar + 5%H2) atmosphere to get the desired L10-FePt phase. A globular morphology was observed using Scanning Electron Microscopy (SEM). The phase transformation investigation was done using synchrotron-based GI-XRD measurements. To investigate the interfacial phase evolution upon annealing, in-situ high temperature synchrotron XRD measurements were performed. These measurements revealed that FePt phase transition initiates at 400 ˚C and 300 ˚C with increasing FePt layer thickness. Bulk magnetic measurements showed that as deposited bilayers show soft magnetic nature and it gradually changes to hard magnetic phase with increasing annealing temperature. The coercivity can increased up to 1.1 kOe for the films annealed up to 600 ˚C. The drastic increase in Hc is expected due to phase transformation of FePt film from soft (A1-phase) to hard (L10-phase). It has been observed that the Hard magnetic L10 phase of FePt can be achieved at relatively lower annealing temperatures for higher thickness.
To investigate the magnetization dynamics and magnetization switching characteristics of these bilayer systems ferromagnetic resonance and magneto-optic Kerr effect (MOKE) based microscopy experiments are underway.

These Microscopic insights into these transformations provided by synchrotron-based GI-XRD and temperature-dependent XRD, as well as magnetization dynamics studies reveal the effect of exchange coupling on the magnetization dynamics and magnetization switching characteristics of these systems for further development of such ultra-fast high density storage devices.

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Magnetic domain wall-based spin torque majority gates: from domain wall input to full logic operations

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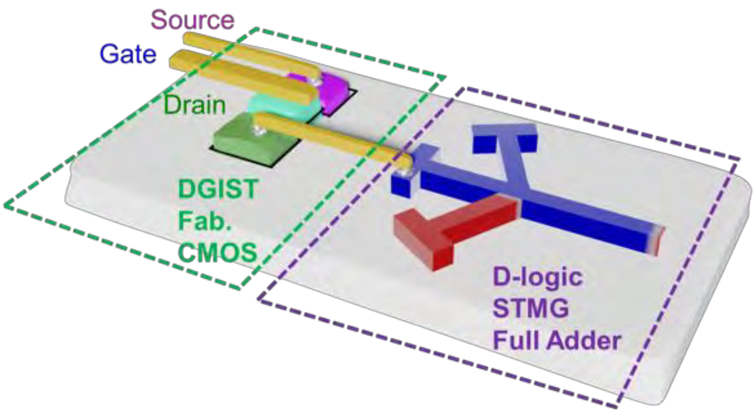
Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

The spin-transfer majority gates (STMG), utilizing spin-orbit torque-induced magnetic domain wall (DW) motion, have been experimentally demonstrated. In contrast to conventional circuits, which rely on combinations of multiple transistor-based NAND gates—producing false outputs only when all inputs are true—majority gates offer a simplified approach to logic operations. Majority gates are 'democratic' devices that output is true when more than 50% of their inputs are true. In their simplest form, they operate with three inputs and a single output. Figure 1 shows the schematic configuration of the magnetic DW motion-based STMG architecture. It consists of three individual chirality-dependent DW inputs, which nucleate DWs by applying the spin Hall effect via electrical current pulse injection. The generated DWs, whether single or multiple, are moved to the junction center of the microwire. Finally, the 'democratic' logic operations (majority computations) are performed with the mechanism of DW expansion and motion at the junction of STMG. With these DW motion-based majority gates, both AND and OR logic gates can be demonstrated.

In this study, the chirality-dependent DW nucleation (input) and spin-orbit torque-induced DW motions are systematically observed using magneto-optical Kerr effect microscopy. First, the combination of the spin Hall effect from a current pulse and the chirality induced by the interfacial Dzyaloshinskii-Moriya interaction causes chirality-dependent DW nucleation. Due to the spin-orbit torque, DWs travel from the DW inputs to the center of the STMG, with their velocity precisely controlled at approximately 10 m/s to ensure accurate displacement for equivalent logic operations. Finally, full STMG logic operations, including AND and OR logic gates, are successfully demonstrated.



Median Mishaps between Domain-Wall Chirality and Spin-Orbit Torque via Hysteresis Loop Shifts

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Spin-orbit torque (SOT) is a critical mechanism for manipulating magnetic states in spintronic devices. One of the most widely measured methods is the measurement via the hysteresis loop shift method due to its simplicity and practicality, but it has been empirically understood as being related to single-domain wall (DW) chirality. In this presentation, we demonstrate that the observed SOT efficiency instead reflects an average of effective magnetic fields from up-down and down-up chiral DW's polarities during depinning, rather than single-chirality switching via random nucleation. By integrating this model with established measurement methodologies and theoretical paradigms, we advance a theoretical framework based on the magnetic domain-wall chirality of individual polarizations and aim to elucidate the phenomena of SOT with clarity. The anticipated outcomes include the rectification of inaccuracies in widely employed measurement methodologies and the enhancement of our comprehension of the fundamental physics, which are expected to propel advancements in next-generation spintronics materials and devices.

Structure engineering of spin-sink for huge self-spin swapping effect

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

The spin swapping effect is a promising phenomenon that provides a symmetry-breaking component for deterministic field-free switching. It is also known as magnetic spin Hall effect, etc. Without any additional magnetic layer, the spin swapping effect can emerge within only one magnetic layer, which we called as self-spin swapping effect. Furthermore, intensity of self-spin swapping can be manipulated by stack structure with Pt layer and Au layer, which have a role as spin sink and spin swapping layer respectively.

In this study, by using DC magnetron sputtering, we made sample series; (a) Au/Co/Au, (b) Pt/Au/Co/Au/Pt, (c) Au/Co/Au/Pt, and (d) Pt/Au/Co/Au as shown in Fig 1. The thickness of all Co layers was set to 0.7 nm and the thickness of all Au and Pt layers was set to 3.0 nm. When current is applied to sample along x-axis, z-axis spin current is generated in magnetic layer and was diffused to neighboring Au layer. For long spin diffusion length of Au, z-spin is converted to x-spin by spin swapping effect in Au layer. These x-spin re-entered to magnetic layer where spin current is generated originally. On the other case, if Pt layer is located above (or under) the Au layer, spin current is penetrate Au layer and diffused out in Pt layer. As a result, symmetric samples show very small self-spin swapping effect because x-spin is canceled out or dissipated in Pt layer respectively as following blue arrow indicating spin direction in Fig 1.a, b. But, asymmetric samples exhibit significant self-spin swapping effect for unbalance of spin injection from upper layer and lower layer, which also means that self-spin swapping effect is flipped among asymmetric samples because of parity reversal. All result is summarized in Fig 2, which is divided into symmetric samples and asymmetric samples.

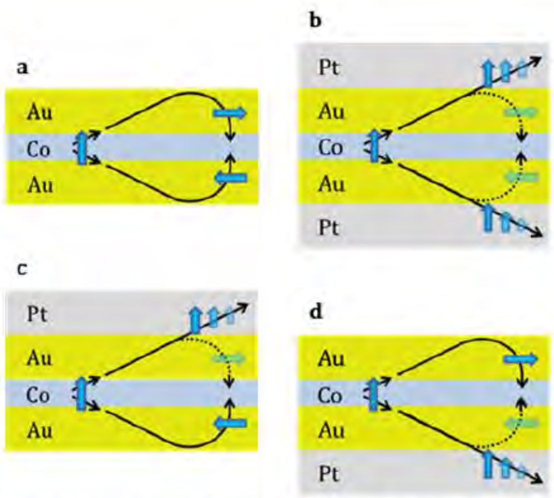

Fig.1 sample structure and scheme for spin flow which is generated by self-spin swapping

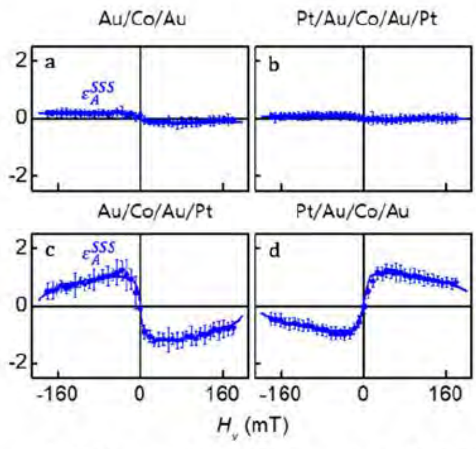

Fig.2 current efficiency of self-spin swapping (ε_A^{SSS}) for all sample series

Why Fe3GaTe2 has higher Curie temperature than Fe3GeTe2?

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Recently, extensive research for van der Waals magnets has been conducted [1,2] to achieve Curie temperature (TC) exceeding room temperature. Among these, Fe_3GaTe_2 has attracted attention with TC as high as 380 K [3]. Isostructural with Fe_3GeTe_2 but with one less valence electron, Fe_3GaTe_2 exhibits higher TC than Fe_3GeTe_2 [4], despite smaller two nearest-neighbor exchange coefficients (J_1 and J_2), challenging the notion that larger J_1 and J_2 lead to higher TC. This study shows that higher-order magnetic exchange coefficients are crucial for higher TC of Fe_3GaTe_2, examined through the magneto-crystalline anisotropy energy (EMCA) and the exchange coefficients using first-principles calculations. Total EMCA of Fe_3GaTe_2 is 1.38 meV/f.u., smaller than that of Fe_3GeTe_2 (3.15 meV/f.u.). Higher order exchange coefficients (J_3 or higher) of Fe_3GaTe_2 are positive but those of Fe_3GeTe_2 are negative resulting in larger total sum of all exchange coefficients for Fe_3GaTe_2. Based on these J values, TC of Fe_3GaTe_2 and Fe_3GeTe_2 are computed using both mean-field theory [5] and Monte Carlo simulation [6].

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Neuromorphic behavior of Mn3Sn--based spin orbit torque device

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Non-collinear antiferromagnets (AFMs), especially D019 hexagonal Mn_3Sn, have attracted tremendous interest as next generation active material in spintronics for designing a high-density and ultrafast speed device, because they have no stray fields perturbing the neighboring cells and have much faster dynamics of the order of picosecond than the ferromagnetic counterparts (nanosecond). However, for Mn_3Sn films prepared by industrially accessible sputtering methods, the full spin-orbit-torque switching is still desired. In this study, we demonstrate the full SOT switching of the sputtered Mn_3Sn device. Our microscopic study successfully proved that controlling the Mn deficiency is key to achieve the switching behavior. Such full switching behavior is also promising to realize the wide dynamic range of the memristive performance of the Mn_3Sn-based device for development of the artificial synaptic device. In this regard, we utilized the observed SOT-switching behavior for developing an artificial synaptic device with excellent linearity, precision, and consistent cycle-to-cycle performance.

Structrual and Magnetic Depth Profiling of Magnetic Thin Films with the POLREF Reflectometer

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Polarised Neutron Reflectometry (PNR) measures surfaces, buried interfaces and layers, yielding information about layer thicknesses, densities, surface/interface roughness and interdiffusion. Uniquely it can provide the magnetic equivalents of these quantities, including the total in-plane magnetisation [1,2]. A large variety of thin-film phenomena can be investigated using the POLREF beamline, including topological insulators, proximity-induced and fundamental magnetism, superconductivity and spintronic devices. Furthermore, POLREF can perform off-specular PNR and specular Polarisation Analysis (PA) measurements. In principle, if the problem can be made flat and is in the right length scales (~1 nm – 200 nm) then it can be measured by PNR. The POLREF time of flight PNR beamline is located in the second target station at the ISIS Neutron and Muon source [3,4]. With a polarised wavelength band of 2-15Å (PEff~98%), low instrument backgrounds of I/I0 < 10-7 and a resolution of dQ/Q better than 1%, QMAX = 0.25-0.3 Å-1 is routinely accessible for small (10x10 mm) samples within reasonable count times. The POLREF beamline has gone through several recent upgrades. Upgrades of the spin flippers and analyser system have improved the capability of the beamline to measure samples with larger moments or weaker spin-flip signals when using the PNR and PA modes. The 1D linear detector efficiency has also been upgraded and now is fully commissioned into the user program providing full off-specular capability in the NR and PNR (see Figure 1) modes and some off-specular PA capability (the maximum Qx being restricted by the analysing mirror). Here, we will present the current capabilities of the POLREF beamline, including science highlights and how to get access to the ISIS neutron facility and POLREF beamline.

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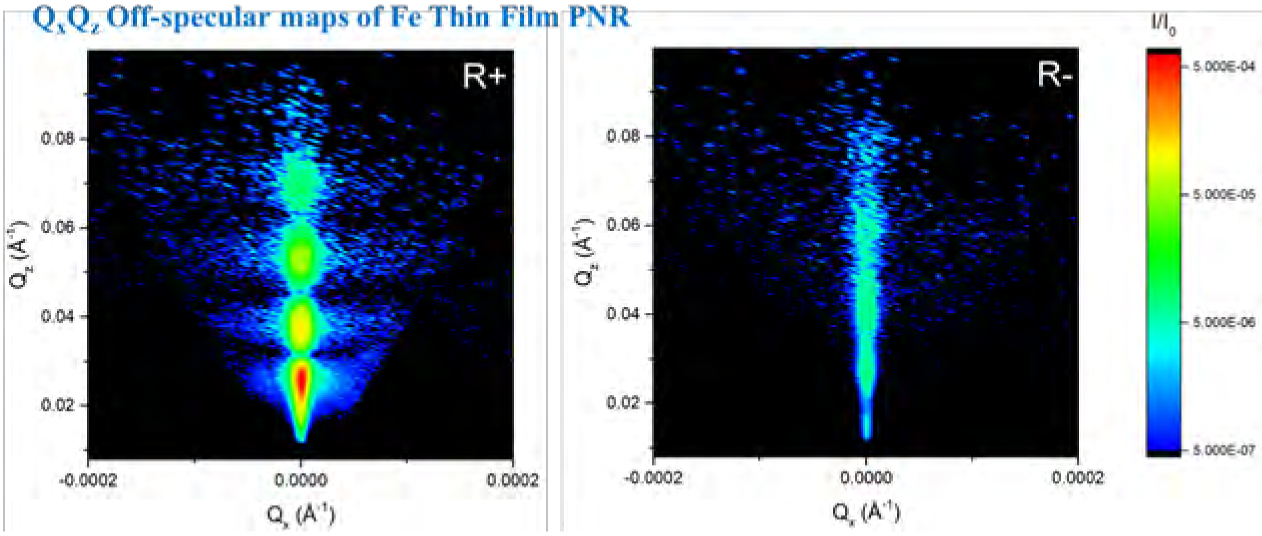

Observation of a hybrid skyrmion domain texture in a Ga+ irradiated SAF system

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Skyrmions are topologically protected magnetic textures of considerable interest due to their potential spintronic applications [1]. The present work looks at skyrmions and domain walls within a synthetic antiferromagnetic (SAF) multilayer. SAF multilayer systems are of interest in spintronics as they offer stray field tunability, leading to increased magnetic texture stability [2].

The present work reports on the observation of a hybrid magnetic texture consisting of skyrmion cylinders present within SAF domains in a CoFeB/CoB based SAF system (Figure 1a). This state was observed in samples that had been irradiated with arrays of point-like defects using the 10 nm FWHM probe of a Ga+ focused ion beam (FIB) microscope, with the purpose of investigating controlled skyrmion nucleation. It was found that magnetic structure could be generated in the SAF coupled field regime by applying an in-plane magnetic field. The hybrid state was observed at low fields under nitrogen-vacancy microscopy (NV microscopy) and Fresnel mode Lorentz transmission electron microscopy (L-TEM). Notably the texture was stable at 0 mT and in low applied out of plane field. Differential phase contrast (DPC) L-STEM was used to carry out a quantitative assessment of the magnetic configuration of the multilayer, shown in figure 1b. It has been shown that the large scale domains possess the SAF coupling but in the skyrmions the film is ferromagnetically coupled though the stack. This assessment is supported by image calculations of the same state. We do note that in its non-irradiated state, the sample has been fully characterised [3], appearing to be uniform in the SAF regime with no magnetic texture visible. Repeating the demagnetisation procedure on the non-irradiated sample maintained this uniform state, indicating that the hybrid state may be driven by the presence of artificial FIB defects.

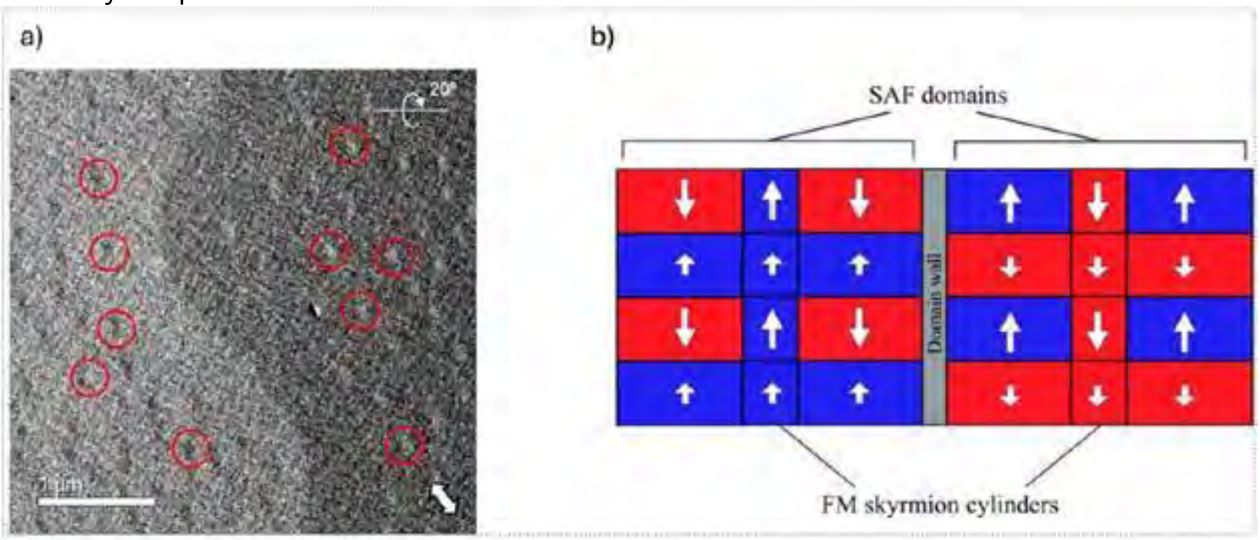

***Figure 1** a) DPC L-STEM image of a domain wall separating two SAF domains containing FM skyrmions (some of which are highlighted with red circles), b) diagram of the magnetic configuration of the multilayer.*

Machine Learning using Chiral Magnonic Neurons

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

We explore all-magnonic artificial neural networks using chiral magnonic resonators [1,2] as their building blocks – magnonic neurons [3]. In Ref. 3, we showed, using micromagnetic simulations and analytical modelling, that one-dimensional chiral magnonic resonators can concentrate energy of incident linear spin waves, leading to a strongly nonlinear response of the resonators' confined modes to the excitation. Here, we extend these conclusions to two-dimensional arrays of nanoscale chiral magnonic resonators, i.e. realizing artificial neural networks proposed in Ref. 1. For modest excitation levels, the effect is described in terms of a nonlinear shift of the resonant frequency ('detuning'), which results in amplitude-dependent scattering of monochromatic spin waves. We show how this behavior can be harnessed to realize a sigmoid-like activation and so to implement artificial neurons in a deep neural network linked by spin waves propagating in a linear medium. Figure 1 exemplifies a numerically simulated spin wave pattern that varies as a function of the excitation strength of a magnonic neuron formed by a Permalloy nanodisk placed above a YIG film (inset). Our numerical results are in good agreement with a phenomenological model in which the nonlinear detuning of the confined mode is quadratic in its amplitude, while the propagation in the medium is linear.

The research leading to these results has received funding from the UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee (Grant No. 10039217) as part of the Horizon Europe (HORIZON-CL4-2021-DIGITAL-EMERGING-01) under Grant Agreement No. 101070347. Yet, views and opinions expressed are those of the authors only and do not necessarily reflect those of the EU, and the EU cannot be held responsible for them.

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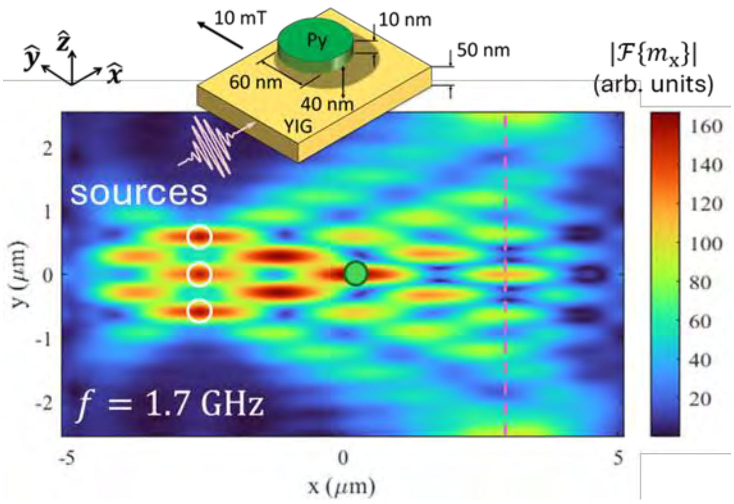

Antiferromagnetic exchange coupling across transition metal films alloyed with magnetic elements

Dominik Legut[1], Sergiu Arapan[1], Erol Girt[2]
[1]Vsb - Technical University Of Ostrava, Czech Republic, [2]Simon-Fraser University, Canada

Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Interlayer exchange coupling has been intensively studied for over thirty years and is incorporated in almost all spintronic devices. However in past, research was focused on the coupling between magnetic layers across a nonmagnetic spacer layer. Here we find that antiferromagnetic interlayer exchange coupling can be achieved across spacer layers containing over sixty atomic percent of magnetic materials. X-ray magnetic circular dichroism measurements reveal that the magnetic atoms in the spacer layer have a large magnetic moment. Magnetic atoms in the spacer layer can double the coupling strength, leading to the largest antiferromagnetic bilinear coupling observed in magnetic multilayers deposited with the industrial technique of choice, magnetron sputtering. Electronic structure calculations predict a dependence of interlayer exchange coupling on both the magnetic material concentration and the spacer layer thickness. The DFT calculations also offer insight into the role of magnetic atom interactions within the spacer layer in influencing interlayer exchange coupling, the role of the interface as well as the role of various magnetic transitional metals in spacer[1-2].

Figure captions:

Fig 1. The experimentally determined dependence of (a) J1 of Co(2)|Ru100−xCox(d)|Co(2) on the spacer layer thickness. A broad, gray line with 1/d2 dependence is added to (a) for comparison. J1 values for Co(2)|Ru100−xCox(d)|Co(2), where x = 37 and 44, and d ≤0.5nm are from Nunn et al. [3] Both solid and dotted lines that connect the experimental data in the figure are drawn to guide the eye. Measurements are performed at 298 K.

Fig. 2: J1 as a function of spacer layer thickness, d of (a) Co|Ru(d)|Co, (b) Co|Ru100−xCox(d)|Co, and (c) Co|Ru100−xFex(d)|Co. Two broad red and blue lines with 1/d2 dependence are added to (b) for comparison. Structures used in calculations are provided to the right of the plot for d = 0.4nm

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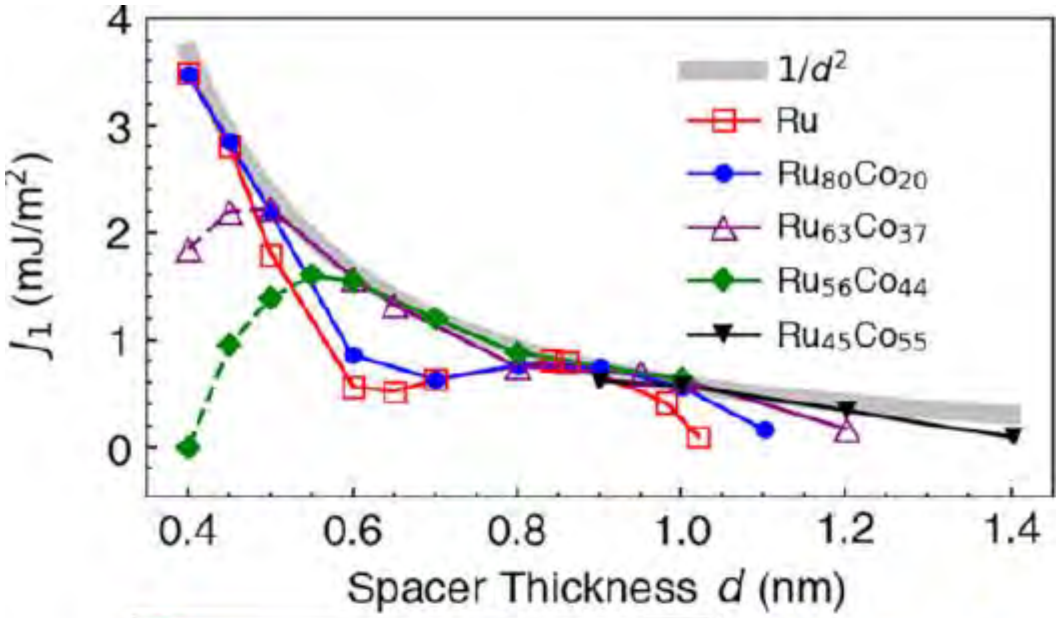
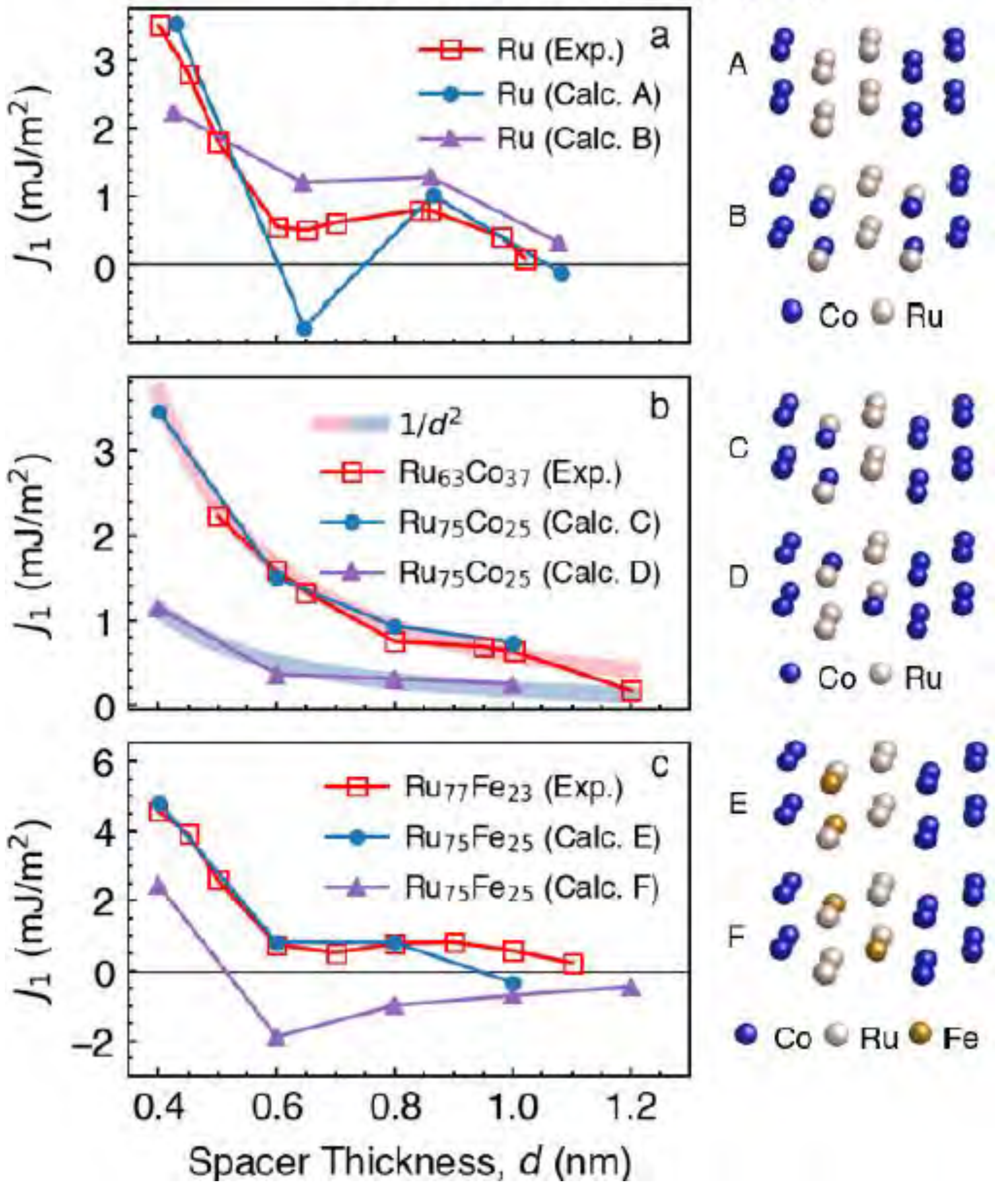


1/d^2
Ru
$Ru_{80}Co_{20}$
$Ru_{63}Co_{37}$
$Ru_{56}Co_{44}$
$Ru_{45}Co_{55}$
J_1 (mJ/m^2)
Spacer Thickness d (nm)



a
Ru (Exp.)
Ru (Calc. A)
Ru (Calc. B)
A
B
Co Ru
b
1/d^2
$Ru_{63}Co_{37}$ (Exp.)
$Ru_{75}Co_{25}$ (Calc. C)
$Ru_{75}Co_{25}$ (Calc. D)
C
D
Co Ru
c
$Ru_{77}Fe_{23}$ (Exp.)
$Ru_{75}Fe_{25}$ (Calc. E)
$Ru_{75}Fe_{25}$ (Calc. F)
E
F
Co Ru Fe
J_1 (mJ/m^2)
Spacer Thickness, d (nm)

Interfacial spin canting in a ferromagnetic metal-semiconductor bilayer

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Ferromagnetic semiconductors and insulators have gained interest due to their potential to increase the efficiency of spintronic devices. This improvement arises from the fact that in insulators, such as europium sulphide EuS, spin currents and spin orbit torques do not involve dissipative charge currents, and thus avoid unnecessary losses due to Joule heating, as in ohmic resistive materials. Furthermore, crucial to developing more power-efficient devices for practical applications is understanding the structural and magnetic coupling e.g., between ferromagnetic insulator/ferromagnetic metal bilayers, as key spintronic phenomena are typically localised at the thin-film interface between materials [1,2].

Inspired by interesting features found in the magnetoresistance of EuS|Py bi-layers indicating non-collinear interfacial magnetic coupling [2,3], here we present results from Polarised Neutron Reflectometry with Polarisation Analysis (PNR-PA), taken at the POLREF beamline of the ISIS Neutron and Muon Source in the UK to investigate the in-plane canting at the EuS|Py interface as a function of depth [4]. We found a significant neutron spin-flip signal, indicating sizable spin canting in the bilayer system. From model fits to determine the depth-dependent magnetisation profile, we find that this spin canting is strongest at the EuS|Py interface and decays further away from the Py, aligning back to the guide field direction (i.e., the applied field direction). At low temperatures, this canting persists for applied magnetic fields up to 75 mT, and disappears above the EuS ferromagnetic transition temperature TC=16 K. The strong spin canting localised at the interface between ferromagnetic metals and insulators could therefore be interesting for spintronic applications, such as spin-transfer torque switching.

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Magnetic ordering in Mn2GaC-based nanolaminated MAX and i-MAX phases

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

MAX phases are intrinsically nanolaminated compounds, composed of a transition metal (M), an A-group element (A) and either carbon or nitrogen (X). The elements arrange in distinct atomic layers in the sequence M–A–M–X–M–A–M–X, with alternating metallic-like M–A bonds and covalent M–X bonds, resulting in a highly anisotropic structure with features of both metals and ceramics. i-MAX phases are quaternary alloys with an additional in-plane honeycomb ordering of two elements within the M layers. The interest in low-dimensional magnetism has prompted the search for new MAX and i-MAX phases with magnetic ordering. The nanolaminated structure gives rise to competing interactions within the M layers and across the A layers, resulting in complex magnetic ordering. An example of this is the MAX phase Mn2GaC which has non-collinear ferromagnetic ordering below 220 K, above which it undergoes a magnetic and structural phase transition to a non-collinear antiferromagnetic phase. Until now, no MAX phase has exhibited ferromagnetism with a significant remanent moment at room temperature, limiting their use in practical magnetic applications.

Here we explore the partial substitution of Mn by either Cr or Sc on the M site of Mn2GaC in order to control the magnetic ordering. These substitutions are guided by spin-dependent density functional theory calculations which predict phase stability and magnetic ordering. The MAX phases are grown as thin films by co-sputtering from elemental sources, which allows us to tune the stoichiometry with great flexibility. We find that substituting Mn by small amounts of Cr stabilizes ferromagnetic ordering at room temperature. The MAX phase (Mn1-xCrx)2GaC, with x in the range 0.06–0.29, is strongly ferromagnetic with an ordering temperature of up to 489 K [1]. The strongest magnetization of 1.25μB per M-atom at 3 K and 0.9μB at 300 K is achieved with x = 0.12, which coincides with a minimum in the unit cell volume. We examine the nature of the magnetic ordering using neutron diffraction measurements on high-quality epitaxial films. We furthermore synthesize the i-MAX phase (Mn2/3Sc1/3)2GaC as an epitaxial thin film [2]. Magnetometry measurements indicate that the i-MAX phase is antiferromagnetic with the moments perpendicular to the M planes. We discuss other possibilities for enhancing the magnetization of this material system by alloying for example with Fe or by strain engineering. The results reveal how the delicate balance between ferro- and antiferromagnetism can be tuned in MAX phases, with potential applications ranging from bulk magnets to antiferromagnetic spintronics.

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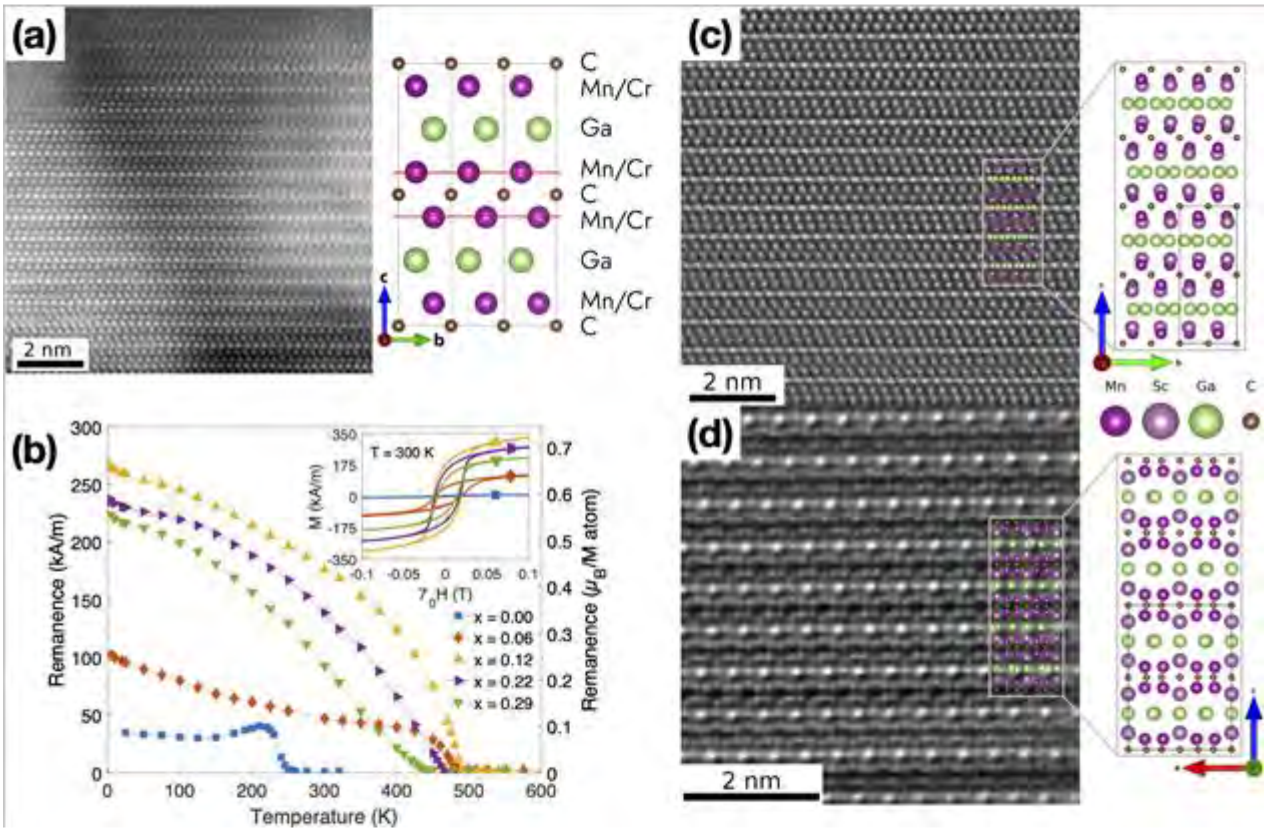
(a)
2 nm
C
Mn/Cr
Ga
Mn/Cr
C
Mn/Cr
Ga
Mn/Cr
C
c
b
(b)
Remanence (kA/m)
Remanence (μ_B/M atom)
Temperature (K)
T = 300 K
M (kA/m)
x = 0.00
x = 0.06
x = 0.12
x = 0.22
x = 0.29
(c)
2 nm
Mn
Sc
Ga
C
(d)
2 nm

Enhancing spin signals in pure spin currents

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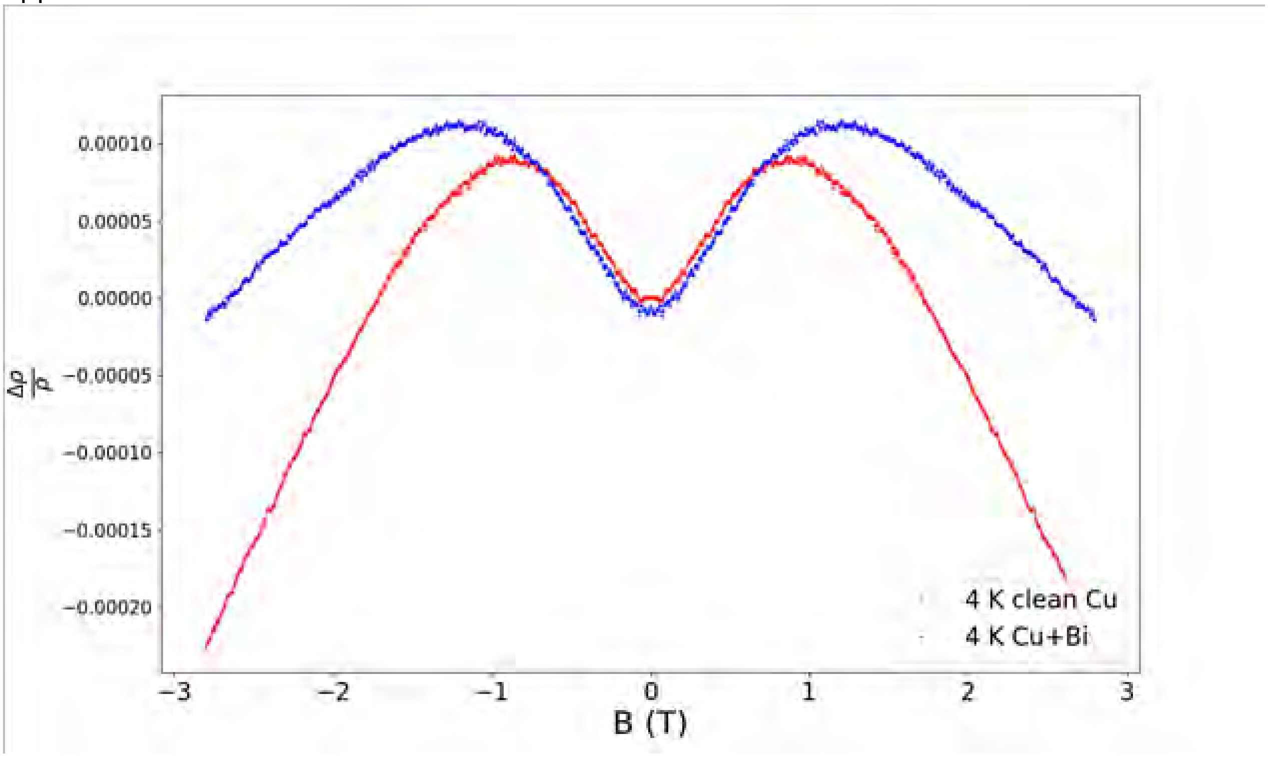
Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

The aim of this research project is the study of lateral spin valves (LSVs) and how they are affected when their non-magnetic channel is doped with impurities of materials with high spin orbit coupling (SOC) such as Bi. It is not only expected to study the effect of impurities in the non-magnetic channel (NM) but also to study the impact of the position they occupy within the NM channel. It has been shown previously that spin signal increases when Fe impurities are located in the Ag channel of a LSV as well as the spin signal is affected by the place they occupy. This unexpected upturn of spin signal may be due to an extra scattering event of unknow nature, which is going to be studied within this project. The applications of this project leads to low energy data manipulation and more efficient information transfer due to the fact that no Joule heat is generated in the transport process as there is a net flow of spin flow in opposite directions.



Electric-field control of magnetism using hafnia-based ferroelectrics

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Electric-field control of magnetism has been extensively studied as a means to develop energy-efficient electronics based on magnetic materials. Perovskite ferroelectrics have been used to achieve large electric-field effects, but they come with drawbacks such as low breakdown voltage, high leakage current, and poor compatibility with semiconductors. In this study, we have characterized the microcrystalline and ferroelectric properties of $Co_{0.4}Fe_{0.4}B_{0.2}/Hf_{0.67}Zr_{0.33}O_2$ bi-layers prepared by sputtering and rapid thermal annealing, which exhibit an orthorhombic phase with large spontaneous polarization. The crystalline texture of $Hf_{0.67}Zr_{0.33}O_2$ was investigated using high-resolution transmission electron microscopy and grazing-incidence X-ray diffraction, revealing that the crystalline structure of $Hf_{0.67}Zr_{0.33}O_2$ is significantly influenced by the annealing temperature. We also investigated the spontaneous polarization of $Co_{0.4}Fe_{0.4}B_{0.2}/Hf_{0.67}Zr_{0.33}O_2$ structures by measuring polarization versus electric field loops. The spontaneous polarization of these ferroelectrics controls both the direction and magnitude of the electric field applied to the ferromagnet, resulting in a non-volatile change in the magnetic anisotropy energy of the ferromagnet by up to 13 μJ/m². The effect of the spontaneous polarization of $Hf_{0.67}Zr_{0.33}O_2$ on the magnetization of $Co_{0.4}Fe_{0.4}B_{0.2}$ was observed by measuring the anomalous Hall effect. The electric fields induced by the spontaneous polarization of $Hf_{0.67}Zr_{0.33}O_2$ influence not only the strength of perpendicular magnetic anisotropy but also the magnitude of the anomalous Hall resistance. This non-volatile change in magnetic anisotropy is observed over a wide temperature range and is attributed to the modification of spin-orbit interaction at the ferroelectric/ferromagnet interface. Our experimental results demonstrate that very thin hafnia-based ferroelectrics, compatible with conventional semiconductor processes, enable the control of the magnetic anisotropy of ferromagnets. This opens the possibility of designing crossover memory that combines ferroelectricity and ferromagnetism to reduce the writing energy of magnetoresistive random-access memory.

Materials Informatics for Magnetic Thin Film Discovery

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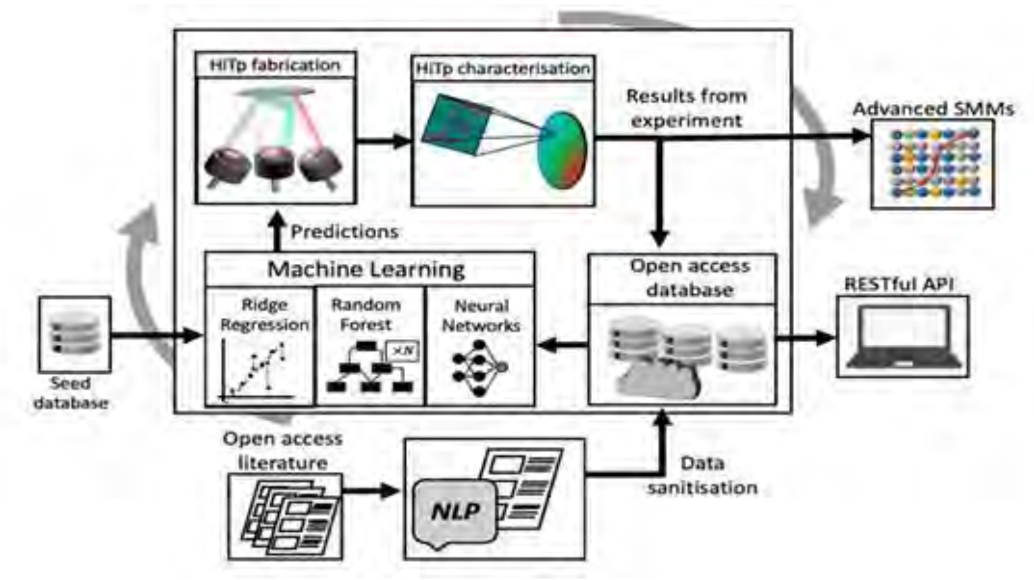
Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Functional magnetic thin films and multilayers are used in a wide range of applications including data storage, neuromorphic computing and high frequency devices. As technology gets smaller and smaller the need for new high performance magnetic thin films and multilayers becomes more urgent. Further the climate emergency has established the need for sustainability within existing and new technologies, which is driving a demand for material innovation. New materials need to be economically sourced from abundant elements, whilst still obtaining the functional characteristics of the existing leading materials. The need for innovation is clear: by improving the material properties of FMMs thin films, technology can fully capitalise on the aforementioned engineering advances in green innovations, thus saving money and benefiting the environment. Traditional material discovery methods, where existing material compositions are tweaked and optimised, are too slow and costly, and not practical or sufficient to address the current material challenges. Material informatics will overcome these existing problems, by using data-driven solutions to reduce the use of natural resources and expensive experiments.

Our research has focused on using Natural Language Processing (NPL) to extract data from open access papers to create a FMM database. This has been achieved by combining the linear approach NPL, which searches for defined compositions and parameters within papers, with semantic networks, to allow the compositions related parameters to be correctly linked together. In doing this we are able to data mine papers, which contain more than one composition and magnetic parameter for the database. While recent work has investigated large language models to extract different forms of data. Having created a large database, machine learning (ML) algorithms are trained on it, which are then used to observe trends within the data, along with predicting compositions with specific magnetic parameters. A range of different models have been investigated, with varying success. These predicted compositions are then fabricated and characterised using high throughput techniques, including combinatorial sputtering, XRD, FMR and MOKE magnetometry. These high-throughput experiments, allow us to investigate over 50 different magnetic films or multilayers providing insight into new materials and behaviours, along with verifying the results from the ML, quickly and cheaply.



Phase and Orientation Mapping of Topological Thin Film Heterostructure using 4D-STEM

Ben Muggleton[1], Craig Knox[1], Ahmet Yagmur[1], Satoshi Sasaki[1], Zabeada Aslam[1], Stuart Micklethwaite[1], Tim Moorsom[1]
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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

This research investigates Bi2Se3 Topological Insulator heterostructures using the Tescan Tensor 4-Dimensional Scanning Transmission Electron Microscopy (4D-STEM) tool.

Trivial insulators experience a bulk energy band gap inhibiting the transfer of carriers from their conduction bad to the valence band. Topological insulators, however, are materials that experience a bulk energy band gap with gapless conducting surface states. The conducting surface states experience strong spin orbit coupling resulting in spin momentum locking [1]. This unique feature of topological materials has promising applications in areas such as spintronics and quantum computing.

Being able to investigate what occurs at the interface between the topological insulators, such as Bi2Se3, and other materials, such as semiconductors and trivial insulators, will help to realise these new technologies, by highlighting the effects of strain, doping and disorder on topological surface states. [2] In particular, heterostructures of Bi2Se3 and the trivial insulator Bi2InXSe3-X are of growing interest because, while they are structurally similar, they vary greatly in topological behaviour. Within these films, the orientation of the planes, phase boundaries and strain could all potentially affect the surface state properties.

We used a Tescan AmberX Plasma Focused Ion Beam Scanning Electron Microscopy (FIBSEM) to produce electron transparent lamellas of Bi2Se3 heterostructures with both Bi2InxSe3-x and Al2O3 interfaces. Then, using 4D-STEM, we generated diffraction patterns, for nanoscale areas of a sample. 4D STEM uses a focused STEM probe, but records diffraction data as well as contrast data; such that each pixel of a STEM image also contains structural information. This powerful technique allows phase and orientation to be mapped at nm resolution [3].Python data analysis techniques were used to map the crystalline structure, identify crystal phase boundaries in the lamellas, and determine their orientation.

We show how the interface between Bi2Se3 and Bi2InXSe3-X is near indistinguishable because of the incredibly similar lattice parameters Figure.1. However, the 4D STEM technique is able to pick up small variations, which can be matched to correlated EDX data to study the layer boundaries. The same phase and orientation mapping can be applied to topological/trivial insulator boundaries, such as Bi2Se3 / Al2O3, where the interface is well defined, in order to extract information and strain and disorder.

Phase and orientation mapping shows how the surface states of our topological material are affected by different buffer layers and substrates. Using this technique in parallel with other characterisation techniques we can produce a better understanding of how the surface states of topological insulators are affected by structure in thin film applications.

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Tailoring magnetic properties of Pt/Co/Pt via in-situ Ar+ ion irradiation

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[1]*Charles University, Czech Republic*

Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Precise control of magnetic properties is crucial for spintronic applications, ranging from Magnetic Tunnel Junctions (MTJs) to domain-based systems. Due to their large variability in magnetic anisotropy controlled via Co layer thickness and relatively easy growth, Pt/Co multilayers serve as a useful testing system to investigate the influence of deposition conditions and post-deposition treatment on the resulting physical properties of the multilayer stack, including surface roughness between individual layers and interlayer mixing. Post-deposition ion irradiation has proven to be a useful tool to variate the magnetic anisotropy and coercivity of cobalt-based multilayers by ion dosage [1]. So far, ion bombardment by Ga+ and He+ ions has been shown to be able to change the magnetic properties drastically. These methods are, however, ex-situ, done after the full growth, and influence the multilayer stack as a whole. Here, we present a novel approach to in-situ modify the physical properties of Pt/Co multilayers using Ar+ ions. As an advantage, this approach allows the modification of any selected interface in the multilayer, which is important in contemporary applications, such as MTJs for Magnetic Random Access Memories consisting of dozens of layers [2].

Two sets of samples, Co(x)/Pt(3nm) and Pt(5nm)/Co(x)/Pt(3nm) with Co thicknesses of 2 and 4 nm, respectively, were prepared by DC magnetron sputtering. The 4nm thick Co layer was in-situ irradiated by Ar+ ions right after the deposition and prior to the top Pt layer deposition for a certain time to etch it down to 2 nm thickness. This allowed us to compare the same multilayer stacks, one with and one without Ar+ ions irradiation, to investigate the changes at Pt/Co interfaces. A proper etching time and Co etching rate were estimated from a set of calibration samples irradiated for various times between 0 and 6 minutes.

Magneto-optical Kerr effect (MOKE) spectra for pairs of two nominally equal Co layers show differences that cannot be explained just by simple variation in the Co layer thickness (see Fig. 1). We employ theoretical MOKE simulations to discuss the possible interface effects leading to the observed changes in the spectral MOKE as well as magnetic hysteresis measurements demonstrating the implications for practical applications of such in situ modifications.

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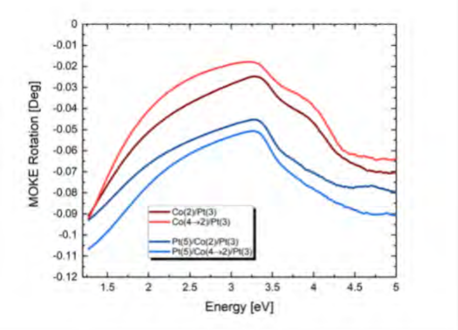

Quantum thermal expectation values of spin systems from classical atomistic spin dynamics simulations

Thomas Nussle[1], Stam Nicolis[2], Iason Sofos[1], Joseph Barker[1]
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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

In the past years, the emergence of artificial intelligence and related numerical methods which drastically augment the already pressing need on ever increasing growth rates of computational power and data storage capacity, electronic components are set to become smaller and smaller, more and more densely packed and operate at lower and lower temperatures, in the case of some candidates of qubits relying on superconducting Josephson junctions for example [1]. Moreover, these devices are also required to operate at faster and faster timescales [2]. With this trend also comes a higher and higher sensitivity to quantum fluctuations, which can no longer be assumed to be drowned in a thermal bath or averaged out over space and time [3]. In the case of spin systems, it is known that at low temperatures, purely classical models are unable to reproduce experimental results such as Bloch's law for magnetisation as a function of temperature. Approaches where quantum statistics are superimposed on classical simulations in order to recover the proper thermal behaviour have emerged and provided very useful insights into fundamental aspects of these systems [4]. We wish to go beyond this, however, and build a method which, starting from a fully quantum spin system cast into a spin coherent state basis, derives an effective Hamiltonian to use in a classical atomistic spin dynamics simulation, from which quantum expectation values can be computed directly, without making any further assumption on which thermal objects are being populated by increasing temperature.

In previous work, we have built an approach to evaluate thermal expectation values of quantum spin systems from effective classical atomistic spin dynamics simulations, which we have applied to simple single spin examples where a quantum spin is coupled to an external magnetic field through a Zeeman Hamiltonian [5] and a second example with a quadratic Hamiltonian including a uniaxial anisotropy term [6]. In the present work we extend this model to go beyond the single spin case and include exchange interaction for the simplest non-trivial case, two spins interacting through isotropic Heisenberg exchange. What is of particular interest is that if the external magnetic field direction is constant, then one can obtain accurate thermal expectation values for the initial quantum system from a classical effective model over the whole temperature range. Even more remarkable is that this also holds in the case of antiferromagnetic exchange, which is famously tricky even in most successful quantum/classical correspondence methods such as quantum Monte-Carlo with the so-called sign-problem [7].

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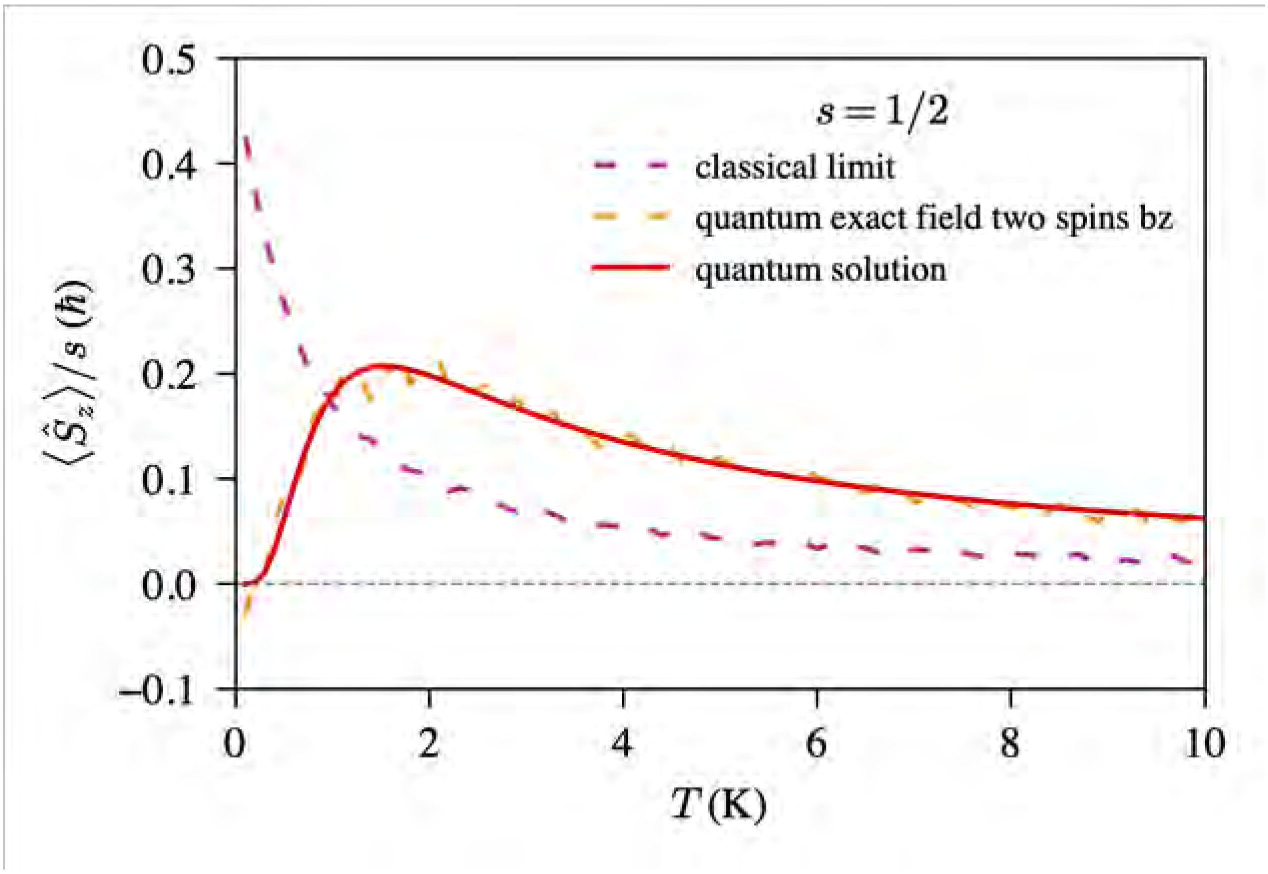

0.5
0.4
0.3
0.2
0.1
0.0
−0.1
0
2
4
6
8
10
$\langle \hat{S}_z \rangle / s\ (\hbar)$
$T\,(\mathrm{K})$
$s = 1/2$
classical limit
quantum exact field two spins bz
quantum solution

Optimisation of magnetic multilayers for surface acoustic wave-driven skyrmion motion

__John Christopher Osborne__[1], Benjamin Brereton[1], Soumyarup Hait[1], Muhammad Khaliq[2], Miguel Niño[3], Michael Foerster[3], Christopher Marrows[1], John Cunningham[1], Thomas Moore[1]
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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Skyrmions, topological magnetic structures, are investigated as candidates for magnetic data storage and computing technologies. Skyrmion motion can be driven by spin–orbit torque [1]. However, using a current can be energy inefficient due to Joule heating effects, and risks annihilation of skyrmions via the skyrmion Hall effect. An alternative approach for controlling skyrmion motion is surface acoustic wave (SAW) devices, which are voltage driven, using strain to vary thin film magnetic properties. Simulations by Jintao Shuai et al. have shown that standing and travelling SAWs generated in lithium niobate ($LiNbO_3$) via interdigitated transducers (IDTs) have the potential to control skyrmion motion [2].

$LiNbO_3$/Ta (5 nm)/[Pt (0.8 nm)/CoB (0.5 - 0.7 nm)/Ru (0.5 nm)] × 6 have been fabricated with the aim of achieving control over multi-skyrmion systems. Stroboscopic x-ray magnetic circular dichroism and photoemission electron microscopy (XMCD-PEEM) techniques have been used to characterise wave amplitude and magnetic structures in these initial devices [3]. A skyrmion phase was shown to be successfully induced via applying a magnetic field from a maze-like remanence state (Fig .1, a, b). Surface acoustic waves were directly imaged in the $LiNbO_3$ substrate (Fig .2, a, b) from which the amplitude of the SAWs can be measured (Fig .2, c). Variations in standing or travelling waves, wave power, and absolute and relative phase, were applied to induce SAW-skyrmion interactions. Work to understand these interactions is ongoing.

Mansell et al. has shown a weakly pinned skyrmion liquid can be formed in Ta/Pt/CoFeB/Ru/Pt multilayers [4]. This shows promise for future work with the implementation of a similar thin film, resulting in SAW driven skyrmion motion.

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Figure 1: XMCD-PEEM images of a $LiNbO_3$/Ta(5 nm)/[Pt(0.8 nm)/CoB(0.6 nm)/Ru(0.5 nm)] x 6 magnetic thin film in states, a. Remanence field with maze-like domain wall pattern, b. At 6.11 mT where skyrmion like magnetic structures appear.

Figure 2: a. and b. Stroboscopic PEEM images of surface acoustic waves in a $LiNbO_3$ substrate, during a bias voltage sweep. The yellow boxes indicate an area selected to measure the intensity of, dark and bright fringe respectively. , c. Plot of selected dark and bright fringe data from a. and b. The difference between two points at the same wave position, 4.11 ± 0.01 V, represents the amplitude of the SAW.

Fig 1.

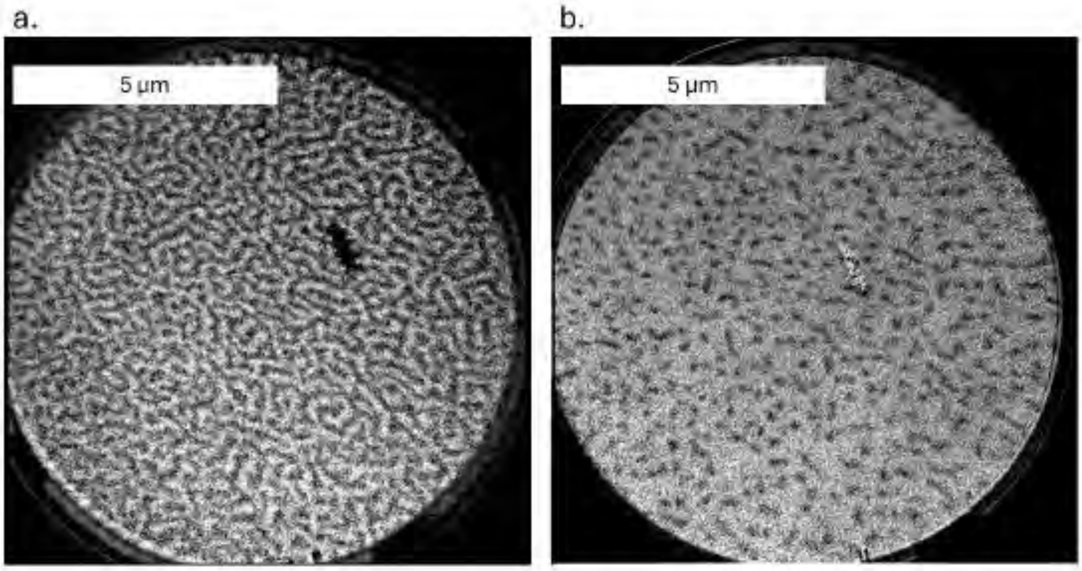
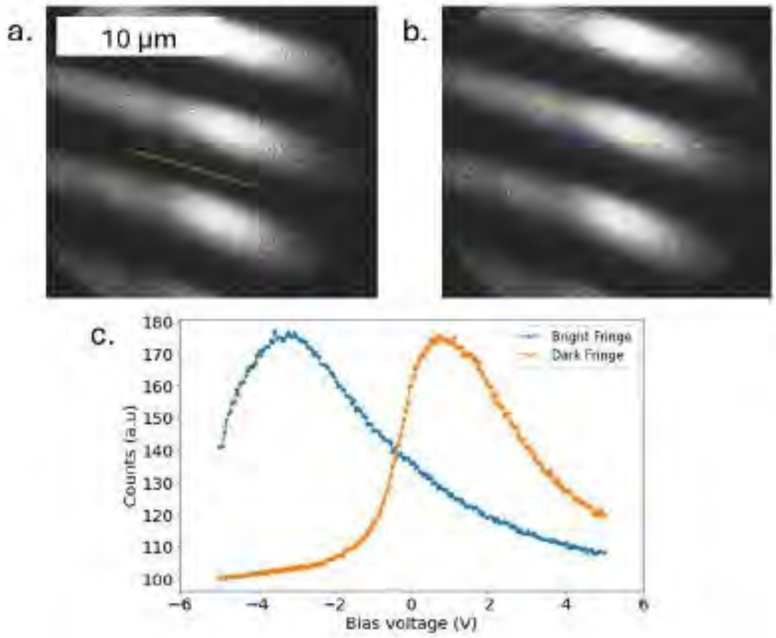

a.
b.
5 µm
5 µm

Fig 2.


a.
b.
c.
10 µm
Bright Fringe
Dark Fringe
Counts (a.u)
Bias voltage (V)

Observation of frustration and anomalous Nernst effect in metallo-molecular Kondo spin lattices

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Ultra-high vacuum scanning tunnelling spectroscopy experiments on metallo-molecular interfaces displaying both single ion Kondo effect and inter-spin site RKKY coupling have suggested emergence of 2D Kondo spin lattices(1–3). Here, we will report beyond ultra-high vacuum environment emergence of a 2D Kondo spin lattice at Pt(111)/Phthalocyanine and Pt/Co(111)/Phthalocyanine interfaces. We will show magnetometry evidence for a metastable frustrated antiferromagnetic state using ZFC/FC magnetisation measurements, with spin freezing temperatures ranging from 240 K to 300 K. Furthermore, we will show an evidence of a colossal anomalous Nernst effect in the vicinity of spin-freezing transition on Pt/Co/Phthalocyanine interfaces close to room temperature, as previously measured in chiral spin liquids(4) and strange metals(5), which are expected to arise in frustrated Kondo-spin lattices in localised limit(6).

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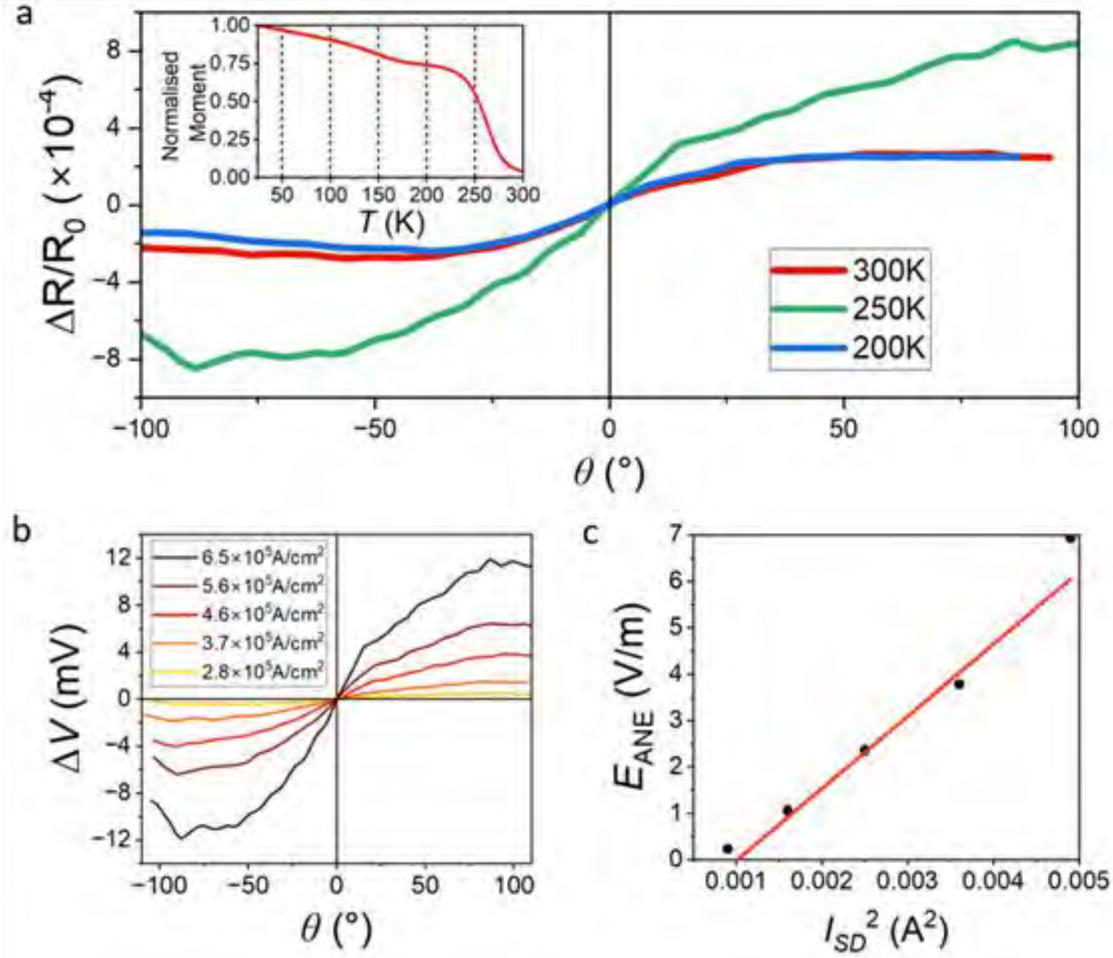

a
ΔR/R0 (×10^-4)
θ (°)
Normalised Moment
T (K)
300K
250K
200K
b
ΔV (mV)
θ (°)
6.5×10^5A/cm^2
5.6×10^5A/cm^2
4.6×10^5A/cm^2
3.7×10^5A/cm^2
2.8×10^5A/cm^2
c
E_ANE (V/m)
I_SD^2 (A^2)

Strange metal states and optical tuning in Bi2Se3 with molecular diodes

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[1]*University Of Leeds, United Kingdom*

Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Topological insulators (TIs) have garnered widespread attention due to their linear dispersion, spin-momentum locking and large Spin-Orbit Coupling (SOC). Recent interest surrounding the control of TI surface states to e.g., form Majorana bound states, is underpinned by the search for an interface material that can tune the TI electron Fermi level and spin transport whilst maintaining robust surface states.

The choice of interface material is predicated by the need to form a pure spintronic device, requiring a material that is both non-magnetic and non-conducting. These are fulfilled at an interface with the fullerene C60 (n-type molecule) or a metal-phthalocyanine (p-type) bilayers, for which the properties of the metallic surface state are influenced via charge transfer, orbital hybridization and the built-in potential at the molecular interface. Both fullerenes and metal-phthalocyanines are well-understood options used in organic solar cells. The resulting rectifying diode can be used both to tune the Fermi level and spin transport in the TI, but is also expected to be capable of converting high frequency ac to dc, and to eventually achieve photovoltaic control of the TI Dirac surface state.

DFT modelling predicts the possible emergence of flat bands and strange metal behaviour at the Bi2Se3 surface. Transport measurements of these structures show that the carrier density can be systematically increased (p-n molecular diode on top of TI) or decreased (n-p diode), while equally doubling the carrier mobility in either case. In addition, there is an enhanced effective SOC, with extremely short spin-orbit scattering times as small as 0.01 ps in Bi2Se3 interfaced with a molecular n-p diode. Raman spectroscopy offers evidence for the control of the vibrational modes and the SOC using optical irradiation.

Visualization of skyrmion-superconducting vortex pairs in a chiral magnet-superconductor heterostructure

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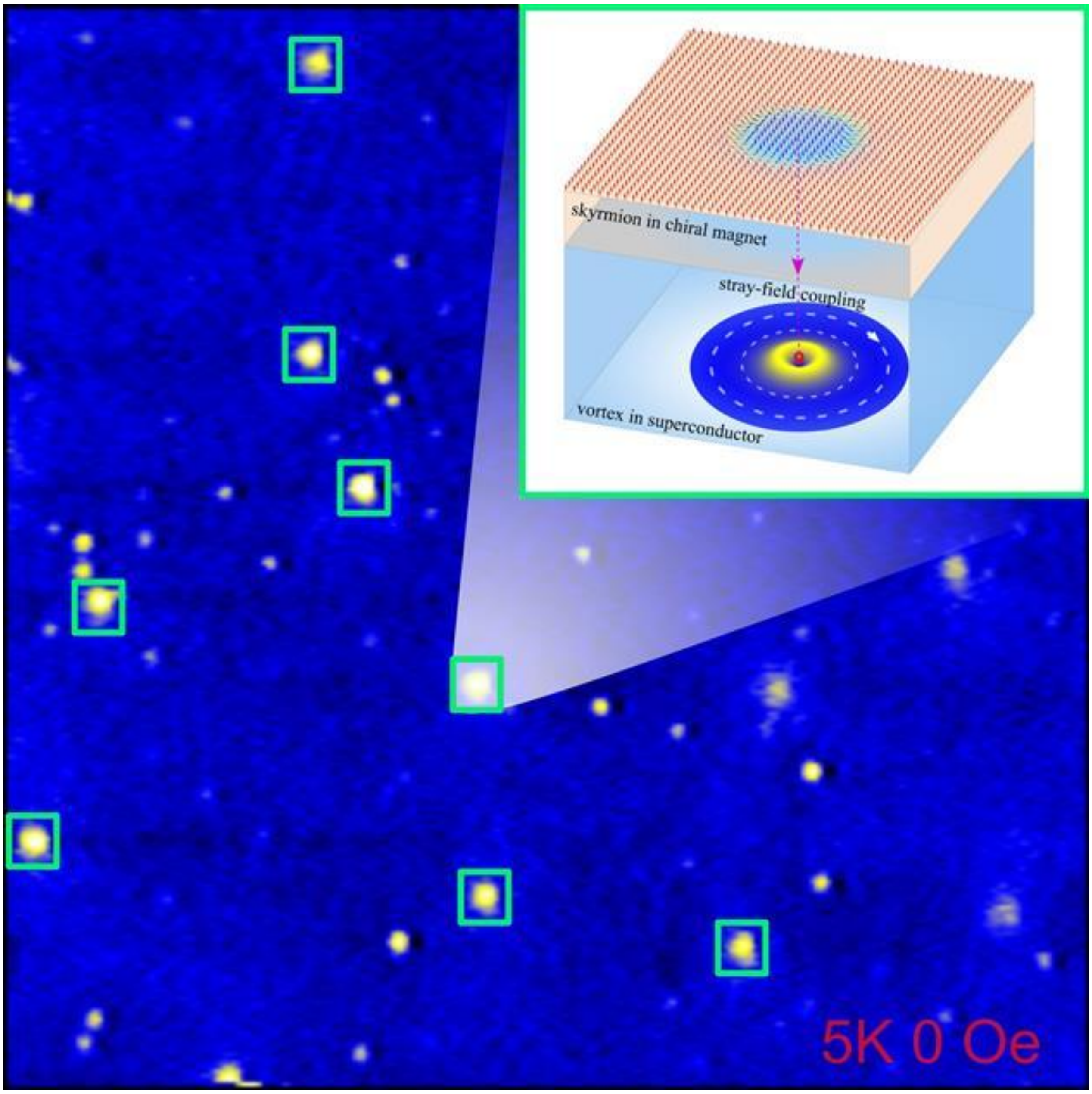
Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Magnetic skyrmions, the topological states possessing chiral magnetic structure with non-trivial topology, have been widely investigated as a promising candidate for spintronic devices. They can also couple with superconducting vortices to form skyrmion-vortex pairs, hosting Majorana zero mode which is a potential candidate for topological quantum computing. A lot of theoretical proposals have been put forward on constructing skyrmion-vortex pairs in heterostructures of chiral magnet and superconductor. Nevertheless, how to generate skyrmion-vortex pairs in a controllable way experimentally remains a significant challenge. We have designed a heterostructure of chiral magnet and superconductor [Ta/Ir/CoFeB/MgO]7/Nb in which zero field Néel-type skyrmions can be stabilized and the superconducting vortices can couple with the skyrmions when Nb is in the superconducting state. We have directly observed the formation of skyrmion-superconducting vortex pairs which is dependent on the direction of the applied magnetic field. Our results provide an effective method to manipulate the quantum states of skyrmions with the help of superconducting vortices, which can be used to explore new routines to control the skyrmions for spintronics devices.


skyrmion in chiral magnet
stray-field coupling
vortex in superconductor
5K 0 Oe

High Resolution Tabletop NV Magnetometry

Jan Rhensius[1], Simon Josephy[1], Björn Josteinsson[1], Andrea Morales[1], Gabriel Hellmann[1]
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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

A large variety of tools, capable of measuring different aspects of magnetic thin films exist. Some are based on photonic interactions, such as X-ray magnetic circular dichroism (XMCD) or Magnetic Optical Kerr Effect (MOKE). Others employ force interaction (MFM) or quantum effects (NV, SQUID). These techniques are subject to certain limitations and are ideally used to make use of their respective strengths. A combination of several techniques can facilitate a more complete understanding of the underlying magnetic properties.

Our turnkey solution for scanning NV magnetometer (QSM) also features MOKE and Magnetic Force Microscopy capabilities. This integrated system empowers users to effortlessly undertake intricate measurement tasks, eliminating the need to independently develop an entire microscope system. The QSM allows for high-resolution (~20nm) quantitative mapping of magnetic fields with uT sensitivity, all achieved at an unprecedented speed [1]. Demonstrating versatility, the QSM has proven applications in imaging intricate magnetic textures like spin cycloids, skyrmions, domain walls in ferro- and antiferromagnets, and its capabilities extend to investigating memory devices and mapping electron currents as well as multiferroics [2].

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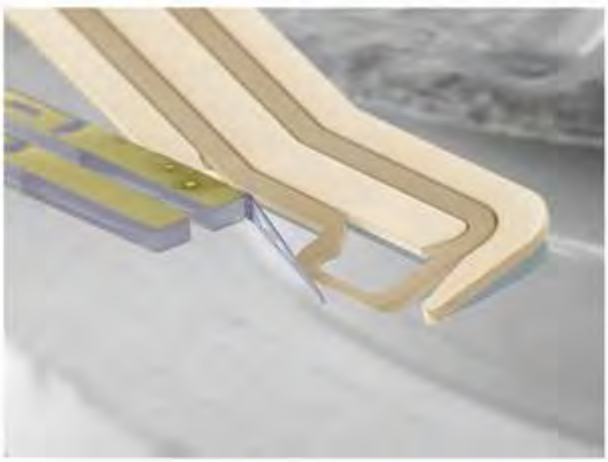
Fig. 1: Tabletop NV magnetometer (QSM) from QZabre Ltd.
Fig. 2: Integrated NV scanning probe featuring a MW line and a tuning fork based force feedback sensor



Quantum resonance effect in ultrathin Pt films

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[1]*Korea University, South Korea*

Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Ultrathin Pt films have been extensively studied in the field of spintronics due to their larger spin-orbit coupling, significant spin Hall effect, and low resistivity. Classical scattering-based electrical transport theories [1-3] provide good explanations for thin films whose thickness is larger than the scattering length. However, these theories fail to describe the resistance of ultrathin Pt films with thicknesses below 10 nm.

In this study, Pt (5) and Pt(5)/amorphous CoFeB(3)/MgO(5)/Ta(2) in nm films were deposited on SiO_2 substrates. To investigate the impact of surface roughness on ultra-thin film transport, Pt films were sputtered at various working pressure. Electrical resistivity and surface roughness were measured with 4 probes and atomic force microscopy (AFM), respectively. Additionally, transmission electron microscopy (TEM) was employed to examine the growth morphology of Pt deposited at 3 mTorr and 20 mTorr for Pt/CoFeB/MgO/Ta films.

Bare Pt layers in higher Ar pressure showed very rough surfaces, such that the films are not very well connected. The very high resistance of the films reflects this. The roughness of bare Pt and Pt/amorphous CoFeB films in Fig. 1 shows that the island-like grown Pt films in high Ar pressure are smoothed with an additional amorphous layer. Resistivity was reduced with the addition of a CoFeB layer also. Discontinuous and Island-like grown bare Pt films are covered up with continuous amorphous CoFeB, so that the continuity is recovered.
Conductance analysis based on quantum resonance effects for Pt/CoFeB with varying surface roughness showed good agreement with the theoretical prediction that conductance is proportional to the inverse square of roughness [4].

Captions
Fig. 1. The roughness of Pt(5) (solid square) and Pt(5)/CoFeB(3)/MgO(5)/Ta(2) (Solid triangle) films is shown for several pressure of Ar. Dotted lines represent interpolations of the data points.
Fig. 2. A log-log plot of conductance versus roughness for Pt/CoFeB/MgO/Ta films is presented. The black arrow indicates the slope corresponding to an inverse square relation ship.

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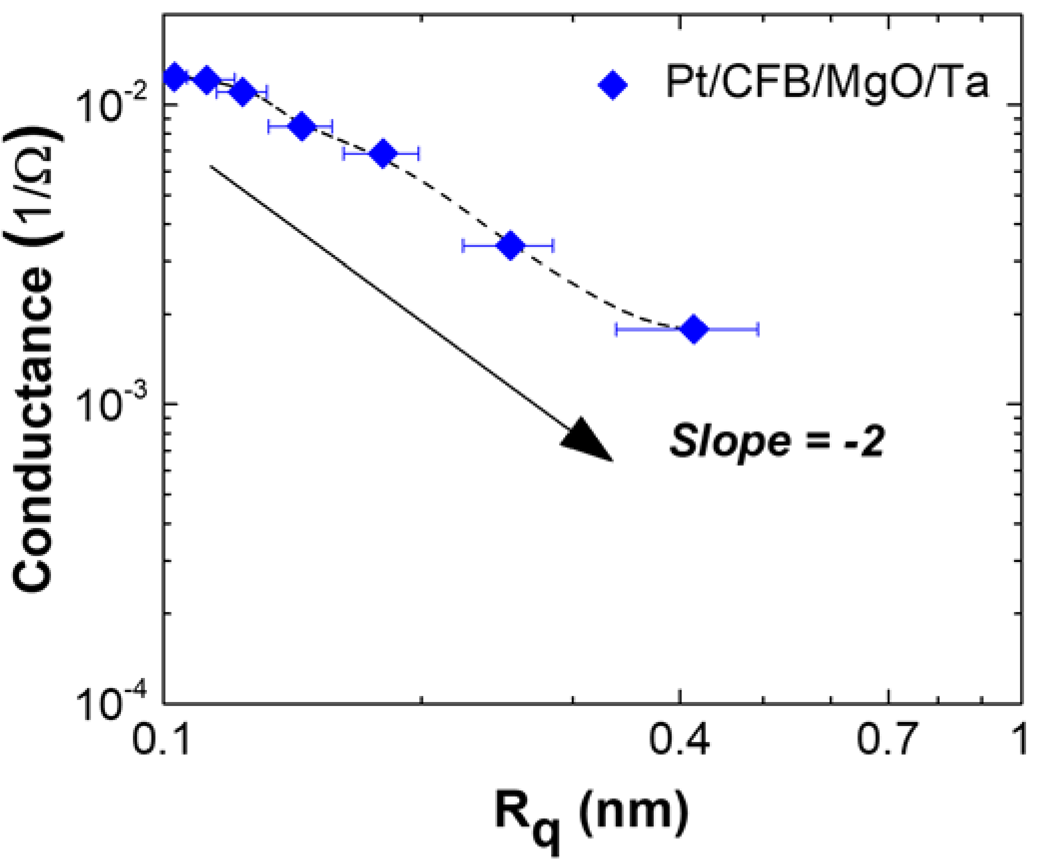

Pt/CFB/MgO/Ta
Slope = -2
Conductance (1/Ω)
10^-2
10^-3
10^-4
0.1
0.4
0.7
1
R_q (nm)

Enhanced Proximity-Induced Magnetization via interactions between two Pt/FM interfaces and the impact on Interlayer Coupling in FM/Pt/FM Systems

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Platinum is of significant interest in spintronics due to properties including large spin-orbit coupling and a high spin Hall angle, critical for spin-current generation and conversion [1] and the origin of interfacial DMI. The Stoner criterion for Pt approaches the ferromagnet limit, and layering it with a ferromagnet (FM) induces proximity-Induced magnetization (PIM) in Pt at the interface, which arises due to d-d hybridization [2]. Interfacial Pt PIM has been extensively studied and contributes to enhancement of the magnetoresistance ratio, reductions in spin Hall effect efficiency, and increases in magnetic damping [3-5]. The potential to control PIM through ionic gating [6] opens a pathway to manipulate the interlayer coupling. However, while Pt PIM is suspected to induce interlayer coupling within FM/Pt/FM systems, neither experimental nor theoretical evidence has supported conclusively this hypothesis, with prior studies attributing the coupling to pinholes or orange-peel coupling effects [7-8].

Our study addresses this by directly linking PIM to interlayer coupling in FM/Pt/FM systems. Using X-ray Magnetic Circular Dichroism (XMCD) and X-ray Resonant Magnetic Reflectivity (XRMR) at the Pt L3-edge, we investigated the Pt moment distribution arising when two FM/Pt interfaces are brought into close proximity and followed the impact of the interlayer coupling on magnetization reversal. Figure 1(a) shows schematics of the structures grown via magnetron sputtering, featuring a wedge-shaped Pt layer. Sample A consists of two identical FM layers (8 nm thick) capped with a Cu layer, while Sample B contains non-identical FM layers. Sample C serves as a control, with an Au spacer layer inserted at one interface for comparison with Sample B. Analysis of XMCD data (Figures 1(b) and (c)) reveals that the total Pt PIM increases as the separation of the two FM interfaces decreases. Comparing Samples B and C, the Au spacer suppresses PIM at one interface, preventing enhancement of Pt moments. XRMR analysis (not shown) further demonstrates enhanced Pt PIM at both interfaces for lower Pt thicknesses, indicating magnetic interaction between the PIMs. Figure 2 illustrates the magnetization reversal behaviour of the two FM layers, probed by Magneto-Optical Kerr Effect (MOKE) and Pt PIM by XMCD. A transition from double-step to single-step switching is observed as the Pt layer thickness reduces, indicating a transition from weak to strong coupling mediated by the PIM. These findings have implications for spintronics, particularly in controlling domain wall nucleation and mobility [9], where interlayer interactions play a critical role.

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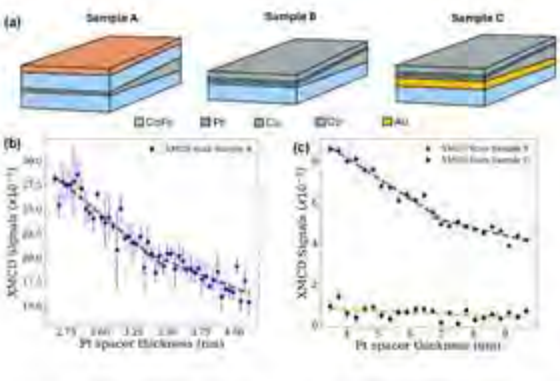

Figure 1. (a) Sample structure with a wedge-shaped Pt thickness: Sample A grown with identical CoFe thickness while Samples B and C include a 0.8 nm Co layer to create unbalanced FM layers. Sample C, with an Au spacer layer, serves as the control sample. (b) and (c) XMCD signals at the Pt L_3-edge plotted against Pt thickness, illustrating the relationship between Pt thickness and XMCD signals.

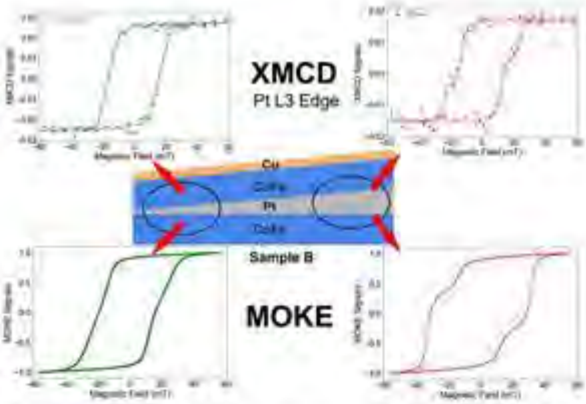

Figure 2. The hysteresis loop for sample B measured with MOKE and XMCD techniques. The MOKE signals predominantly probing the magnetization reversal for FM layers while the XMCD measured at Pt L_3-edge probing the Pt PIM at both interfaces.

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Observation of Spin Seebeck Effect in YIG/Pt-Rh

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Thermoelectric power generated from spin Seebeck effect (SSE) can be enhanced by using a heavy metal with a high spin Hall conductivity. In this study, to improve SSE, we fabricated a YIG/Pt-Rh film. The Pt-Rh is expected to show a high spin Hall angle like typical binary alloys. In addition, Rh has a face-centered cubic (fcc) crystal structure similar to Pt, and their lattice mismatch is only less than 2.7 %, which means Pt-Rh alloys are all proportional solid solution and the lattice structure is stable.

The sample structure is SiO2 (200 nm)/ YIG (50 nm)/ Pt100-xRhx (3 nm) (Figure1). Bilayer films of YIG and Pt-Rh were deposited by magnetron sputtering. The Rh composition x varied from 0 to 100. The YIG layer was annealed at 1023 K in air to obtain a garnet crystalline structure. The spin Seebeck voltage (V_SSE) was then measured under various temperature differences (ΔT) while sweeping an in-plane magnetic field (H) from −0.3 T to +0.3 T. The ΔT was applied to the sample using a pair of Peltier devices. Additionally, the sample resistivity was measured with probes placed 10 mm apart.

Figure 2 shows the dependences of V_SSE/ΔT and ρ on the Rh composition x. While the V_SSE/ΔT reaches its maximum value around x = 40, similar to SSE using the other binary alloys [1][2], the resistivity shows a consistent increase with increasing x unlike most binary alloys. To obtain optimal power output from SSE devices, both a high V_SSE/ΔT and low resistivity are required. However, there is generally a positive correlation between V_SSE/ΔT and ρ. The different trends of V_SSE/ΔT and ρ in YIG/ Pt-Rh indicate that possibility of getting a composition that simultaneously offers high V_SSE/ΔT and the low resistivity.

This study was supported by KAKENHI (No. JP23K22827, JP22KK0056, JP24H00030, JP24H02235, and JP24H02235), the Center for Spintronics Research Network (Osaka), and the X-NICS (No. JPJ011438).

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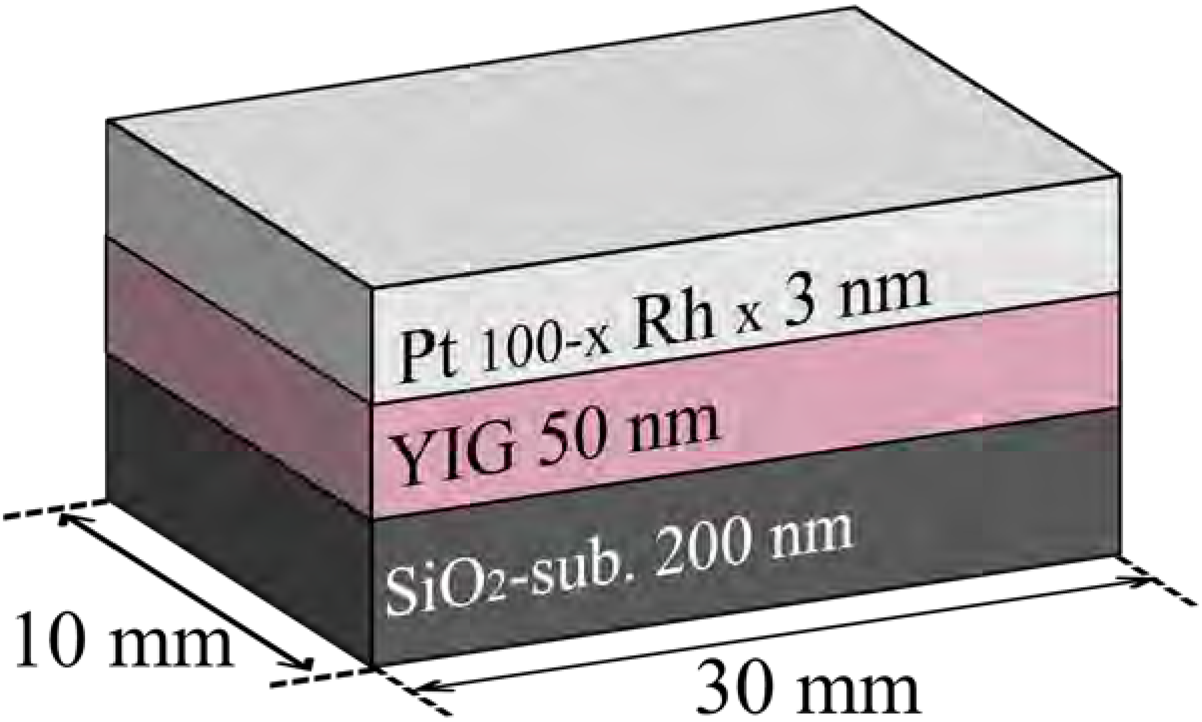

Figure 1

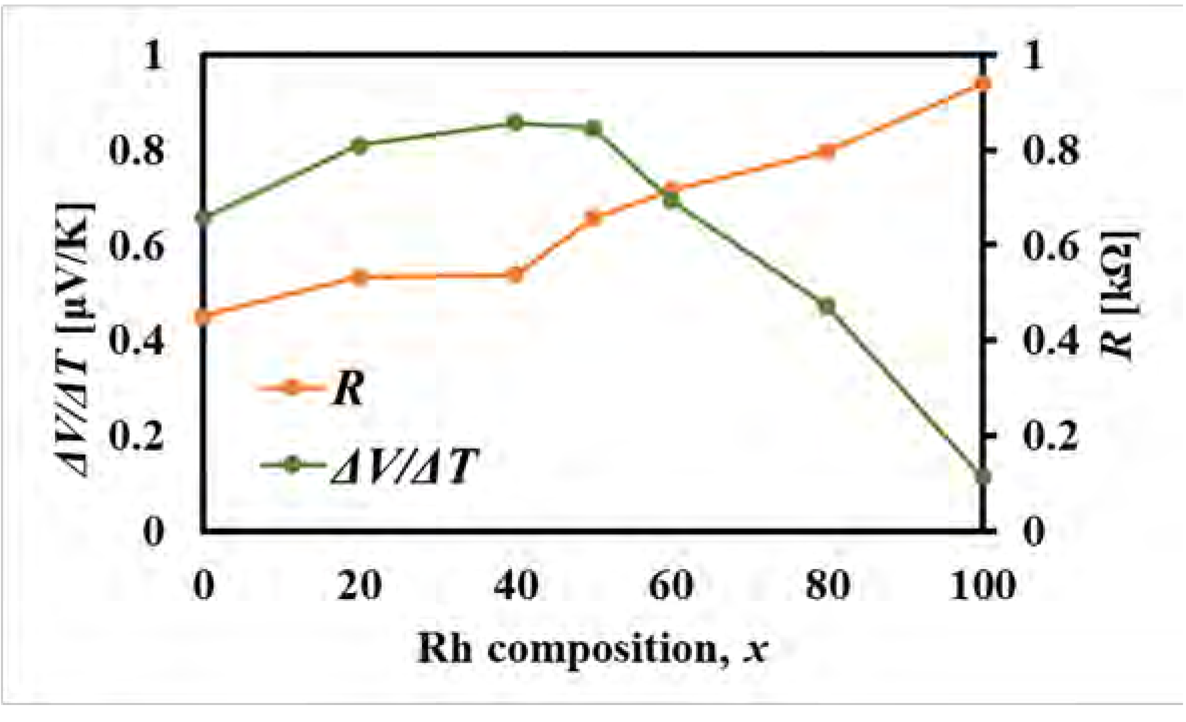

Figure 2

Gate-driven studies in InAs/GaSb quantum well devices for the detection of spin-polarised edge states

Abhirami Saminathan[1,2], Megan Kelly[1,2], Mark Rosamond[2], Lianhe Li[2], Satoshi Sasaki[1], Edmund Linfield[2], Christopher Marrows[1]
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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Heterostructures supporting topologically protected spin-polarised edge states are ideally suited for spintronics device application. The quantum spin Hall (QSH) state achievable in III-V semiconductor heterostructures of InAs/GaSb quantum wells hosts a pair of counter-propagating spin-polarised edge states, along each edge [1]. The inversion of bands in InAs/GaSb quantum wells above the critical thickness causes the opening of a hybridisation gap that can host QSH states [1,2]. Molecular beam epitaxy-grown heterostructure (Fig. 1 (a)) consisting of AlSb/InAs/GaSb/AlSb (50 nm/12.5 nm/8 nm/50 nm) grown over GaSb substrate and 1.2 μm dielectric layer of AlGaSb has been patterned into mesoscopic double-gated Hall bar devices as shown in the right inset in Fig. 1 (b). The nanoscale Hall bar features are shown in the transmission electron microscopy image in the left inset in Fig. 1 (b). Magnetotransport measurements have been carried out within ±8 T magnetic field at 1.5 K, at a constant backgate voltage of 0 V. The electron and hole carrier densities have been obtained by fitting the Hall resistance to the two-carrier transport model. As seen in Fig. 1 (b), applying an increasingly negative topgate voltage causes the system to transition from an electron-dominated regime (I) to a hole-dominated regime (III). The peak in the longitudinal resistance at -6 V indicates the charge neutrality point (CNP). Regime II (CNP regime) corresponds to the hybridisation gap and is expected to host the QSH states. Probing the hybridisation gap through non-local resistance measurements did not yield unambiguous signatures of QSH states. However, the co-existence of holes and electrons states in regime III indicates that the hybridisation of the InAs-GaSb bands arising due to band inversion is not lost. Additionally, the presence of an un-quantised parallel conduction channel has been inferred from the non-zero resistance values of Shubnikov-de Haas oscillation minima in the single-carrier transport regime. With the objective of detecting the masked spin-polarised edge states (QSH states), ferromagnetic contacts of permalloy have been patterned on micron-scale quantum well devices. The required high-quality contact between the ferromagnetic leads and the quantum well channel has been confirmed in the transmission line model device shown in Fig. 1 (c). Further studies on nanoscale devices with ferromagnetic permalloy contacts will probe the spin-momentum locked edge states using spin-polarised currents.

Fig. caption:
Fig. 1 (a) Molecular beam epitaxy-grown III-V semiconductor heterostructure with InAs/GaSb quantum well. (b) Sheet resistance (Rs) and electron (Ne) and hole (Nh) sheet carrier densities (Ns) as a function of topgate voltage. Right inset shows optical micrograph of gated Hall bar device. Left inset shows transmission electron microscopy image of the Hall bar. (c) Optical micrograph of a transmission line model device with permalloy (Py) ferromagnetic contacts on micron-scale InAs/GaSb channel.

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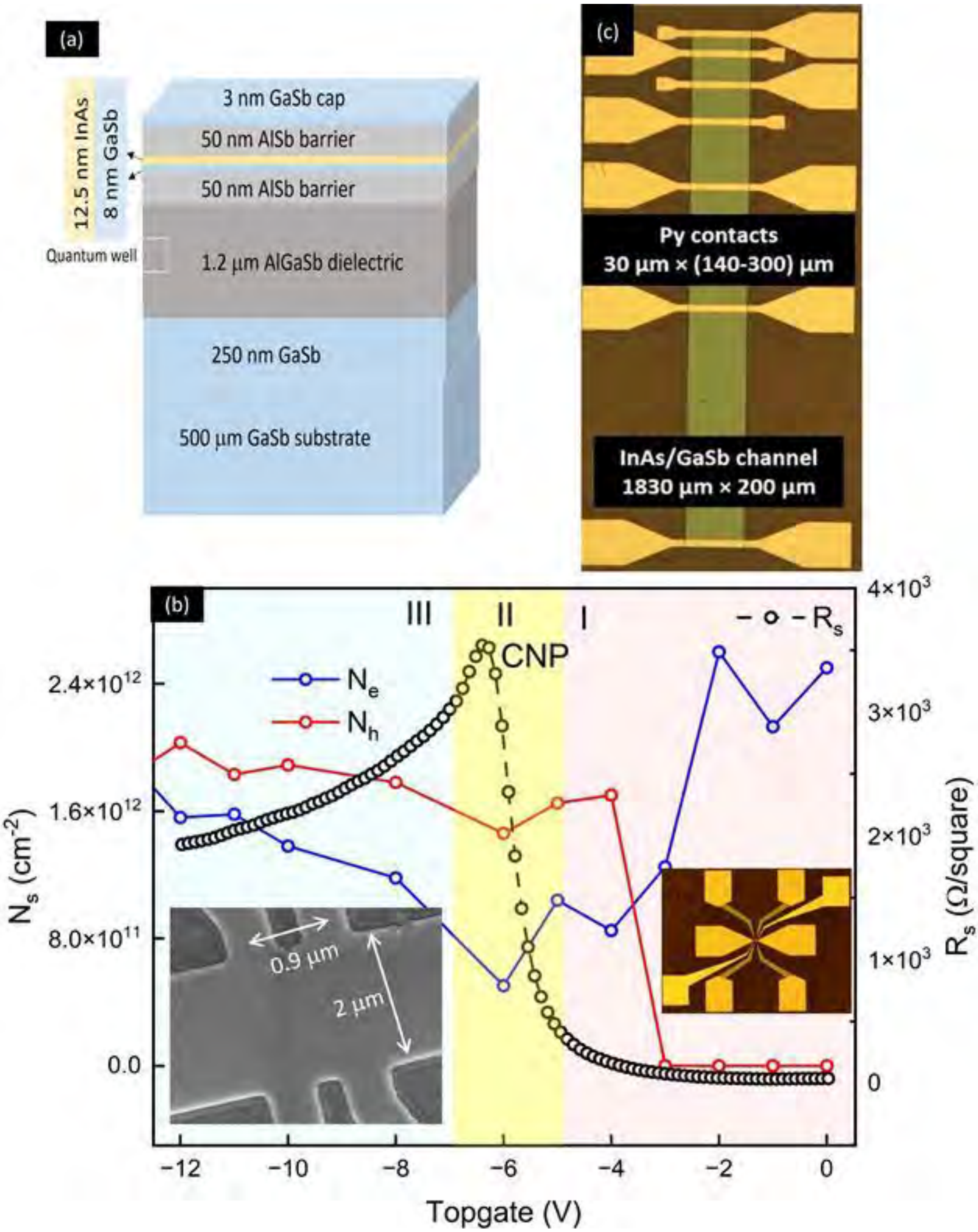

(a)
12.5 nm InAs
8 nm GaSb
Quantum well
3 nm GaSb cap
50 nm AlSb barrier
50 nm AlSb barrier
1.2 μm AlGaSb dielectric
250 nm GaSb
500 μm GaSb substrate
(c)
Py contacts
30 μm × (140-300) μm
InAs/GaSb channel
1830 μm × 200 μm
(b)
III
II
I
CNP
N_e
N_h
R_s
0.9 μm
2 μm
N_s (cm^{-2})
R_s (Ω/square)
Topgate (V)

Ferromagnetic Materials for Josephson π Junctions

Nathan Satchell[1]
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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

The past two decades have seen an explosion of work on Josephson junctions containing ferromagnetic materials. Such junctions are under consideration for applications in digital superconducting logic and memory. In the presence of the exchange field, spin-singlet Cooper pairs from conventional superconductors undergo rapid oscillations in phase as they propagate through a ferromagnetic material. As a result, the ground-state phase difference across a ferromagnetic Josephson junction oscillates between 0 and π as a function of the thickness of the ferromagnetic material. π-junctions have been proposed as circuit elements in superconducting digital logic and in certain qubit designs for quantum computing. If a junction contains two or more ferromagnetic layers whose relative magnetization directions can be controlled by a small applied magnetic field, then the junction can serve as the foundation for a memory cell. Success in all of those applications requires careful choices of ferromagnetic materials. Often, materials that optimize magnetic properties do not optimize supercurrent propagation, and vice versa.

I will present our recent review, where we discuss the significant progress that has been made in identifying and testing a wide range of ferromagnetic materials in Josephson junctions over the past two decades. The review concentrates on ferromagnetic metals, partly because eventual industrial applications of ferromagnetic Josephson junctions will most likely start with metallic ferromagnets (either in all metal junctions or junctions containing also an insulating layer) and briefly mentions work on non-metallic barriers, including ferromagnetic insulators, and some of the exciting work on spin-triplet supercurrent in junctions containing noncollinear magnetic inhomogeneity. The centerpiece of the review is methodically curated Tables that contain the key performance parameters for each material currently available in the literature, allowing a degree of direct comparison between ferromagnetic materials.

Finally, I will share progress from my new group at Texas State University (SUPERMAGLab.com) on the characterization of PdNi ferromagnetic Josephson junctions.

Reference:

Norman O. Birge, Nathan Satchell; Ferromagnetic materials for Josephson π junctions. APL Mater. 12 (4): 041105 (2024). https://doi.org/10.1063/5.0195229

Direct Observation of Plateau Formation in Ultrafast Spin-Orbit-Torque Driven Magnetization switching

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Current-driven magnetization switching via spin-orbit torque (SOT) has attracted significant attention as a key mechanism for next-generation spintronics devices [1-2]. SOT-induced switching is characterized by an instantaneous response due to the perpendicular alignment of the initial magnetization with the injected spin direction. This configuration maximizes spin torque, providing a significant advantage for high-speed device operation

However, a notable aspect of SOT switching is the appearance of a plateau in the magnetization trajectory. This plateau occurs when the magnetization aligns with the injected spin direction, leading to a temporary pause in further magnetization changes. The magnetization can only escape from the plateau once the current pulse ends. Therefore, the formation of the plateau delays the overall switching process, which is disadvantageous for SOT-based device development. Consequently, understanding the factors that govern the formation and duration of the plateau remains a critical research challenge.

In this study, we experimentally observed the plateau phenomenon using a time-resolved magneto-optic Kerr effect (tr-MOKE) setup with a pump-probe technique [3-4]. We used a femtosecond laser and a photoconductive switch to generate a fast-current pulse with a sub-nanosecond pulse width, which was used as the pump. The probe was employed in a polar MOKE setup to measure the magnetization changes. Through these measurements, as shown in Fig 1 (a), we confirmed the presence of a plateau in the Mz variation under specific current density and external magnetic field. The plateau emerged after the peak of the current pulse and was observed after the magnetization crossed the xy-plane, stabilizing at a specific point.

Micromagnetic simulations using MUMAX yielded results consistent with the experiments, as shown in Fig 1(b) [5]. Through the simulations, we investigated how the duration of the t_"plateau" are affected by external magnetic field strength and current density. The simulations revealed that t_"plateau" decreases with increasing external magnetic field and decreasing current density. Importantly, under certain conditions, the plateau effect was minimized, enabling ultrafast switching (~100 ps).

This work highlights the importance of understanding the plateau phenomenon for optimizing SOT-based devices. By tuning the external magnetic field and current density, it is possible to achieve high-speed switching.

Figure 1 (a) Time-resolved measurement of the M_z component (blue) and current profile (red) with respect to the delay time. The plateau (t_"plateau") is indicated by the dashed lines. (b) Micromagnetic simulation results showing the M_z component of magnetization (blue) and current profile (red) as a function of time. The plateau (t_"plateau") is indicated

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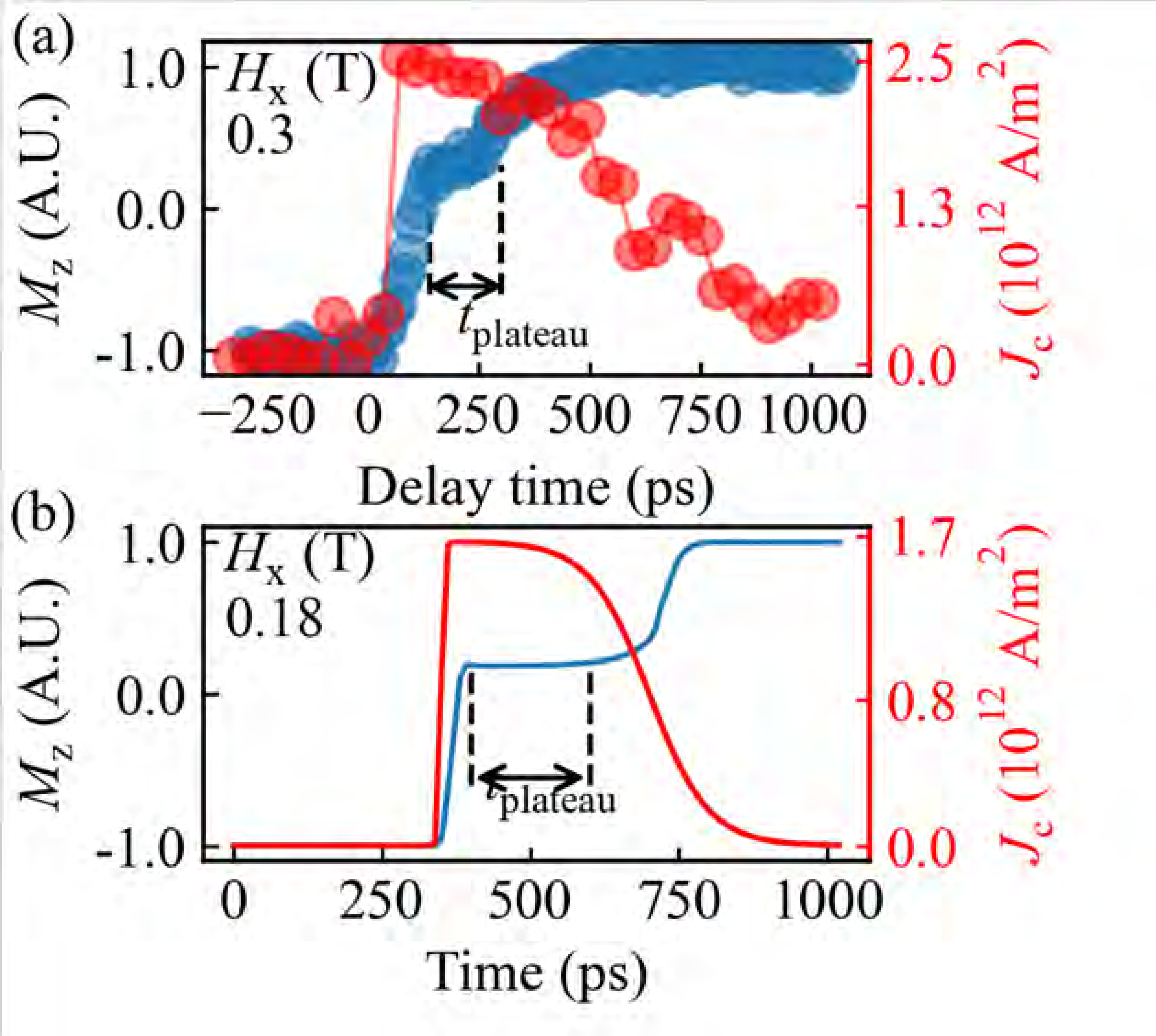

(a)
H_x (T)
0.3
M_z (A.U.)
$t_{plateau}$
J_c (10^{12} A/m^2)
1.0
0.0
-1.0
2.5
1.3
0.0
−250
0
250
500
750
1000
Delay time (ps)
(b)
H_x (T)
0.18
M_z (A.U.)
$t_{plateau}$
J_c (10^{12} A/m^2)
1.0
0.0
-1.0
1.7
0.8
0.0
0
250
500
750
1000
Time (ps)

Flexible magnetic sensor fabricated by drop casting method using multilayered film ink

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Flexible magnetic sensor fabricated by drop casting method using multilayered film ink
In recent years, the demand for flexible devices, including wearable devices and flexible sensors, has been rapidly expanding in the field of electronics [1]. Multilayer films exhibiting magnetoresistance (MR) effects have garnered significant attention as essential materials for high-sensitivity sensors and high-density data storage devices. In response to these demands, this study focuses on the development of flexible magnetic sensors utilizing inkjet printing technology. Inkjet printing enables the direct implementation of devices onto flexible substrates, offering potential advantages such as mass production and cost reduction.
In this study, we first established a method to fabricate metal flakes derived from exchange-biased magnetic multilayer films to serve as the ink material. Specifically, IrMn/CoFeB bilayers were deposited onto Si substrates coated with a resist. After annealing to pin the magnetization, the bilayers were dissolved in acetone using an ultrasonic cleaner to produce metal flakes. Magnetization curves measured by a vibrating sample magnetometer (VSM) confirmed that the flakes retained exchange bias even after processing into a flake form. We successfully observed the exchange bias in the flakes (See Fig. 1).
Next, to achieve higher sensitivity in flexible sensors, we developed metal flakes derived from magnetic multilayer films exhibiting the giant magnetoresistance (GMR) effect. A spin-valve structure was employed for the GMR film to enable high-sensitivity detection under low magnetic fields. The multilayer structure consisted of Au/Ta/Ru/IrMn/CoFe/Cu/CoFe/NiFe/Cu/Au, with Au adopted for the surface layer to ensure electrical conductivity.

Based on the methodologies demonstrated in these experiments, we aim to further develop inks that balance the diversity of flexible material options, fine pattern formation, and high-sensitivity detection under low magnetic fields.

This study was supported in part by the JST, ACT-X Grant Number JPMJAX21K5, KAKENHI (JP22KK0056, JP24H00030, and JP24H02235), Micron Technologies Foundation Inc., the MEXT Initiative to Establish Next-Generation Novel Integrated Circuits Centers (X-NICS) (JPJ011438), and Iketani Science and Technology Foundation.

Fig. 1 VSM measurement results for uniform metal film and metal flakes with the same film configuration.

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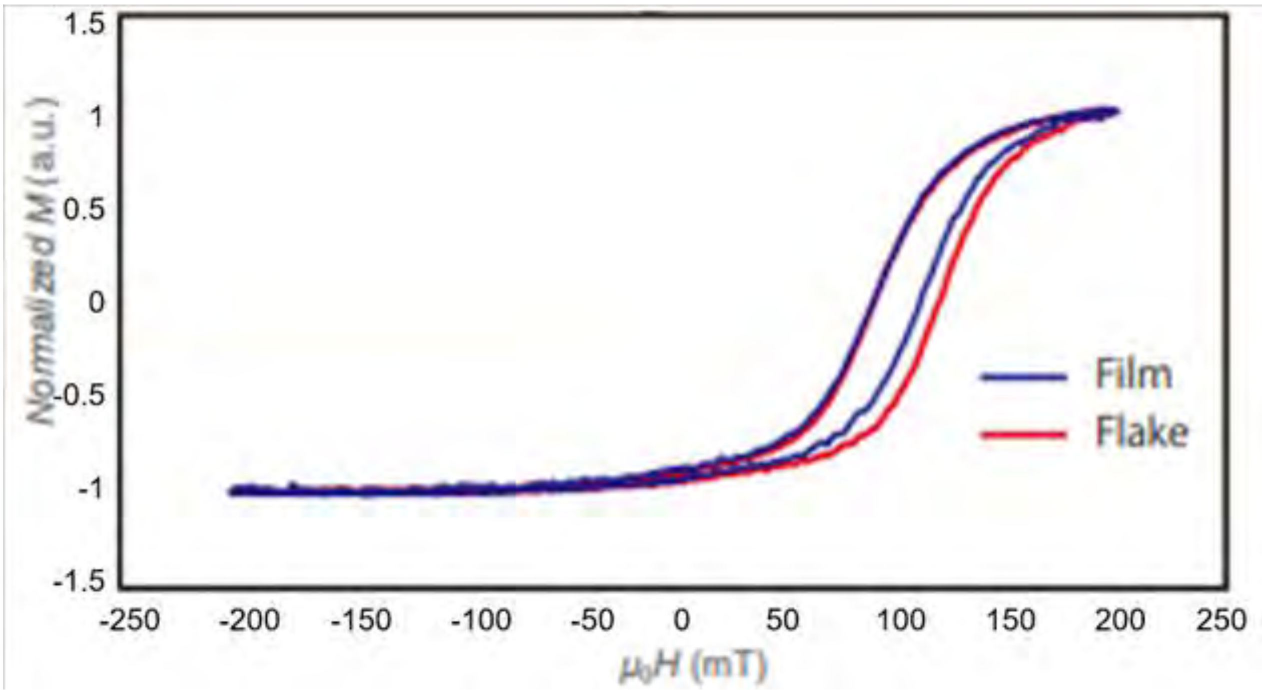

Normalized M (a.u.)
μ0H (mT)
Film
Flake
1.5
1
0.5
0
-0.5
-1
-1.5
-250
-200
-150
-100
-50
0
50
100
150
200
250

Theoretical Study of Application of Bi-2212 Cuprate Thin Film to Quantum Devices

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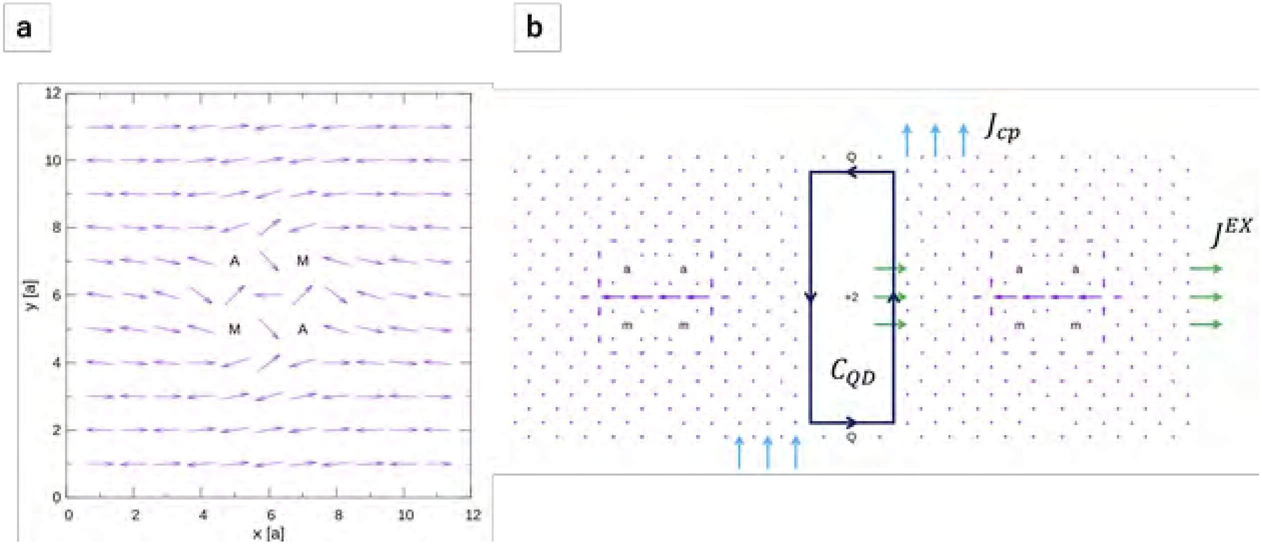
Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

The bilayer cuprate superconductor Bi-2212 cleaves between CuO2 bilayers, easily, and retains superconductivity even in the single CuO2 plane (or half-unit cells) with the superconducting transition temperature of the bulk material (above the liquid nitrogen temperature in the ambient pressure) [Y. Yu, et al., Nature 575, 156 (2019)]. These characteristics make it a promising material for quantum device applications. Our group has been studying the application of the Bi-2212 thin films to quantum devices, especially, qubits of quantum computers. The parent compounds of cuprate superconductors are FMott insulators; upon hole doping, they become superconductors. Within the CuO2 planes, the doped holes form small polarons in the bulk due to the strong hole-lattice interaction. A theory predicts vortex-like twists in the surrounding electron spins [H. Koizumi, A. Ishikawa, J. Supercond. Nov. Magn., 34, 2795 (2021)]. As a consequence, a Berry connection arises to preserve the single-valuedness of the many-body electronic wave function as a function of coordinates. This Berry connection induces persistent loop currents called, the Spin-vortex-induced loop currents (SVILCs) as a collective mode with carrier mass of the free electron [H. Koizumi, J. Phys. A: Math. Theor. 56, 455303 (2023)]. Based on this idea, we have developed a new theoretical framework that explains the superconductivity in the cuprates. Each SVILC is characterized by the topological integer, 'winding number'. We use this topological degree-of-freedom for qubits. A single qubit is constructed on a nano-island structure, composed of four spin vortices as shown in Fig.1a (Four spin-vortices in the CuO2 plane.`a' is the lattice constant. The centers of spin-vortices are denoted by 'M' and A', where 'M' and 'A' denote the spin-votives with the winding numbers +1 and −1, respectively). The qubits are controlled by feeding external currents or irradiating electromagnetic field. We can control the coupling between qubits in different nano-islands by introducing currents through quantum dots that connect the nano-islands as shown in Fig.1b (Loop with two quantum dots that connects two CuO2 islands each with a qubit. The qubit state is controlled by the feeding current). The current flowing through quantum dots is also characterized by the winding number, and we have found that the coupling of nano-islands requires a nonzero winding number. We have also calculated the magnetic fields generated by the loop currents of the qubit states as shown in Fig.2 (Left: Spin-vortex-induced loop currents (SVILCs). `m' and `a' indicate the winding number +1 and -1 loop currents, respectively; Right: The component of the magnetic field normal to the CuO2 plane produced by the SVILCs). It indicates that the magnetic field distribution varies depending on the qubit states, thus, it can be used for the readout of qubit states. Our proposed quint is nano-sized including the coupler. Thus, a large number of qubits will be assembled. High quality qubits constructed using the Bi-2212 thin films may lead to the development of practical fault-tolerant quantum computers.



a
b
y [a]
x [a]
A
M
M
A
a
a
m
m
+2
Q
Q
J_{cp}
J^{EX}
C_{QD}

Epitaxial Mn3−xGaC Antiperovskite / Fe bilayers: Control of magnetocaloric properties by exchange coupling

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Magnetocaloric materials offer the potential for efficient solid-state refrigeration by harnessing temperature changes induced under varying magnetic fields. Among these, manganese-based antiperovskites (APVs) — with the general formula Mn3AX — have attracted considerable attention because of their sharp, tunable first-order magnetostructural transitions and relatively low material cost [1]. However, practical implementation is often challenged by the need to shift the transition temperature closer to ambient conditions, minimize hysteresis, and enhance the overall magnetocaloric response.

One of the possible ways is to tailor the magnetic exchange interactions responsible for the phase transition. In thin film model systems, engineering magnetic interfaces and layer compositions can effectively modify exchange pathways, thereby shifting and sharpening the transitions. Here, we investigate an APV/Fe bilayer system, leveraging interfacial coupling and strain to manipulate the magnetocaloric properties. The results demonstrate that interface-driven exchange can significantly impact the magnetostructural transition.

Mn3-xGaC antiperovskite films were epitaxially grown on MgO(111) using pulsed laser deposition and exchange-coupled to a ferromagnetic (FM) Fe layer from an alloy target at T = 773 K. The presence of a 5 nm Fe overlayer shifts the first-order transition from 189 K to 175 K and increases thermal hysteresis from 8 K to 10 K, indicating that the Fe stabilizes the ferromagnetic (FM) phase via the interface. Meanwhile, the second-order ferromagnetic-to-paramagnetic transition at 250 K remains unaffected, and the previously compensated antiferromagnetic (AFM) state in the APV is converted into an uncompensated state (Figure 1). Interestingly, the FM-AFM transition was completely suppressed at magnetic fields (B) larger than 1T. In the uncoupled APV, magnetocaloric effect (MCE) values near 10 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ are observed for moderate magnetic fields (6 T), in line with the literature [1]. However, in the coupled APV/Fe system, the MCE at the first-order transition diminishes to approximately 1 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ at 2 T, presumably due to interface-induced strain or exchange fields that hamper the abrupt magnetostructural change.

Since the transition to antiferromagnetic state is driven by shortening of Mn–Mn bonds upon colling [2], we propose that the transition temperature might be shifted to higher values by coupling APVs with materials featuring large magnetovolume effects or similar first-order transitions with direct MCE near 200–250 K. Additionally, a relatively large misfit in the coefficient of thermal expansion, resulting in compressive strain, could further optimize performance. This approach offers a route to enhance magnetocaloric performance in coupled system for magnetocaloric application.

Figure 1. (a, b) Temperature and (c) magnetic field dependence of magnetization in uncoupled Mn3−xGaC[24 nm] and coupled Mn3−xGaC[42 nm]/Fe[5 nm] thin film system grown on MgO(111)

Acknowledgement
Funding by the Deutsche Forschungsgemeinschaft (DFG) within CRC/TRR 270, project B02 (Project-ID 405553726) is gratefully acknowledged.

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Novel molecular beam epitaxy synthesis of Heusler alloy-based short period superlattices

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Heusler alloys order into cubic compounds possessing a remarkable array of functionalities, including half-metals, Slater-Pauling semiconductors, topological insulators, and superconductors. Ternary cubic $L2_1$ structure based on composition A_2BC (i.e., Cu_2MnAl type) is a natural superlattice, such that lattice stacking along the [111] direction corresponds to ABAC with a unit cell period of 12 atomic layers. Theoretical calculations indicate that artificial superlattices of these compounds can be engineered to produce combinations of highly tunable properties and functionalities, including stable halfmetallic states and perpendicular magnetic anisotropy.[1] Here, we report molecular beam epitaxy (MBE) synthesis and characterization of artificial superlattices, consisting of two ternary Heusler alloys with 4 to 6 chemical elements tailored atomic layer by atomic layer with a supercell period between 12 and 36 atomic layers and a supercell repeat of about 30. Specifically, epitaxial growth of superlattices on Ge (111) substrates with a composition of approximately 33.3% Co, 16.6% Fe, 25% Mn, and 25% Si, and various atomic stacking sequences along the growth direction have been investigated. The stacking sequences include one that mimics two cubic full Heusler alloys of Co_2MnSi and Fe_2MnSi with an atomic layer sequence of Mn-Co-Si-Co-Mn-Co-Si-Co-Mn-Fe-Si-Fe, another one that corresponds to inverse Heusler ($CuHg_2Ti$ type) with a sequence of Mn-Co-Co-Si-Mn-Co-Co-Si-Mn-Fe-Fe-Si, and other sequences like Mn-Co-Si-Co-Mn-Fe-Si-Co-Mn-Co-Si-Fe. Structural properties were characterized in-situ by RHEED (reflection high energy electron diffraction) and ex-situ by XRD (x-ray diffraction). These results show that some stacking sequences yielded high quality coherent single crystalline structures with a cubic lattice, whereas other stacking sequences yielded coherent hexagonal structures. Our MOKE (magnetoopitc Kerr effect) and magnetometry experiments show that the superlattices exhibit ferromagnetism at room temperature with magnetic anisotropy that depends sensitively on the stacking sequences, including a light polarization induced anisotropy. The short period superlattices correspond to a new archetype of functional ferromagnetic materials. Such materials can be synthesized in the nonequilibrium regime with atomic layers used as the “Lego blocks” and engineered via the atomic stacking sequences to possess potentially non-centrosymmetric structures and novel tunable electronic and magnetic functionalities.

The work was supported in part by NSF DMR 1905651.

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Investigating Variation in Domain Wall Properties of RE-TM Ferrimagnets at the Compensation Point via Scanning NV Magnetometry

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Ferrimagnetic materials are of significant interest in the field of spintronics, as they combine the advantageous features of antiferromagnetic materials (fast logic and nonvolatility) with the advantages of ferromagnetic materials (strong signal and compatibility with existing frameworks). These materials enable the development of energy-efficient devices that utilize domain wall dynamics for logic and memory applications.

In particular, rare-earth (RE) and transition-metal (TM) ferrimagnetic materials exhibit tuneable magnetic properties. They can transition between ferromagnetic and antiferromagnetic (or compensated) magnetic phases by varying the material composition or the temperature of the system.[1] This changes the properties of magnetic textures that occur in the systems, such as domain walls.

This study focuses on investigating current-induced domain wall motion in GdFeCo devices across the compensated phase. Imaging the propagation of the domains with MOKE microscopy shows that domain wall speeds reach their maximum in samples near the compensation point.[2] To further understand this behaviour, we image the domain walls using NV (nitrogen-vacancy) magnetometry, a high-resolution, high-sensitivity surface stray field imaging technique. This approach allows us to observe domain walls in both ferromagnetic and antiferromagnetic phases. Additionally, we can extract the domain wall properties, such as chirality and width, to better understand the intrinsic changes to the domain walls that allow them to reach higher velocities.[3]

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Weak anti-localization in Bi implanted Cu devices

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Exotic charge transport properties can emerge in ordinary metallic layers engineered with disorder in terms of dimensional scaling or impurity localization. The quantum interference of electron waves in such a disordered metallic system at the nanoscale allows for variation in the time scales of electron scattering by different mechanisms such as elastic, inelastic, magnetic or spin-orbit interactions. These interference effects can be detected using the magneto-transport measurements utilizing a deep understanding of weak (anti-) localization effects.
In this work, we demonstrate an enhancement of the spin-orbit scattering in Cu devices (thickness = 10 nm) implanted with Bi ions (energy 50 keV) with a dose of 10^{15} ions/cm^2 over the length scale of 35 µm × 10 µm (figure 1a). The implantation was performed using P-NAME facility, which provides a high-resolution focused ion beam with sub-10nm ion beam imaging and direct-write ion beam doping. The impact of Bi-ion implantation was examined on the length scales of the different mechanisms of electron scattering by modelling the temperature dependent magneto-resistance curves using the Hikami-Larkin-Nagaoka (HLN) theory (figure 1b). Despite a classical 3-dimensional system (since calculated mean free path is greater than thickness), modelling the magneto-resistance curves using HLN theory provides strong evidence of the quantum interference effects prevailing in 2-dimensions only, since the extracted phase coherence length was 74 nm which is much larger than the thickness of devices. The calculated spin-orbit scattering lifetime decreased from 13.4 ps to 2.2 ps after implanting Cu devices with Bi ions. Hence, Bi-ion implantation enhances the spin-orbit scattering in Cu devices. To further determine the effect of this implantation on the optoelectronic properties, we performed scattering type scanning near-field optical microscopy (s-SNOM) on Cu devices in which full length was implanted to map the properties on nanometre length scales. In figure 1c, a 2D whitelight image is shown that plots the frequency-averaged scattered near-field amplitude (at 3rd demodulation order). A strong contrast is observed between the implanted and unimplanted region. As the near-field amplitude directly relates to reflectivity (and thereby conductivity via local dielectric function), it indicates that the conductivity of Cu devices at the area of Bi ion exposure considerably decreases. This corroborates well with the magneto-transport measurements, demonstrating that the Bi ion implantation in Cu devices creates not only the scattering centres for inelastic scattering, but also the spin-orbit scattering increases significantly. These experiments demonstrate that utilizing nanoscale doping we can alter the spin-orbit interaction in devices on length scales that will be useful in spin current devices. This understanding will allow us to design the doping of non-magnetic layers in spintronic devices.

Figure 1: (a) Schematic for Bi ion implanted Cu devices (b) magneto-resistance curves at 2 K (c) 2D whitelight image of scattering near-field intensity demodulated at third harmonic order.

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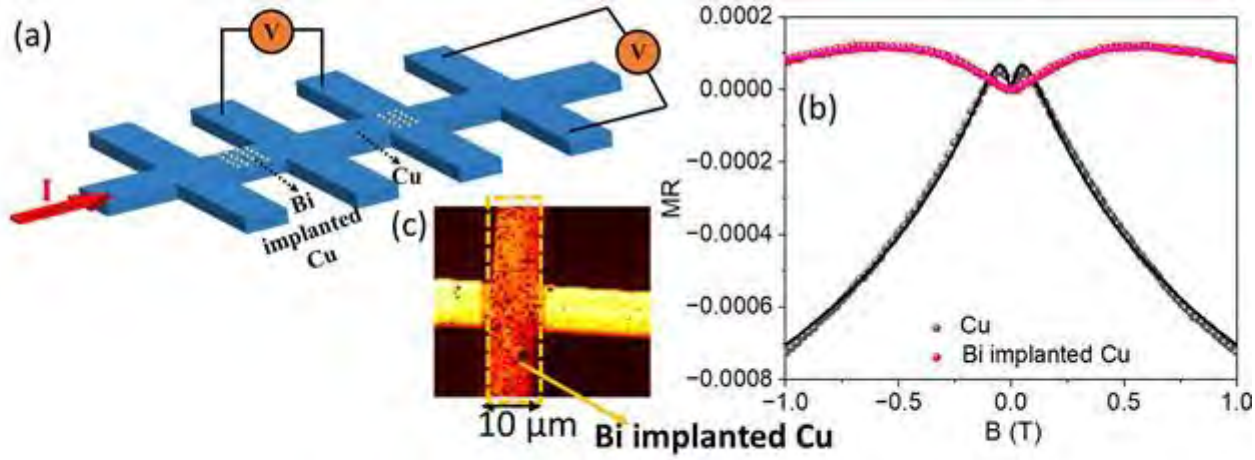
(a)
V
V
I
Bi
implanted
Cu
Cu
(c)
10 μm
Bi implanted Cu
(b)
MR
B (T)
Cu
Bi implanted Cu
0.0002
0.0000
−0.0002
−0.0004
−0.0006
−0.0008
−1.0
−0.5
0.0
0.5
1.0

Current induced thermally activated propagation of domain walls in NdCo5/Ni8Fe2 reconfigurable racetracks: exchange-bias and statistics

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

The magnetic racetrack paradigm is the focus of intense research due to the need to develop energy-efficient data storage technologies. Our work is focused on a NdCo5/Ni8Fe2 bilayer that features a periodic stripe domain pattern to create a reconfigurable domain wall racetrack [1] in which propagation path can be reoriented with an external field. The NdCo5 alloy presents weak Perpendicular Magnetic Anisotropy and adjusting the layer thickness, this material can present a magnetic stripe domain configuration. These linear up/down stripe domains at the NdCo5 layer provide a reconfigurable magnetic potential that guides the propagation of head-to-head (H2H) or tail-to-tail (T2T) domain walls (DW) within the top permalloy (Ni8Fe2) layer [2]. Magnetic transmission X-ray microscopy experiments have shown the thermally activated process that allows for controlled propagation of these DW, under the effect of pulsed currents (~20 ns) over a threshold current density of 3×10^11 A/m2. The DW propagation sense depends on the magnetic history of the multilayer, its H2H/T2T character and whether there is an external magnetic field being applied, but it does not depend on the sign of the applied current pulse. In the remnant state, it is found that DW propagation direction is controlled by magnetic history, i.e. by the sign of the magnetic field used to previously saturate the sample. On the other hand, when there is an external field being applied, the propagation follows the direction of the applied field. Using micromagnetic simulations we have been able to confirm that each DW hosts either a vortex or antivortex (V/AV) texture with skyrmionic charge close to ±1/2. Moreover, the guiding effect and the asymmetries in propagation direction have been linked to the magnetic history of the NdCo5. There is an exchange-bias effect that acts as a magnetic spring selecting a favourable sense for DW movement. The equivalent bias field related to this exchange spring has been estimated to be |μ0·Hbias| ≈ 9 mT [1]. The probability of DW nucleation and propagation at the upper/lower branches of bifurcations within the stripe domain pattern has been studied as a function of applied transverse fields and/or interfacial DMI created by a Pt capping layer in order to break the symmetry of the system.

Work supported by Spanish AEI, Asturias FICYT and FEDER funds.

Figure 1: Micromagnetic simulations of 80 nm NdCo5/40 nm Py bilayer in the remnant state. a) Linear −|mx| reversed domain that ends in a vortex. b) Spatial distribution of the exchange energy density (ε_ex) in two cross sections. The arrows represent the magnetization, showing the relationship between the magnetization on the Py layer and the NdCo5 layer. Two very different rotations can be seen when mx is pointing in the +X direction in both layers with respect to having a reversed domain in the Py layer, which contributes to the ε_ex difference.

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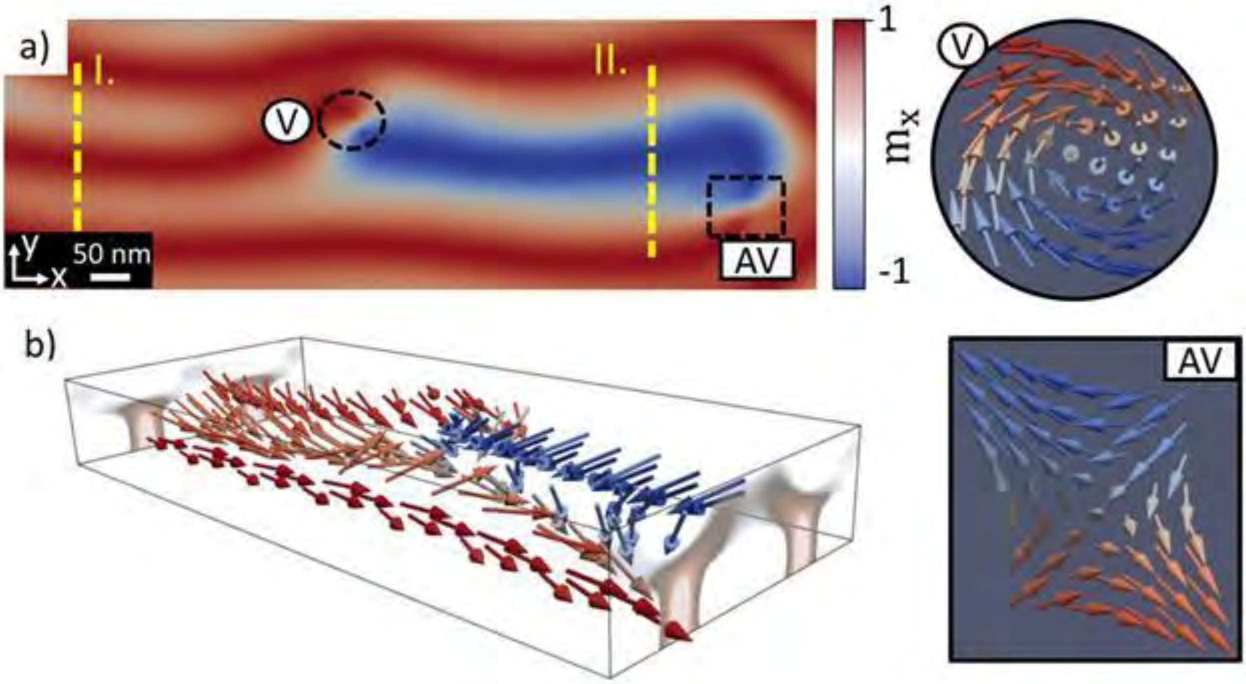

a)
I.
II.
V
AV
y
x
50 nm
1
-1
m_x
V
b)
AV

Real-time optically imaging the antiferromagnetic domain switching in CoO(001) films

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Antiferromagnetic (AFM) spintronics has garnered substantial attention in the past decade due to its potential applications in fast speed and high density storage devices. The information storage in AFM spintronic devices is encoded in the Néel vector n within AFM domains. Therefore, directly imaging the AFM domains is pivotal for comprehending their switching behaviors during the information installation process. Recent reports have shown that the magneto-optical birefringence (MOB) effect can provide powerful capability to directly image the AFM domains in compatible with external field or current.

We imaged the current switching of CoO AFM domains in Pt/CoO(001) system based on MOB effect [1]. The CoO domains can be switched into the state with the Néel vector (n) perpendicular to the current direction (j). Moreover, critical current density is almost independent of the CoO thickness, suggesting the dominance of the thermomagnetoelastic effect. It was surprisingly observed that the n can be further switched parallel to the current direction (n"∥" j) at higher current density while maintaining the same current direction, indicates the potential to manipulate AFM domains in a two-terminal device solely by adjusting the current density.

We also found an intriguing perpendicular magnetic anisotropy (PMA) system involving an ultrathin Fe(001) layer on an AFM CoO(001) surface [2]. The measured perpendicular anisotropy field is inversely proportional to the Fe thickness, indicating an interfacial origin of PMA. We concurrently imaged the ferromagnetic (FM) and AFM domains by leveraging the magneto-optical Kerr effect and birefringence effect. A strong coupling effect between these domains was observed near the spin reorientation transition (SRT), contrasting sharply with areas of stronger PMA that exhibited weak coupling.

The Fe spins were found to possess a tilted easy axis near the SRT region. The in-plane projection of tilted easy axis is perpendicular to the n of CoO. By applying a current parallel to the easy axis of CoO, the CoO domains switched to the direction parallel to the current, thereby facilitating the field-free switching of Fe. The differences in the canting angles of Fe spins caused by the different orientations of the CoO domains lead to distinct anomalous Hall effect signals in Fe. This can be used to electrically detect the direction of the CoO domains, which is much larger then the traditional spin Hall magnetoresistance in CoO/Pt system.
Our experimental investigation not only offers a deeper understanding of current-driven AFM domain switching but also unveils novel prospects for manipulating and detecting AFM domains in AFM spintronic devices.

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Magnon Transport in Thulium Iron Garnet Fabricated by Radio-Frequency Magnetron Sputtering

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Ferrimagnetic garnet is a promising material for magnon devices thanks to the small damping constant and small saturation moment. An important character for real-life application is perpendicular magnetic anisotropy, which offers reciprocity configurations, which is beneficial for magnonic devices with low power consumption. Thulium iron garnet (TmIG) has remarkably large perpendicular magnetic anisotropy by harnessing the epitaxial strain and the inverse magneto-striction effect [1]. Although the transport measurement is important for understanding the magnons in TmIG, the number of reports is still limited [2]. Here, we report the transport of magnons in this fascinating material.

TmIG film was sputtered on a gadolinium gallium garnet (GGG) substrate using radio frequency (RF)-magnetron sputtering. The deposition condition was described elsewhere [3,4]. The thickness of TmIG was 18 nm. The hysteresis loop of TmIG was measured by using Quantum Desing MPMS-3. The damping constant was measured using broad-band ferromagnetic resonance (BB-FMR) measurement. The transport of the magnons were examined using propagating spin wave spectroscopy (PSWS) measurement.

The BB-FMR measurement was performed at room temperature. The microwave frequency was swept from 7 to 12 GHz. Clear FMR signals were observed. The frequency dependence of the resonance field and the half-width at half maximum were investigated. From the linear fitting, the damping constant of the 18 nm-thick TmIG was estimated to be 1.5×10-2, which was less than half of that of TmIG film on neodymium gallium garnet substrate[2]. The improvement in the deposition technology resulting in a smaller damping constant is noteworthy, offering benefits for magnon’s transport.

For the PSWS measurement, after the post annealing at 800C°, antennas were fabricated by electron beam lithography followed by deposition of Ti (3 nm)/ Au (100 nm). The PSWS measurement was conducted in an in-plane field at room temperature. A typical result is shown in Fig. 1. The transport of the magnons was observed over a distance range from 1.3 to 3.3 μm. The absolute value of S21 parameters vs the channel length Lch is shown in Fig. 2. From the fitting considering the exponential decay of magnon population, the attenuation length of the spin wave was evaluated as 6 μm. The group velocity of the transported spin wave was 0.4 km/s at 100 mT, which is as same order as the previous research [2]. These results provide a better understanding of the magnon’s transport in TmIG for the device application and the circuit design.

This work was supported by JST ACT-X JPMJAX23KJ, Nippon Sheet Glass Foundation for Materials Science and Engineering, and R1-TECHNOLOGIES LLC.

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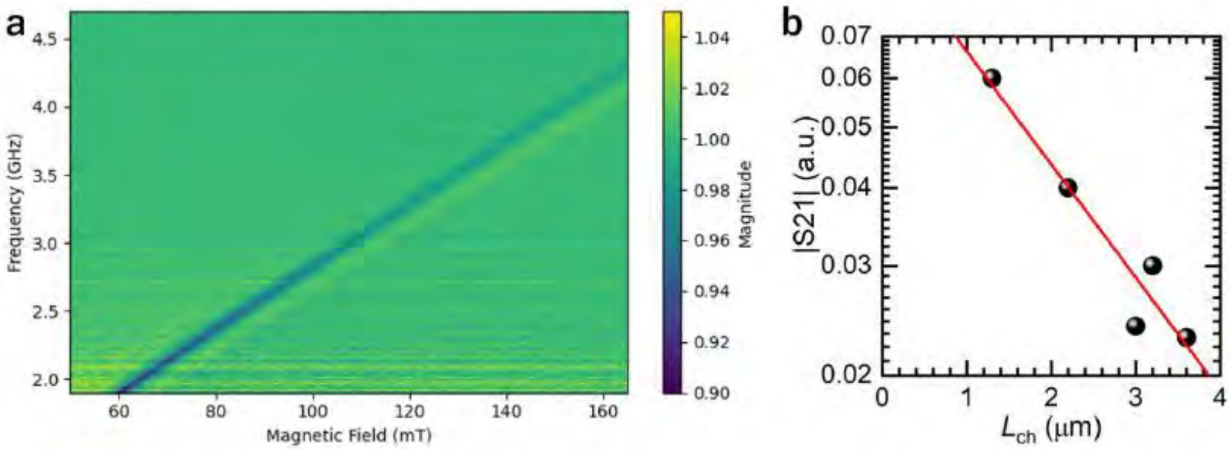
Figure 1a. Result of propagating spin wave spectroscopy for L_{ch} of 3.2 μm.

Figure 1b. Channel length dependence of the spin wave signals measured by PSWS.



Quantitative measurement of figure of merit for transverse thermoelectric conversion in Fe/Pt metallic multilayers

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

Transverse thermoelectric conversion, in which a temperature gradient induces a transverse electric field, represents a promising avenue for next-generation energy harvesting technologies [1]. Unlike conventional longitudinal thermoelectric systems, transverse thermoelectric devices offer simpler structures and enhanced thermal energy harvesting efficiency due to minimized electrical and thermal contact resistance. Among transverse thermoelectric effects, the anomalous Nernst effect (ANE) in magnetic materials stands out as a key phenomenon. The performance of transverse thermoelectric conversion for the ANE is characterized using the figure of merit $(z_T)T$ [$= (S_T)^2(\sigma_{yy})T/(\kappa_{xx})$], where S_T, σ_{yy}, κ_{xx}, and T denote the transverse thermoelectric coefficient, electrical conductivity, thermal conductivity, and absolute temperature, respectively. Metallic multilayers are promising transverse thermoelectric materials, and it has been demonstrated that S_T is enhanced by multilayering for various ferromagnetic/nonmagnetic combinations [2,3]. In addition, the inherent structural anisotropy of multilayers, as illustrated in Fig. 1(a), holds the potential to reduce out-of-plane κ_{xx} while maintaining in-plane σ_{yy}, leading to an enhancement of $(z_T)T$. Despite these advantages, a reliable method to evaluate $(z_T)T$ in thin films, including multilayers, had not been established.

To address this challenge, we proposed and demonstrated a methodology for accurately evaluating $(z_T)T$ in thin-film forms [4]. Our approach involves the measurement of κ_{xx}, S_T, and σ_{yy} with the time-domain thermoreflectance [5], the heat flux method [6], and the four-terminal method, respectively. This technique was applied to epitaxial and polycrystalline Fe/Pt multilayers with varying stacking repetitions N. The high-angle annular dark-field (HAADF) scanning transmission electron microscopy (STEM) images indicated that all the Fe/Pt multilayers successfully formed layer stackings with clear interfaces [inset of Fig. 1(b)]. We systematically investigated the dependence of κ_{xx}, S_T, and σ_{yy} on N, and evaluated $(z_T)T$ using three parameters. We found that the multilayer structure effectively suppresses κ_{xx}, while S_T drastically increases with increasing N, resulting in a significant enhancement of $(z_T)T$ as shown in Fig. 1(b). Furthermore, we clarified epitaxial multilayers have higher transverse thermoelectric conversion performance than polycrystalline multilayers. This study represents a pioneering effort in the evaluation of $(z_T)T$ in thin-film forms. We anticipate that this approach will accelerate materials research in thermoelectricity and spin caloritronics, paving the way to advanced energy harvesting solutions.

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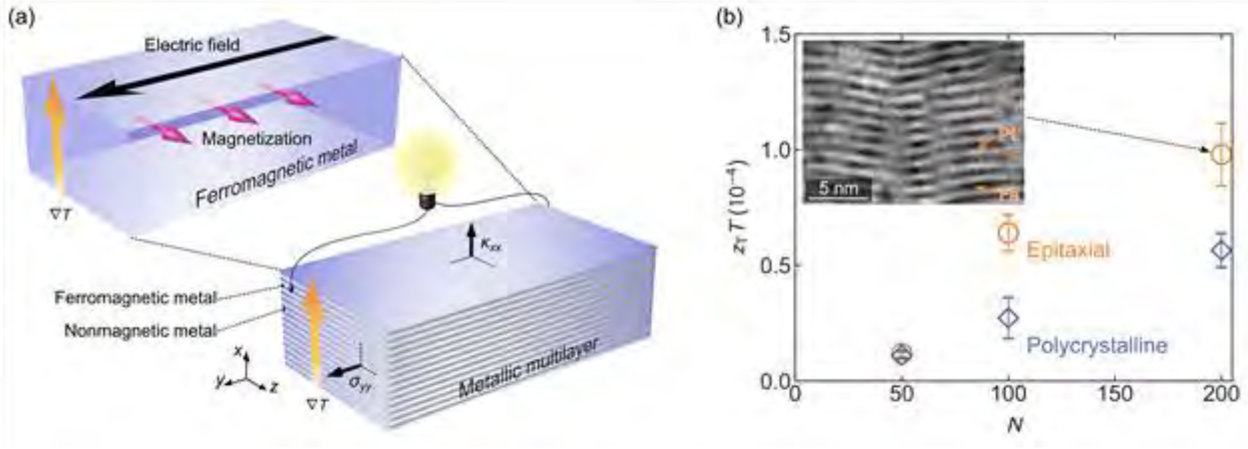
Fig. 1 (a) Schematic illustration of transverse thermoelectric conversion based on the ANE in a metallic multilayer. (b) Stacking repetitions N dependence of transverse thermoelectric figure of merit $(z_T)T$ for epitaxial and polycrystalline Fe/Pt metallic multilayers. The inset shows the cross-sectional HAADF-STEM image of the epitaxial Fe/Pt metallic multilayer with N = 200.


(a)
Electric field
Magnetization
Ferromagnetic metal
∇T
Ferromagnetic metal
Nonmagnetic metal
κ_{xx}
σ_{yr}
∇T
Metallic multilayer
(b)
5 nm
Pt
Pt
Epitaxial
Polycrystalline
$z_T T$ (10^{-4})
N

Tailoring unusual Ferrimagnetism of Rare-Earth Iron Garnet via Graphene Interlayers

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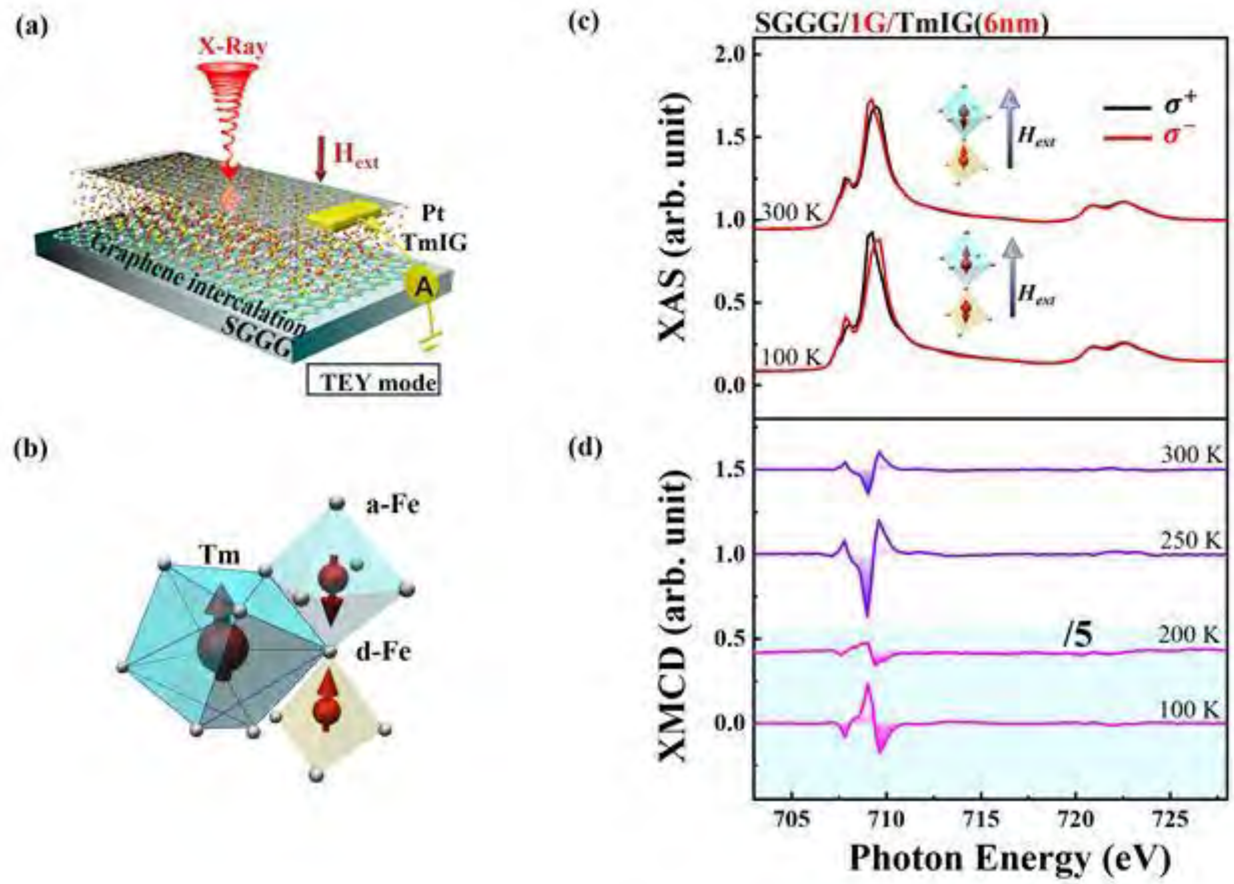
Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

Ferrimagnets (FiMs), especially for compensated FiMs, composing of coupled sublattices with antiparallel and inequivalent magnetic moments, present a unique material platform for its magnetism regulation which is highly desirable for the design of spin-based devices. However, highly efficient methods of controlling its magnetism is still limited due to the required a close match between FiMs films and substrate lattice constants for producing an excellent quality and fully featured films. Here, multiple tunability of ferrimagnetism for the rare-earth iron garnet (REIG) film, thulium iron garnet (Tm3Fe5O12 (TmIG)), are demonstrated via graphene interlayers method. A continuous evolution of magnetic anisotropy and an unexpected/tunable magnetization compensation point (TM) are realized. Through the analysis of soft x-rays absorption spectroscopy, the presented anisotropic behavior of orbit moments provides direct evidence for the modulation of magnetic anisotropy and a giant tunability of its value (~300% for TmIG (6nm); ~1000% for TmIG (12nm)) is achieved. The appeared TM with giant enhancement (300%) is further confirmed by temperature-dependent x-ray magnetic circular dichroism signal which reveal a tunable exchange coupling for inequivalent magnetic atoms. These results establish an efficient strategy to tailor magnetism in low dimensional REIG films through interlayers engineering and advance the study of REIG-based spintronics.



Coherent magnon transport in a van der Waals antiferromagnet

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Afternoon Break 2 and Poster Session 1, July 15, 2025, 15:00 - 16:30

The discovery of van der Waals magnets at sizes down to the two-dimensional limit opens a frontier in the realm of spintronics and magnonics. In particular, van der Waals antiferromagnets such as CrCl3, CrSBr and CrPS4 are A-type antiferromagnets with interlayer AFM exchange coupling and intralayer ferromagnetic exchange coupling [1]. The interlayer AFM coupling is several orders of magnitude weaker than the intralayer coupling. Consequently, the magnon frequencies in van der Waals antiferromagnets are typically in the GHz range, presenting signi cant opportunities for exploring AFM magnons using microwave technology. Further more, the interlayer AFM coupling introduces unique properties to the magnons in these materials, includ ing the emergence of optical and acoustic magnon bands due to the presence of two sublattices. In particular, in the van der Waals antiferromagnet CrPS4, the intersections of these magnon modes under symmetry breaking conditions can lead to strong magnon-magnon coupling, creating a promising platform for investigating AFM magnonic quantum systems [2]. Optical methods have been previously employed to study magnon-exciton coupling in the CrSBr, however, for practical inte gration of magnonic devices and circuits, electrical exci tation and detection are essential. Recent studies have demonstrated DC detection of incoherent magnon spin transport in CrPS4 [3] [4] , while information on coherent magnon transport and manipulation remains elusive.

In this Letter, we explore the excitation and detection of coherent magnon transport in a CrPS4 single crystal, integrated with a pair of nanoscale microwave antennas. By varying the angle of the external magnetic field relative to the crystalline axis, we observe a strong magnon-magnon coupling between the optical and acoustic modes, leading to the emergence of a forbidden gap for magnon propagation. As a result, the frequency of the hybridized magnon modes can be tuned by control ling the external field direction, allowing for tunability over a broad frequency range exceeding 10 GHz. Additionally, we experimentally determined the magnon dispersion by measuring the magnon frequency as a function of the wavevector of the excitation field, and propose an analytical model for the AFM magnon dispersion CrPS4. Furthermore, a reciprocal magnon transport is found as the temperature approaches the Néel temperature.

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Orbital-excitation-dominated magnetization dissipation and quantum oscillation of Gilbert damping in Fe films

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Afternoon Break 3 and Poster Session 2, July 16, 2025, 15:00 - 16:30

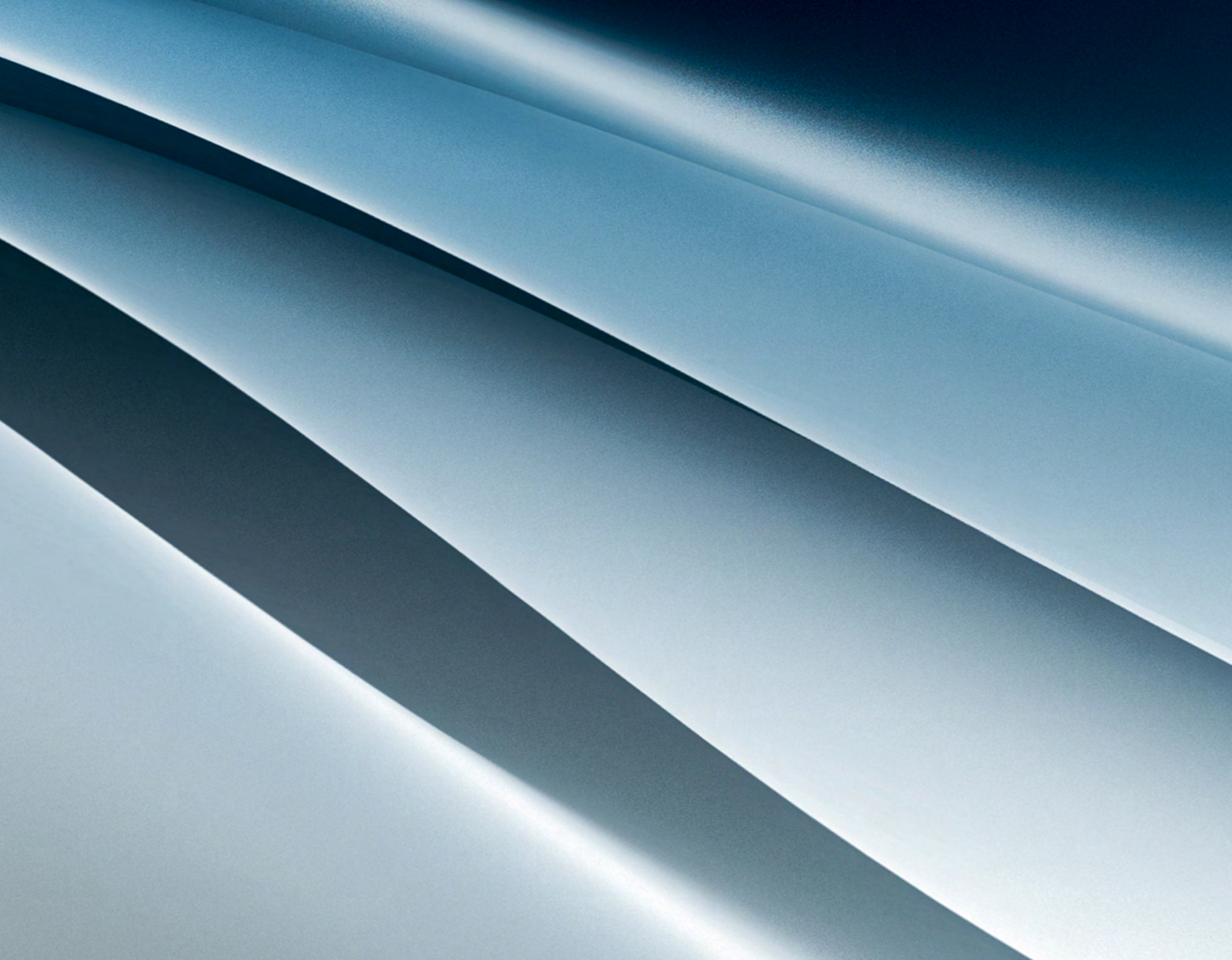
Using first-principles electronic structure calculation, we demonstrate the spin dissipation process in bulk Fe by orbital excitations within the energy bands of pure spin character. The variation of orbitals in the intraband transitions provides an efficient channel to convert spin to orbital angular momentum with spin-orbit interaction. This mechanism dominates the Gilbert damping of Fe below room temperature. The theoretical prediction is confirmed by the ferromagnetic resonance experiment performed on single-crystal Fe(001) films. A significant thickness-dependent damping oscillation is found at low temperature induced by the quantum well states of the corresponding energy bands. Our findings not only explain the microscopic nature of the recently reported ultralow damping of Fe-based alloys, but also help for the understanding of the transport and dissipation process of orbital currents.

Poster Presentations: Poster Session 1 Tuesday

Poster Board No.	First Name	Last Name	Organisation	Paper Title
Applications: Biomimetic, neuromorphic, reservoir and probabilistic computing, Sensors, Recording and memories, Energy, Qubits				
1	Sachin	Gupta	University of Leeds	Electrically Switchable Ferromagnetic Josephson Junctions for Cyrogenic Memory
3	Volodymyr	Kruglyak	University of Exeter	Machine Learning using Chiral Magnonic Neurons
5	Yuto	Takatsu	University of Tsukuba	Theoretical Study of Application of Bi-2212 Cuprate Thin Film to Quantum Devices
Novel Characterisation Techniques: Photon, Neutron, Electron, Magnetometry, Imaging, Spectroscopies and Time-resolved studies				
7	Christy	Kinane	ISIS	Structrual and Magnetic Depth Profiling of Magnetic Thin Films with the POLREF Reflectometer
9	Jan	Rhensius	QZabre	High Resolution Tabletop NV Magnetometry
11	Rui	Yu	University College London	Tailoring unusual Ferrimagnetism of Rare-Earth Iron Garnet via Graphene Interlayers
Phenomena: Novel surface-interface behaviour, Emergent behaviour, Electric and voltage control, Anisotropy, Exchange bias and springs, DMI, skyrmions				
13	Jaehun	Cho	DGIST	The effects of magnetic field annealing on the magnetic properties of Co thin films
15	Robert	Frömter	Johannes Gutenberg University Mainz	Homochiral antiferromagnetic merons, antimerons and bimerons realized in synthetic antiferromagnets
17	Soumyarup	Hait	University of Leeds	Impact of the spin-orbit torque source and buffer layer on driving skyrmion dynamics in ultrathin magnetic multilayers
19	Dian Putri	Hastuti	National Institute of Advanced Industrial Science And Technology	The first and second-order magnetic anisotropy in multilayer Co/h-BN heterostructure
21	Ankit	Kadian	University of Delhi	Effect of Interfacial Exchange on Anisotropy and Magnetization Dynamics of Permalloy/L10-FePt Bilayers
23	Dominik	Legut	VSB - Technical University of Ostrava	Antiferromagnetic exchange coupling across transition metal films alloyed with magnetic elements
25	Naëmi	Leo	Loughborough University	Interfacial spin canting in a ferromagnetic metal-semiconductor bilayer
27	Byoung-Chul	Min	Korea Institute of Science and Technology	Electric-field control of magnetism using hafnia-based ferroelectrics
29	Lukas	Nowak	Charles University	Tailoring magnetic properties of Pt/Co/Pt via in-situ Ar+ ion irradiation
31	John Christopher	Osborne	University of Leeds	Optimisation of magnetic multilayers for surface acoustic wave-driven skyrmion motion
33	Servet	Ozdemir	University of Leeds	Observation of frustration and anomalous Nernst effect in metallo-molecular Kondo spin lattices
35	Debi	Rianto	Durham University	Enhanced Proximity-Induced Magnetization via interactions between two Pt/FM interfaces and the impact on Interlayer Coupling in FM/Pt/FM Systems
37	Ivan	Tarasov	University of Duisburg-Essen	Epitaxial Mn3−xGaC Antiperovskite / Fe bilayers: Control of magnetocaloric properties by exchange coupling
Quantum Materials: Topological systems, Dirac, Weyl, Superconductor, Low dimensional, van der Waals materials				
39	Callum	Brennan-rich	University of Leeds	Phase mapping of Magnetic FexSn1-x Thin Films
41	Daniel	Burrow	University of Manchester	Enhancement of spin signal via spin-dependent electron optics in graphene
43	Mairbek	Chshiev	Spintec, University Grenoble Alpes, Cea, Cnrs	Field-Free Spin-Orbit Torque Switching in Janus Chromium Dichalcogenides
45	Ismet	Gelen	University of Leeds	MBE growth of high-quality Bi2Se3 topological insulators on [0001] oriented sapphire substrate and with (Bi, In)2Se3 buffer layer
47	Ryo	Iijima	Institute of Chemical Research, Kyoto University	Device Width Dependence of Critical Current Density and Superconducting Diode Effect in Nb/V/Ta Artificial Superlattice
49	Fridrik	Magnus	University of Iceland	Magnetic ordering in Mn2GaC-based nanolaminated MAX and i-MAX phases
51	Ben	Muggleton	University of Leeds	Phase and Orientation Mapping of Topological Thin Film Heterostructure using 4D-STEM
53	Zac	Parkin	University of Leeds	Strange metal states and optical tuning in Bi2Se3 with molecular diodes
55	Xianggang	Qiu	Institute of Physics, Chinese Academy of Sciences	Visualization of skyrmion-superconducting vortex pairs in a chiral magnet-superconductor heterostructure
57	Kungwon	Rhie	Korea University	Quantum resonance effect in ultrathin Pt films
59	Abhirami	Saminathan	University of Leeds	Gate-driven studies in InAs/GaSb quantum well devices for the detection of spin-polarised edge states
61	Nathan	Satchell	Texas State University	Ferromagnetic Materials for Josephson π Junctions
63	Kanglin	Yu	Beihang University	Coherent magnon transport in a van der Waals antiferromagnet
Simulation and Theory: Micromagnetics, First principles, Quantum compute, Machine learning				
65	Bomin	Kim	University of Ulsan	Why Fe3GaTe2 has higher Curie temperature than Fe3GeTe2?
67	Thomas	Nussle	University of Leeds	Quantum thermal expectation values of spin systems from classical atomistic spin dynamics simulations

Poster Presentations: Poster Session 2 Wednesday

Poster Board No.	First Name	Last Name	Organisation	Paper Title
Functional Materials: Multiferroics, Magneto-optics, Magneto-ionics, Semiconductors and Molecular magnets, Hard magnets, Soft magnets				
2	Markus	Goessler	Chemnitz University of Technology	Magneto-ionic control of coupled spin-valve heterostructures
4	Mi-Jin	Jin	Institute for Basic Science	Strong spin-to-charge conversion driven by interfacial spin orbit coupling at full oxide ferromagnetic / quasi-2-dimensional structures
6	Nicola	Morley	University of Sheffield	Materials Informatics for Magnetic Thin Film Discovery
8	Frank	Tsui	Physics and Astronomy, Unc-chapel Hill	Novel molecular beam epitaxy synthesis of Heusler alloy-based short period superlattices
Nanostructures: Patterned, hybrid, self assembly, 3 - Dimensional				
10	William	Griggs	University of Manchester	Magnetic imaging of thermally switchable antiferromagnetic/ferromagnetic modulated thin films
Spintronics and Dynamics: Antiferromagnets, Altermagnets, Ultrafast dynamics, Domain wall motion, Magnonics, Spin-orbit torques, Spin transport, Caloritronics, Spin-charge conversion and other conversion phenomena				
12	Unnar	Arnalds	University of Iceland	Spin Polarization Profile and Terahertz Emission in Pt/(Amorphous CoAlZr) Bilayers and Multilayers Deposited via Magnetron Sputtering
14	Dirk	Backes	Diamond Light Source	Magnon-Magnon Coupling in a Pinned Synthetic Antiferromagnet
16	Christopher Elliot Alexander	Barker	National Physical Laboratory	Skyrmion motion in a synthetic antiferromagnet by asymmetric spin wave emission
18	Ben	Brereton	University of Leeds	Growth of chiral magnetic multilayers on topological insulator Bi2Se3 epilayers and observation of hosted spin textures
20	Jaeha	Choi	Pusan National University	Exploring the Magnetic and Topological Properties of Mn_3Ga Films
22	Guang-yu	Guo	National Taiwan University	Nonlinear electric generation of magnetization in time-reversal-even centrosymmetric metals
24				
26	Julia	Herrero-Albillos	Universidad de Zaragoza. INMA (CSIC-UZ)	Morphology and dynamics of domains and domain walls through asymmetric hole density-graduated 2D-arrays
28	Sohei	Horibe	University of Tokyo	Nonlinearly excited magnetization fluctuation in a nanoscale magnetic tunnel junction
30	Alexandra	Howzen	Texas State University	Development and Characterization of RuO2 and Mn5Si3 Altermagnetic Heterointerfaces for Applications in Josephson Junctions
32	Mae	Jankowski	University of Leeds	Bismuth ferrite-lead titanate thin films for an investigation of the effects of the morphotropic phase transition on magnetic properties
34	Keyu	Jing	Zhejiang University	Current-driven domain wall motion in ferrimagnetic nanowires
36	June-seo	Kim	DGIST	Magnetic domain wall-based spin torque majority gates: from domain wall input to full logic operations
38	Kitae	Kim	Seoul National University	Structure engineering of spin-sink for huge self-spin swapping effect
40	Minhwan	Kim	Seoul National University	Median Mishaps between Domain-Wall Chirality and Spin-Orbit Torque via Hysteresis Loop Shifts
42	Sanghoon	Kim	University of Ulsan	Neuromorphic behavior of Mn3Sn--based spin orbit torque device
44	Colin	Kirkbride	University Of Glasgow	Observation of a hybrid skyrmion domain texture in a Ga+ irradiated SAF system
46	Malena	Martinez Cameros	University of Leeds	Enhancing spin signals in pure spin currents
48	Shuto	Sahara	Kyushu University	Observation of Spin Seebeck Effect in YIG/Pt-Rh
50	Jiho	Shin	Seoul National University	Direct Observation of Plateau Formation in Ultrafast Spin-Orbit-Torque Driven Magnetization switching
52	Masamune	Taguchi	Kyushu University	Flexible magnetic sensor fabricated by drop casting method using multilayered film ink
54	Laura	Van Schie	Eth Zurich	Investigating Variation in Domain Wall Properties of RE-TM Ferrimagnets at the Compensation Point via Scanning NV Magnetometry
56	Garima	Vashisht	University of Leeds	Weak anti-localization in Bi implanted Cu devices
58	Maria	Velez	Universidad de Oviedo	Current induced thermally activated propagation of domain walls in NdCo5/Ni8Fe2 reconfigurable racetracks: exchange-bias and statistics
60	Yizheng	Wu	Fudan University	Real-time optically imaging the antiferromagnetic domain switching in CoO(001) films
62	Naoto	Yamashita	Kyushu University	Magnon Transport in Thulium Iron Garnet Fabricated by Radio-Frequency Magnetron Sputtering
64	Takumi	Yamazaki	Tohoku University	Quantitative measurement of figure of merit for transverse thermoelectric conversion in Fe/Pt metallic multilayers
66	Zhe	Yuan	Fudan University	Orbital-excitation-dominated magnetization dissipation and quantum oscillation of Gilbert damping in Fe films



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