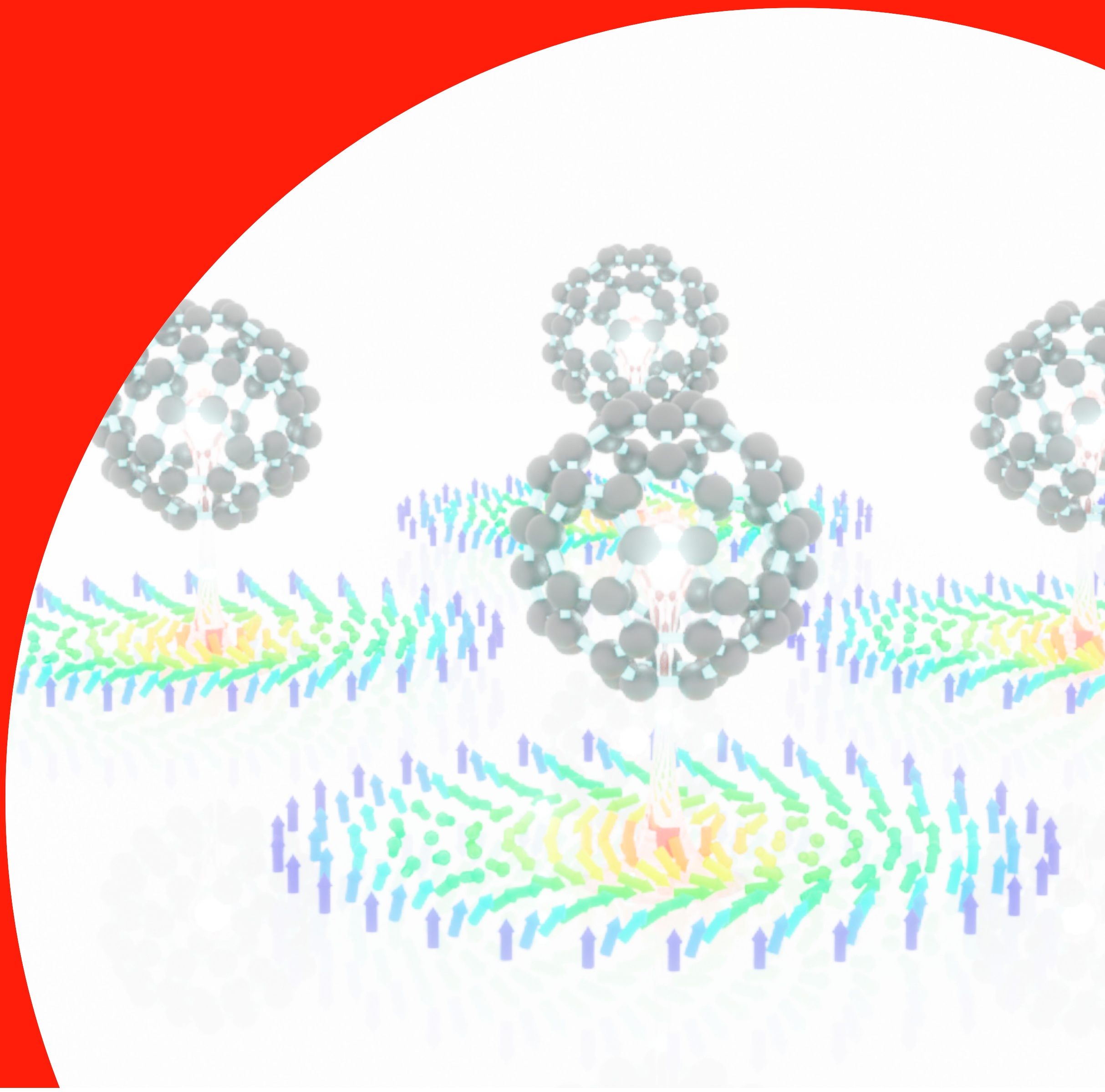
Magnetism 2025

7–8 April 2025

The Cutler's Hall, Sheffield, UK



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Magnetism 2025

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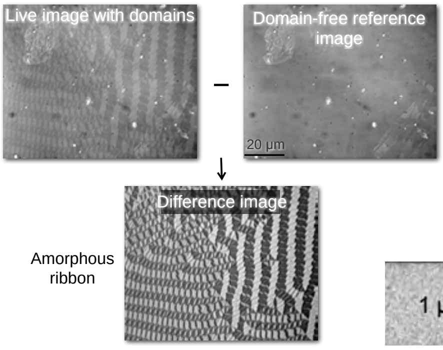
Magneto-Optical Kerr-Microscope & Magnetometer

The evico magnetics GmbH was founded in 2006 as spin-off of the Leibniz Institut for Solid State and Materials Research (IFW) Dresden. The main products are: (i) Advanced magneto-optical wide-field Kerr microscope systems for the visualization of magnetic domains and magnetization processes in all kinds of magnetic materials. The Kerr microscopes also serve as magneto-optical magnetometers for the sensitive and local measurement of hysteresis loops by MOKE magnetometry. (ii) High Pressure Milling Vials with a gas temperature monitoring system for the synthesis of magnetic powders and hydrogen storage materials. See www.evicomagnetics.com for information

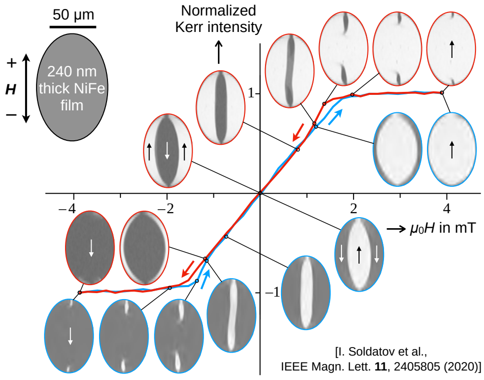
Image processing

Background subtraction eliminates topographic contrast, leaving just domain contrast that can be enhanced digitally



Magneto-optical (MOKE) magnetometry

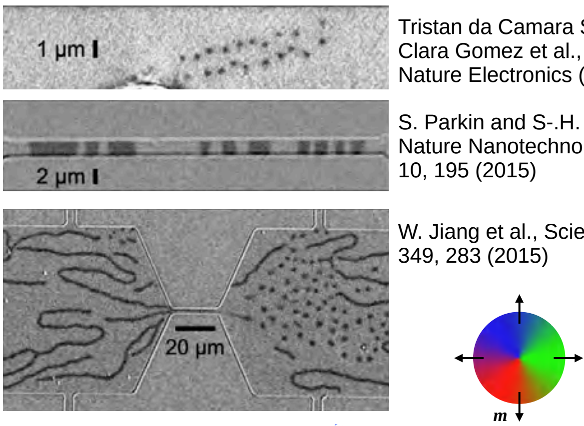
Our wide-field Kerr microscope serves as a *MOKE magnetometer* by plotting the Kerr intensity of a selectable image spot as a function of magnetic field. The domains responsible for the magnetization curve are supplied in real time



[I. Soldatov et al., IEEE Magn. Lett. **11**, 2405805 (2020)]

Current-induced domain generation and motion

The first experimental evidence for domain wall motion in the racetrack memory and skyrmionic-bubble generation by electrical currents was provided in evico magnetics Kerr microscopes

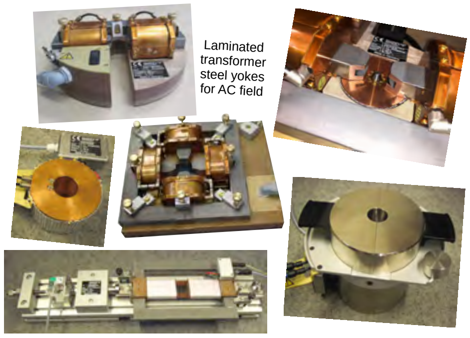


Tristan da Camara Santa Clara Gomez et al., Nature Electronics (2005)

S. Parkin and S.-H. Yang, Nature Nanotechnology 10, 195 (2015)

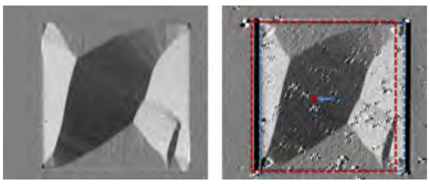
W. Jiang et al., Science 349, 283 (2015)

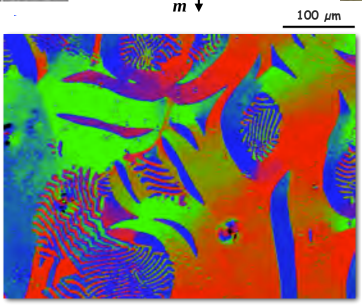
Numerous types of magnets for in-situ magnetization



Drift stabilization

Sample drift in all spatial directions is in-situ compensated to guarantee perfect domain images





I. Soldatov and R.S., Phys. Rev. B. 95, 014426 (2017)

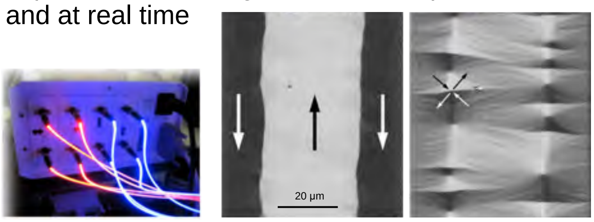
Quantitative Kerr-microscopy

Magnetization vector fields of soft magnetic specimens and their dynamics can be quantitatively measured

CGT crystal, 200 µm thick

Multi-component real-time imaging

Separated or combined imaging of longitudinal, transverse and polar magnetization components by sophisticated LED light source, computer-controlled and at real time

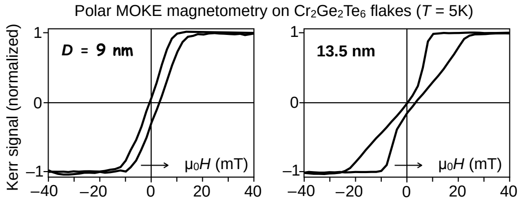


[I. Soldatov and R. Schäfer, Rev. Sci. Instrum. **88**, 073701 (2017)]

Low- and high-*T* MOKE

Domain imaging and magnetometry can be performed in a temperature range between 4 K and 850 K in optical cryostat and heating stages, compatible with in-plane and out-of-plane magnets

Polar MOKE magnetometry on $Cr_2Ge_2Te_6$ flakes (T = 5K)



[I. Soldatov, et al., IEEE Access 12, 181025 (2024)]

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Monday, April 7, 2025

	Room: Old Banqueting	Room: Drawing
9:00 AM - 10:00 AM	Registration and refreshments	
10:00 AM - 11:15 AM	Session 1: Spintronics 1 Invited Speaker: R. Lebrun Session Chair: Sergiu Ruta	Session 2: Thin films Session Chair: Nicola Morley
11:15 AM - 11:40 AM	Morning coffee break	
11:25 AM - 11:40 AM	Maximising the Benefits of IOP Membership - Matthew Lovell Whether you are an existing or prospective IOP member, Matthew will share his expertise and provide an overview of IOP member benefits. Matthew will also have a stand at the conference which you can visit during the refreshment breaks, lunch or networking sessions.	
11:40 AM - 1:00 PM	Session 3: Spintronics 2 Invited Speaker: G. Reiss Session Chair: Safeer Chenattukuzhiyil	Session 4: Quantum Material and Devices Session Chair: Freya Johnson
1:00 PM - 2:30 PM	Lunch and Careers panel / IEEE AGM Careers Panel will take place in the Old Banqueting room (Chair: Del Atkinson) and the IEEE meeting will take place in the Drawing room (Chair: Liam O'Brien)	
2:30 PM - 3:30 PM	Plenary: Tomas Jungwirth	
3:30 PM - 3:45 PM	Afternoon coffee break	
3:45 PM - 5:00 PM	Session 5: Spin Textures Session Chair: Kelly Morrison/ Tim Moorsom	Session 6: Patterned Thin Films and Nanomagnetism Invited Speaker: J. Gartside Session Chair: Paul Keatley
5:00 PM - 6:30 PM	Poster Session and Drinks Reception	
7:00 PM - 10:30 PM	Conference Dinner Included in the registration fee	

Tuesday, April 8, 2025

	Room: Old Banqueting	Room: Drawing
9:00 AM - 10:00 AM	Wohlfarth: Julie Staunton Chair: James McKenzie	
10:00 AM - 10:30 AM	Morning coffee break.	
10:30 AM - 12:00 PM	Session 7: High Frequency / Ultrafast Dynamics Invited Speaker: R. Mikhaylovskiy Session Chair: Maciej Dabrowski	Session 8: Low Dimensional Magnetism Invited Speaker: S. Chenattukuzhiyll Session Chair: Ivan Vera Marun
12:00 PM - 1:30 PM	Lunch and poster session / IOP AGM	
1:30 PM - 1:45 PM	Poster Awards Chair: Tom Hayward	
1:45 PM - 3:00 PM	Session 9: Intelligent Computing - Devices and Materials for Applications Session Chair: Jack Gartside	Session 10: Antiferromagnetism Invited Speaker: F. Johnson Session Chair: Rostislav Mikhaylovskiy
3:15 PM - 3:30 PM	Afternoon coffee break.	
3:30 PM - 5:00 PM	Session 11: Computational Chair: Julie Staunton	Session 12: Novel Phenomena and Techniques Invited Speaker: P. Wadley Session Chair: Trevor Almeida

Direct observation of self-supported vortex and skyrmion textures in 3D curved magnets

Almeida T, Fallon K, Dugato D, Kovács A, Cooper D, Dunin-Borkowski R, McVitie S, Garcia F

Session 5: Spin Textures, April 7, 2025, 15:45 - 17:00

Magnetic textures in self-supported nanostructures, such as vortex or skyrmion states, are promising for magnetic hyperthermia therapy and spintronics due to their low remanent state and topological protection. These configurations emerge from energy minimization in confined systems, and by controlling geometrical features such as their curvature it becomes possible to design magnetic structures with customized functionalities beyond the reach of planar structures.

This work presents the use of colloidal lithography to fabricate curved nanostructures with unique magnetic properties, called nanocaps (Fig. 1a) [1]. The magnetic properties of single-layer permalloy ($N_{80}Fe_{20}$) nanocaps were systematically studied using micromagnetic simulation modelling to create a phase diagram showing the ground magnetic state in relation to nanocap thickness and diameter, varying from onion, uniformly magnetised and vortex states (Fig. 1b). The advanced TEM technique of electron holography experimentally confirmed that nanocaps with diameter of 500 nm and thicknesses of 10 nm, 20 nm and 50 nm (Fig. 1c,d), all exhibited a vortex magnetic configuration as the ground state, consistent with the phase diagram.

Multi-layered [Pt(1 nm)/Co(t)/Pt(1nm)]×10 nanocaps with varying Co thickness (t) were fabricated to explore a range of chiral spin textures [2]. A phase diagram constructed using micromagnetic simulations showed the ground state in relation to effective radial anisotropy constant (K_rad) and interfacial Dzyaloshinskii-Moriya interaction (iDMI), varying from vortex, planar ring, stripe, radial state and skyrmionics states (Fig. 1e). The K_rad resulting in skyrmionic states corresponded to 2 nm thick Co layers and was examined experimentally using electron holography. The nanocap curvature provides a tilt angle required for electron holography to be sensitive to the in-plane magnetic component, ϕm, of Néel-type skyrmions. The phase image (Fig. 1f) and magnetic induction map (Fig. 1g) confirms the presence of a single Néel-type skyrmion (labelled 'sk') and is consistent with that observed from Néel skyrmions in thin films [3,4]. Some nanocaps with 2 nm thick Co layers are observed to comprise two skyrmions, whilst nanocaps with 1.5 nm thick Co layers are consistent with stripe domain states. This works provides fundamental insight into the impact of geometric curvature on controlling ground states and iDMI, allowing effective engineering of vortex and skyrmionic configurations without the need to apply fields at room temperature.

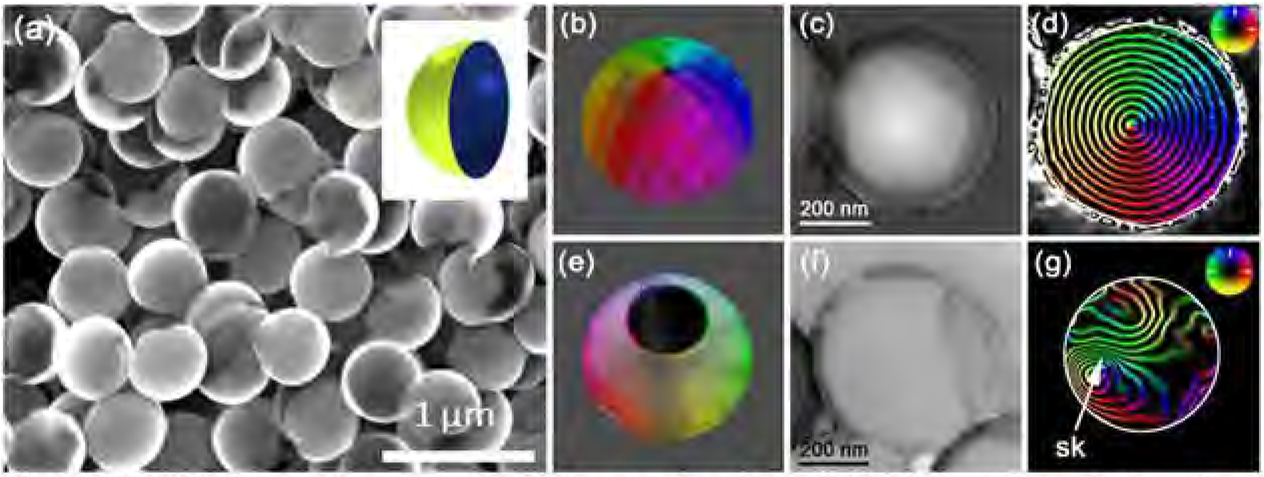


Figure 1. (a) SEM image of nanocaps (d = 500 nm) produced by colloidal lithography and schematic of their idealised geometry (inset). (b) Micromagnetic simulation; (c) electron holography phase image and (d) associated reconstructed magnetic induction map of a permalloy nanocap showing its vortex configuration. (e) Micromagnetic simulation; (f) phase image and (g) associated reconstructed magnetic induction map of a multi-layered [Pt(1 nm)/Co(2 nm)/Pt(1nm)]×10 nanocap confirming the presence of a single Néel-type skyrmion (labelled 'sk'). The contour spacings are (d) 1.26 rad and (g) 0.157 rad, and the direction of magnetic induction is indicated by the colour wheel (inset).

Skyrmion motion in a synthetic antiferromagnet by asymmetric spin wave emission

Barker C, Parton-Barr C, Marrows C, Kazakova O, Barton C

Session 7: High Frequency / Ultrafast Dynamics, April 8, 2025, 10:30 - 12:00

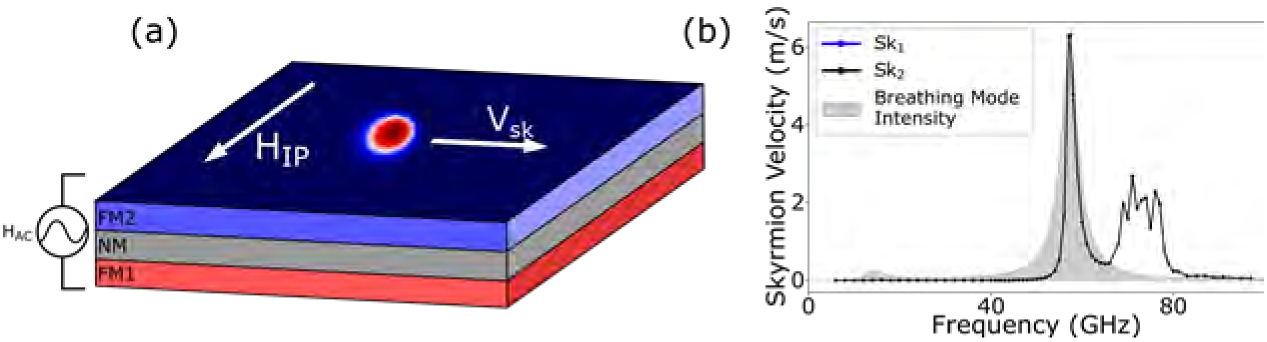
Skyrmions—topologically protected vortex-like spin structures—have been proposed as the new information carriers in racetrack memory devices [1]. To realise such devices, a small size; high speed of propagation; and minimal deflection angle are required. Modelling has shown that synthetic antiferromagnets (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.

[1] W. Jiang et al., Physics Reports 704, 1-49 (2017)
[2] R. Tomasello et al., J. Phys. D: Appl. Phys. 50 325302 (2017)
[3] W. Legrand et al., Nature Materials 19, 34 (2020)
[4] L. Qiu et al., Appl. Phys. Lett. 118, 082403 (2021)



Anisotropic magnetization dynamics in Fe5GeTe2 at room temperature.

Bera A, Jana N, Agarwal A, Mukhopadhyay S

Session 8: Low Dimensional Magnetism, April 8, 2025, 10:30 - 12:00

The determination of Lande’s g factor and the damping constant is central to extracting crucial information
about the spin-spin and spin-orbit interactions in magnetically ordered systems. In insulating compounds based
on 3d elements, the spin-orbit interaction can be effectively probed by investigating the ground state of the
corresponding free 3d ion within the crystalline environment. For metallic systems, the problem is nontrivial
because of additional band structure effects. Here, we investigate the anisotropic magnetization dynamics in bulk
single-crystalline Fe5GeTe2, a van der Waals 2D itinerant ferromagnet at room temperature, using broadband
ferromagnetic resonance spectroscopy. We demonstrate the absence of intrinsic anisotropy of magnetization
damping close to room temperature, suggesting diminished role of spin-orbit interaction. However, there is a
sizable anisotropy in the Lande’s g factor near room temperature, which is attributed to anisotropic critical spin
fluctuations. (DOI: 10.1103/PhysRevB.110.224401)

Direct Measurement of Interfacial Spin Pumping in NiFe/Cr/CoFeB Spin-Valves via Depth-Dependent Dynamic Probing

Bollard J, Hesjedal T, Van Der Laan G

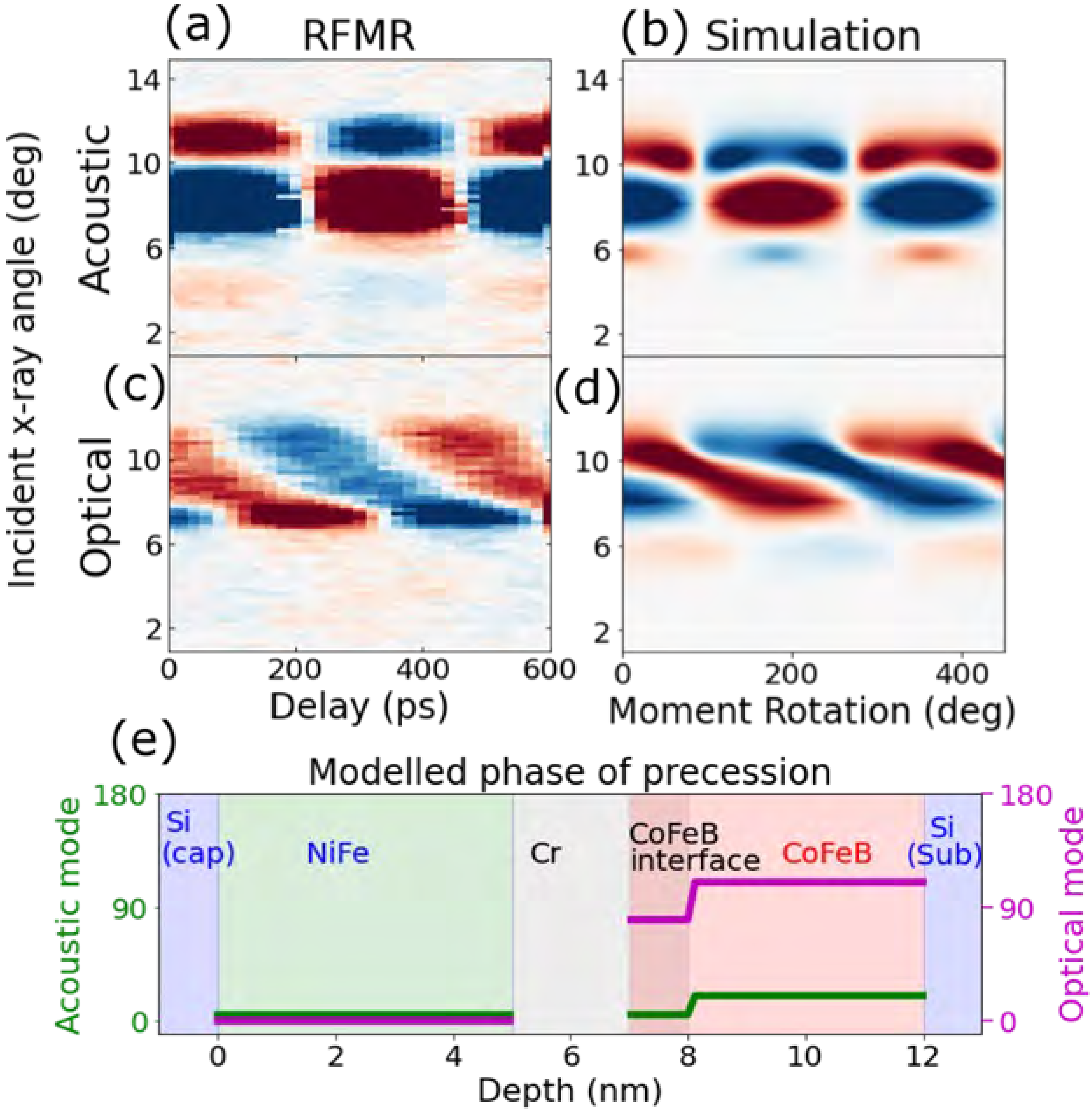
Session 12: Novel Phenomena and Techniques, April 8, 2025, 15:30 - 17:00

Spin-pumping is essential for transferring angular momentum across interfaces in magnetic heterostructures, but directly probing its depth-dependent effects remains a significant experimental challenge. Reflectivity ferromagnetic resonance (RFMR) combines the time resolution of x-ray detected ferromagnetic resonance (XFMR) with the depth resolution of x-ray magnetic reflectivity (XRMR) to probe magnetisation dynamics across buried interfaces [1].

Here, we investigate spin-pumping in NiFe/Cr/CoFeB spin-valves, where interfacial dynamics are influenced by Ruderman-Kittel-Kasuya-Yosida (RKKY) coupling. RFMR reveals a distinct precessional phase lag localised near the Cr/CoFeB interface, which is not captured by reflectivity models assuming homogeneous precession. Instead, our results indicate that spin current absorption is concentrated within an interfacial region extending beyond the structural roughness (~0.3 nm) but comparable to the transverse spin coherence length (~1 nm) (see Fig. 1). This region exhibits a unique precessional opening angle and phase shift, distinguishing it from the uniform magnetisation dynamics in the CoFeB bulk.

Our findings provide direct experimental evidence of interfacial spin-pumping and reveal the spatial extent over which angular momentum transfer occurs. By disentangling interfacial and bulk magnetisation dynamics, this work establishes a new methodology for studying buried spin transport phenomena, with implications for optimising spintronic devices and engineered heterostructures.

Fig. 1: Scattering angle dependence of the Fe dynamics: (a,c) RFMR measurements on the Fe L3 edge performed with a 2 GHz RF pump, showing data for (a) the acoustic mode at 90 mT and (c) optic mode at 40 mT. (b,d) Simulations using the XRMR model. These simulations provide depth-dependent profiles for the entire heterostructure as Fe is contained in both ferromagnetic layers. (e) Depth-dependent phase variations extracted from the simulations, illustrating the dynamic behaviour within the multilayer.


(a)
RFMR
(b) Simulation
Incident x-ray angle (deg)
Acoustic
Optical
(c)
(d)
Delay (ps)
Moment Rotation (deg)
(e)
Modelled phase of precession
Acoustic mode
Optical mode
Si (cap)
NiFe
Cr
CoFeB interface
CoFeB
Si (Sub)
Depth (nm)

Investigating the Spatial Phase Distribution in Magnetic FexSn1-x Thin Films

Brennan-rich C, Collins S, Drummon-Brydson R, Marrows C

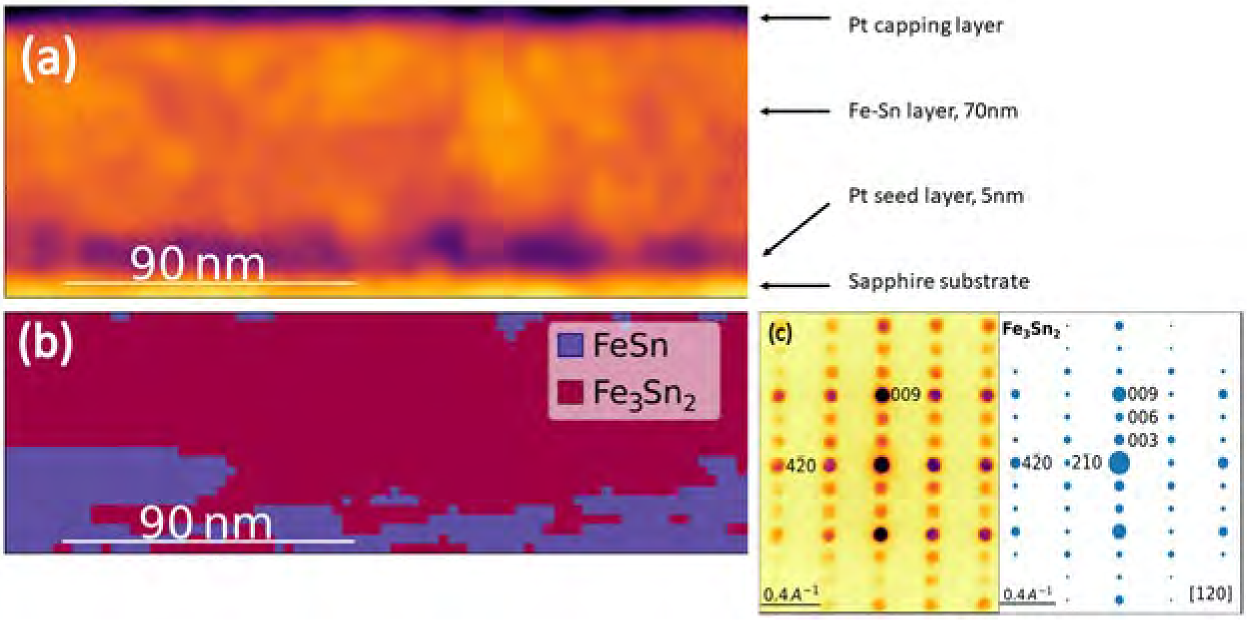
Session 2: Thin films, April 7, 2025, 10:00 - 11:15

The Fe-Sn intermetallic alloys form layered structures that have distinct magnetic properties. FeSn is an antiferromagnet [1] while Fe3Sn2 is a frustrated ferromagnet [2]: these differ only in the stacking sequence of their layers. Fe3Sn2 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. 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 its interaction with the antiferromagnetic-ferromagnetic boundary.

[1] H. Inoue et al., Molecular beam epitaxy growth of antiferromagnetic kagome metal FeSn, Appl. Phys. Lett. 115, 072403 (2019)
[2] M. Yao et al., Switchable Weyl nodes in topological kagome ferromagnet Fe3Sn2, arXiv:1810.01514, October (2018)
[3] L.A. Fenner, A.A. Dee and A.S. Wills, Non-collinearity and spin frustration in the itinerant kagome ferromagnet Fe3Sn2. J. Phys.: Cond. Matt. 21, 452202 (2009)
[4] Z. Hou et al., Current-Induced Helicity Reversal of a Single Skyrmionic Bubble Chain in a Nanostructured Frustrated Magnet, Adv. Mater. 32, 1904815, 2020
[5] D. Zhang, Z. Hou and W. Mi, Anomalous and topological Hall effects of ferromagnetic Fe3Sn2 epitaxial films with kagome lattice. Appl. Phys. Lett. 120, 232401 (2022)
[6] C. Wang et al., Manipulating and trapping skyrmions by magnetic field gradients, New J. Phys. 19 083008 (2017)
[7] S. Cheng et al., Atomic layer epitaxy of kagome magnet Fe3Sn2 and Sn-modulated heterostructures, APL Mater. 10, 061112 (2022)


(a)
90 nm
Pt capping layer
Fe-Sn layer, 70nm
Pt seed layer, 5nm
Sapphire substrate
(b)
FeSn
Fe3Sn2
90 nm
(c)
009
420
0.4 A-1
Fe3Sn2
009
006
003
420
210
0.4 A-1
[120]

Advancing Spatially Selective All-Optical Magnetic Switching in Nanomagnets for Magnetic Memory and Computing

Bromley D, Farchy T, Gartside J, Vanstone A, Cielecki D, Zheng T, Xiao X, Holder H, Stenning K, Sapienza R, Oulton R, Branford W

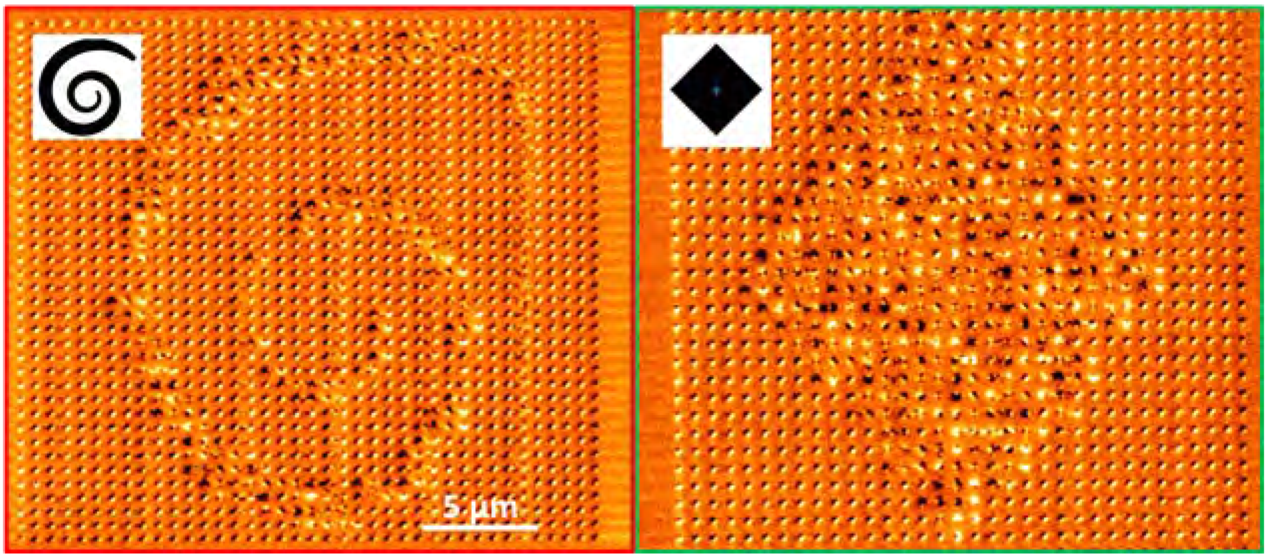
Session 9: Intelligent Computing - Devices and Materials for Applications, April 8, 2025, 13:45 - 15:00

The realisation of spatially selective control of nanomagnets using pulsed lasers, specifically through all-optical magnetic switching, promises ultrafast magnetisation control while circumventing the requirement for an external magnetic field, and addressing a longstanding goal in data storage and computational technologies.

Traditional state-control approaches, utilising magnetic field and thermal protocols, access only a limited fraction of magnetic microstates, while alternative techniques, such as scanning magnetic tips[1], are impeded by slow setups and susceptibility to tip damage. Furthermore, existing methodologies relying on complex magnetic materials[2] underscore the need for a rapid and localised microstate control method across extensive nanomagnetic networks.

Building on our prior breakthrough in all optical writing of single-layer NiFe nanomagnets within dense arrays[3] using continuous wave (CW) lasers, we have made significant progress in increasing the robustness, fidelity, and speed, and the complexity of the resulting magnetic textures. We observe that optimising the quality of the NiFe layer plays a crucial role in determining fidelity, even among samples with nearly identical coercive fields. NiFe is an exciting choice of material for AOMS technology. It is an affordable and non-toxic alloy, and eliminates the reliance on rare and geopolitically sensitive materials. Moreover, we have demonstrated that nanopatterned NiFe is highly amenable to optical writing using both continuous wave and fast pulsed laser illuminations. Additionally, our approach enables intricate microstate engineering of complex patterns to create magnetic images, greatly expanding potential applications in data storage and computational technologies.

1. Gartside, Jack C. Nature nanotechnology, 13.1 (2018): 53-58.
2. Igarashi, J. Nano Lett. 20, (2020): 8654–8660.
3. Stenning, Kilian D. Cell Reports Physical Science 4.3 (2023).



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

Burrow D, Deveci O, Thomson T, Vera-Marun I

Session 8: Low Dimensional Magnetism, April 8, 2025, 10:30 - 12:00

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 encapsulated graphene devices with magnetic point contacts [1,2,3] to investigate spin transport in the ballistic regime, motivated by a desire to reduce momentum scattering of spin carriers. We utilise transverse magnetic focusing to demonstrate 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. Furthermore, we observe structure in the focusing peaks consistent with spin-dependent quantum electron optics arising from the ferromagnetic nanowire contacts. We find that ballistic transport survives up to room temperature, paving the way for future applications of such devices. These experimental results constitute the first realisation of a ballistic spin valve transistor in 2d materials, with applications to spin pumping and spin filtering in quantum nanotechnology. Moreover, we hope this work will inspire future efforts towards building a comprehensive picture of ballistic spin transport in graphene, which requires innovative device design and new measurement paradigms.

[1] Guarochico-Moreira, V. H., et al. (2022). Nano Letters, 22(3), 935–941.
[2] Toscano-Figueroa, J. C., et al. (2024). Npj Spintronics, 2(1), 38.
[3] Burrow, D., et al. (2025). arXiv:2501.06160.

Physical Reservoir Computing with Voltage-Controlled Superparamagnetic Devices: Moving towards Real-World Application

Chen Z

Session 9: Intelligent Computing - Devices and Materials for Applications, April 8, 2025, 13:45 - 15:00

Zf. Chen1, A. Welbourne1, A. L. R. Levy3, M. O. A. Ellis2, H. Chen1 , M. J. Thompson1, D.A. Allwood1, N. A. Morley1, E. Vasilaki2, and T. J. Hayward1
1- Department of Materials Science and Engineering, University of Sheffield, UK
2 – Department of Computer Science, University of Sheffield, UK
3 - Department of Physics, École Polytechnique, Paris, France

Reservoir computing has continued to gain attention for its potential to reduce the energy consumption associated with training and running artificial neural networks and its ability to be realised with a plethora of physical systems [1]. While many devices have been proposed that meet the requirements of non-linearity and memory [2]-[4], questions remain as to how to tailor reservoir design (system and i/o) towards robust, energy-efficient and high accuracy operation for practical real world applications.

To best maximize the promised energy-efficiency, we have proposed a superparamagnetic nanodot ensemble based reservoir, driven by ultra-low-energy cost strain-induced magnetoelectric coupling stimulated by voltage (Fig. 1a) and have reported its theoretical feasibility with simulations [5]. Two key challenges stand in the way of realising this device. Firstly, translating the proposal to fabrication and, secondly, overcoming problems arising due to changes in temperature during computation in our thermally driven reservoir. Here, we present a series of experimental and simulation results that illustrate our milestone achievements in prototype preparation and thermal robustness.

In terms of fabrication, we introduce a fabrication roadmap (Fig. 1b) that achieves high-quality nanodot ensembles with minimum diameters of 65nm (Fig. 1c). Moreover, voltage medication of the magnetic anisotropy in our device (Fig. 1d) is experimentally demonstrated (verified by L-MOKE measurements), serving as a foundation toward ultra-low energy computing. On the question of enhancing the device's computational robustness, we propose a heterogeneous nanodot pattern (Fig. 1e) that offers higher thermal stability . By using a Bayesian optimization methodology we achieve a device that exhibits excellent thermal stability across a wide temperature range (Fig. 1f). By adaptive tuning of hyperparameters we can effectively balance peak performance and thermal sensitivity. Through progress on both threads we are approaching the first full experimental realisation
of our ultra-low-energy-cost, thermally-driven reservoir computing device.

[1] G Tanaka et al. ' Recent advances in physical reservoir computing: A review', Neural Networks, Volume 115, 2019, Pages 100-123, ISSN 0893-6080,
[2] G. Bourianoff, D. Pinna, M. Sitte, and K. Everschor-Sitte, 'Potential implementation of reservoir computing models based on magnetic skyrmions', AIP Adv., vol. 8, no. 5, p. 055602, May 2018, doi: 10.1063/1.5006918.
[3] K. Vandoorne et al., 'Toward optical signal processing using Photonic Reservoir Computing', Opt. Express, vol. 16, no. 15, p. 11182, Jul. 2008, doi: 10.1364/OE.16.011182.
[4] L. Appeltant et al., 'Information processing using a single dynamical node as complex system', Nat. Commun., vol. 2, no. 1, Art. no. 1, Sep. 2011, doi: 10.1038/ncomms1476.
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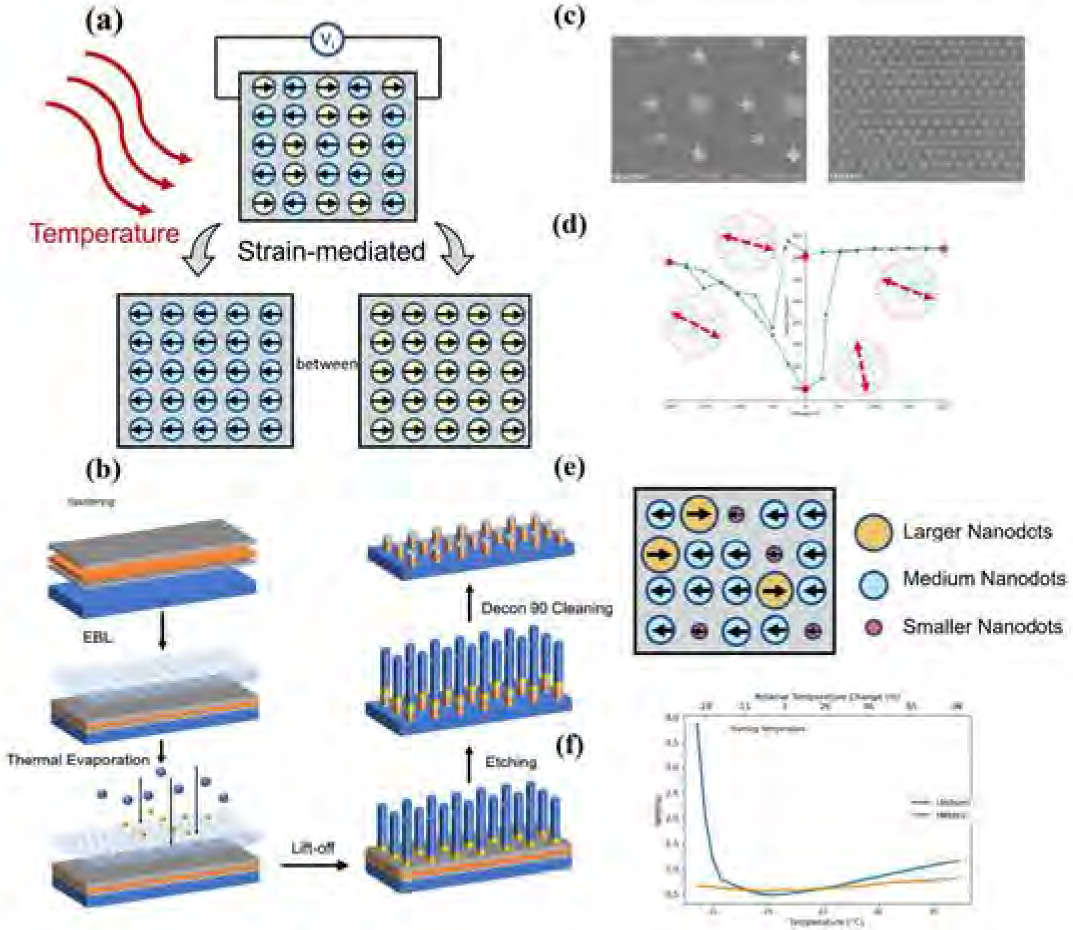

Figure 1: (a) A schematic diagram of voltage-controlled superparamagnetic nanodot ensemble subjected to temperature variations, (b) A schematic diagram of the preparation route, (c) An SEM picture of nanodot array with alignment marks(left) and an SEM picture of nanodots with a diameter of 70nm (right), (d) Variation of the anisotropy axis angle as a function of the applied voltage on the PMN-PT/CoFeB heterostructure, (e) A schematic diagram of the heterogeneous reservoir and (f) The comparison of NRMSE value in NARMA-10 across temperatures for uniform and heterogeneous reservoirs.

Spin-charge interconversion in 2D van der Waal materials

Chenattukuzhiyil S

Session 8: Low Dimensional Magnetism, April 8, 2025, 10:30 - 12:00

Graphene has been known as an excellent material for long-distance spin transport due to its weak spin-orbit coupling (SOC). However, the same reason makes graphene an adverse candidate for different spintronics applications in which strong SOC is required, such as the spin-charge interconversion applications. It was predicted theoretically that SOC can be induced in graphene so that spin-orbit phenomena such as spin Hall effect (SHE) or Rashba-Edelstein effect can be obtained. In our work, by using van der Waals heterostructure-based lateral spin valve [1], we experimentally demonstrated the first unambiguous measurement of spin-to-charge conversion (SCC) due to SHE in graphene via spin-orbit proximity with transition metal dichalcogenides (TMD), MoS2[2] and WSe2 [3]. We extended similar experiments in graphene combined with an insulator, Bi2O3[4] and CuOx[5]. Then we demonstrated gate tuneable SHE in graphene with SCC efficiency larger than in some of the best SCC materials such as topological insulators [3]. Using a similar approach, we performed another set of experiments demonstrating large-efficiency SCC in semi metallic TMDs such as MoTe2 [6-8], NbSe2 [9], and TaS2 [10]. Also, due to the low symmetry crystal structure of these materials, we detect, along with the conventional SCC, unconventional SCCs where the spin polarization, the spin current and the charge current are not mutually orthogonal to each other. In summary, all these different experiments spread light into the understanding of spin-orbit effects in van der Waal materials opening exciting opportunities in a variety of future spintronic applications.

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Spiral annealing influence on magnetic properties in magnetic microwires

Chizhik A, Zhukov A

Session 12: Novel Phenomena and Techniques, April 8, 2025, 15:30 - 17:00

A pre-processing technique named "spiral annealing" was applied for the first time to cylindrical magnetic microwires. In this process, the sample was arranged in a flat spiral shape during annealing, and subsequent measurements were conducted on the unbent sample with the induced stress distribution along and transverse to the sample. The research utilized both magnetic and magneto-optical methods. The original method developed by us for observing magnetic structures on curved surfaces was applied [1]. The distribution of the bending stress is shown in volume of sample Fig. 1a) and in cross-section Fig 1b).
The anisotropy field magnitude in both the volume and surface of the microwire was measured, and for the first time, a direct correlation between the anisotropy field and the curvature of a spirally annealed microwire was established. Additionally, a connection between the type of surface domain structure and the degree of spiral curvature was identified. The preservation of the distribution of spiral annealing-induced magnetic properties both along and across the microwire is a key effect influencing the technological application of the microwire. The range of induced curvature within which a specific helical magnetic structure can exist was also determined. This insight links the conditions of spiral annealing to the selection of microwires as active elements in magnetic sensors.

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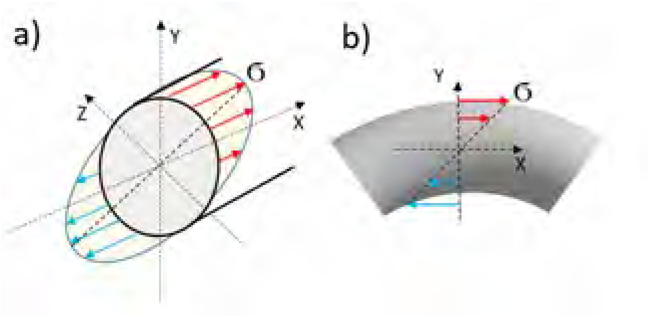

Ultrafast setting of exchange bias by single-shot laser pulses

Cronshaw C, Evans R, Chantrell R

Session 11: Computational, April 8, 2025, 15:30 - 17:00

Since its discovery in 1956 [1], exchange bias (EB) has been an intriguing and complex phenomenon in magnetism. EB traditionally refers to the interaction between an antiferromagnet and a ferromagnet, which, when cooled through its Néel temperature, pins the ferromagnet magnetisation, causing a shift of the ferromagnet's hysteresis loop [2]. However, recent studies have investigated the interaction between a ferrimagnet and an antiferromagnet. Whilst exchange bias currently plays a crucial role in applications including spintronic devices, magnetic sensors and data storage, the study of antiferromagnetic/ ferrimagnetic bilayers offers additional applications. The possibility of switching the exchange bias of a ferrimagnetic/ antiferromagnetic bilayer with single-shot laser-induced switching within picosecond and femtosecond time scales was recently discovered [3]. However, the physics of the process is not fully understood. Here we present atomistic simulations of single-shot ultrafast switching of coupled IrMn/CoGd, including the granular structure of the γ-$IrMn_3$ film [4]. We demonstrate that the value and sign of the exchange bias field can be controlled through the application of a single femtosecond laser pulse in the IrMn/CoGd bilayers, shown in Fig 1. We show that the application of a femtosecond laser pulse causes single-shot reorientation of the antiferromagnet, repeated for 10 pulses and 268 grains. Our results show a complex switching process for IrMn that is probabilistic in nature, with each laser pulse completely demagnetising the IrMn, preventing the switching displaying accumulative effects. We find the exchange bias is set by the exchange originating from the Co sublattice rather than an externally applied field, setting in picoseconds, and providing the fastest and most energy efficient method of setting the exchange bias. The high ordering temperature and thermal stability of the IrMn/CoGd bilayers make it highly suited for applications within ultrafast spintronic devices. This work used the ARCHER2 UK National Supercomputing Service (https:/www.archer2.ac.uk).

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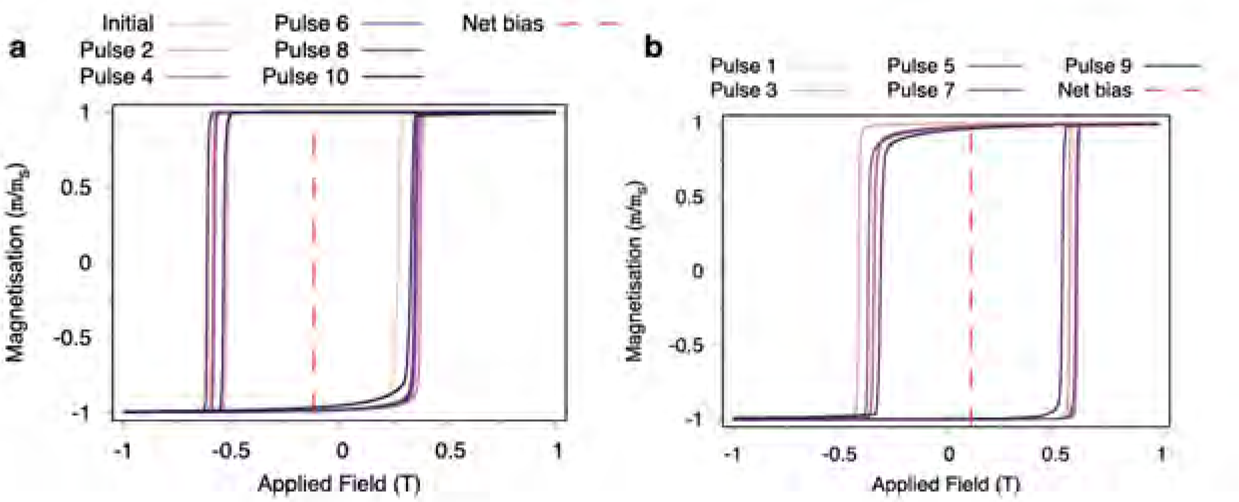


Laser-induced manipulation of antiferromagnetic NiO and CoO domains

Dabrowski M, Wu T, Sait C, Xu J, Keatley P, Wu Y, Gomonay O, Hicken R

Session 10: Antiferromagnetism, April 8, 2025, 13:45 - 15:00

Laser pulses promise the fastest and most energy efficient means of manipulating electron spin, offering applications in magnetic data storage. Unlike ferromagnetic and ferrimagnetic materials, the optical control of antiferromagnets (AFMs) is largely unexplored, primarily due to difficulties in detecting AFM domains with conventional methods. Furthermore, optical manipulation of magnetic domains usually involves an ultrafast demagnetization, where laser pulses lead to a strong non-equilibrium excitation of the material's electron system, which subsequently transfers its energy to the spin system. However, since most AFMs are insulators, the photon energies typically obtained from lasers do not facilitate this type of excitation.

Here, we utilize a magneto-optical birefringence effect to directly image fully compensated AFM domains in thin epitaxial CoO and NiO films grown on MgO(001) substrates. This method enables the detection of in-plane projections of the Neel vector, while eliminating artifacts from surface morphology. In the ground state, the shape of the AFM domains preferentially reflects the <100> crystallographic symmetry, with spins oriented along two orthogonal axes, <110> and <1-10> (see Figure 1). To enable absorption and ultrafast demagnetization, we use an adjacent metallic layer, allowing laser pulses with photon energy below the bandgap of the insulating AFM to excite the hot electron system of the metallic layer, which then transfers energy to the AFM's spin system. Our results demonstrate that the domain structure of both CoO and NiO films can be modified by exposure to optical pulses, provided they are capped with metallic layers. The optical pumping typically results in the creation of smaller domains, randomly shaped domains, with the spins remaining along the <110> and <1-10> axes. Under specific conditions, we demonstrate that partial switching of the AFM domains can be achieved by sweeping the laser beam across the sample surface along the <1-10> axis.

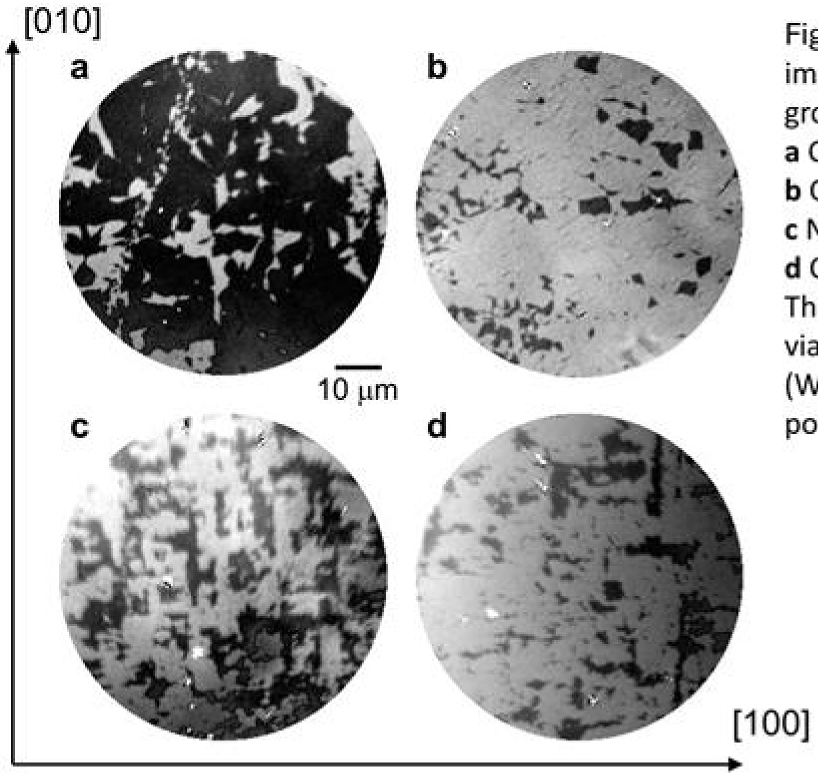
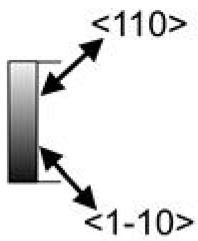


Figure 1. Domain structure images of thin CoO and NiO films grown on MgO(001):
a CoO(8 nm)/Al2O3 (3nm),
b CoO(8nm)/Pt(2nm)/Al2O3(3nm)
c NiO(16nm)/Pt(2nm) and
d CoO(8nm)/NiO(5nm)/Pt(2nm).
The measurements were acquired via wide-field Kerr microscopy (WFKM) at RT with the light polarization along the <100> axis.



Gilbert damping in large-area CVD monolayer MoS2/permalloy heterostructures

De Libero H, Chalmers E, Natera Cordero N, Strudwick A, Vera Marun I, Thomson T

Session 8: Low Dimensional Magnetism, April 8, 2025, 10:30 - 12:00

The understanding of Gilbert damping in NM/FM heterostructures is critical for the advancement of next-generation spintronic devices [1]. While damping mechanisms in conventional NM/FM heterostructures are well-studied, 2D-material/FM heterostructures are an emerging field. Transition metal dichalcogenides (TMDs), notable for their high spin-orbit coupling and charge-to-spin conversion capabilities, have garnered significant interest for spintronic applications [2] and advances in fabricating large-area TMDs demonstrate a viable route towards applications [3]. However, key mechanisms in charge-spin conversion and spin relaxation need further study.
Here, we report on Gilbert 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. By varying the NiFe thickness, we explored both bulk and surface contributions to Gilbert damping [4]. Notably, our results show no enhancement in effective damping due to spin pumping. However, the bulk damping contribution to the effective damping in NiFe increased when interfaced with monolayer MoS2 compared to SiO2 (Fig. 1).
X-ray diffraction analysis indicated an increase in (220) and a decrease in (111) crystallite grains for NiFe grown on MoS2, suggesting a link between crystallinity and bulk damping via spin-lattice scattering. Atomic force microscopy also revealed an increased surface roughness for 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 results highlight the significance of optimizing ferromagnet growth parameters on large-area TMDs to control Gilbert damping, which is crucial for the development of efficient spintronic devices.

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

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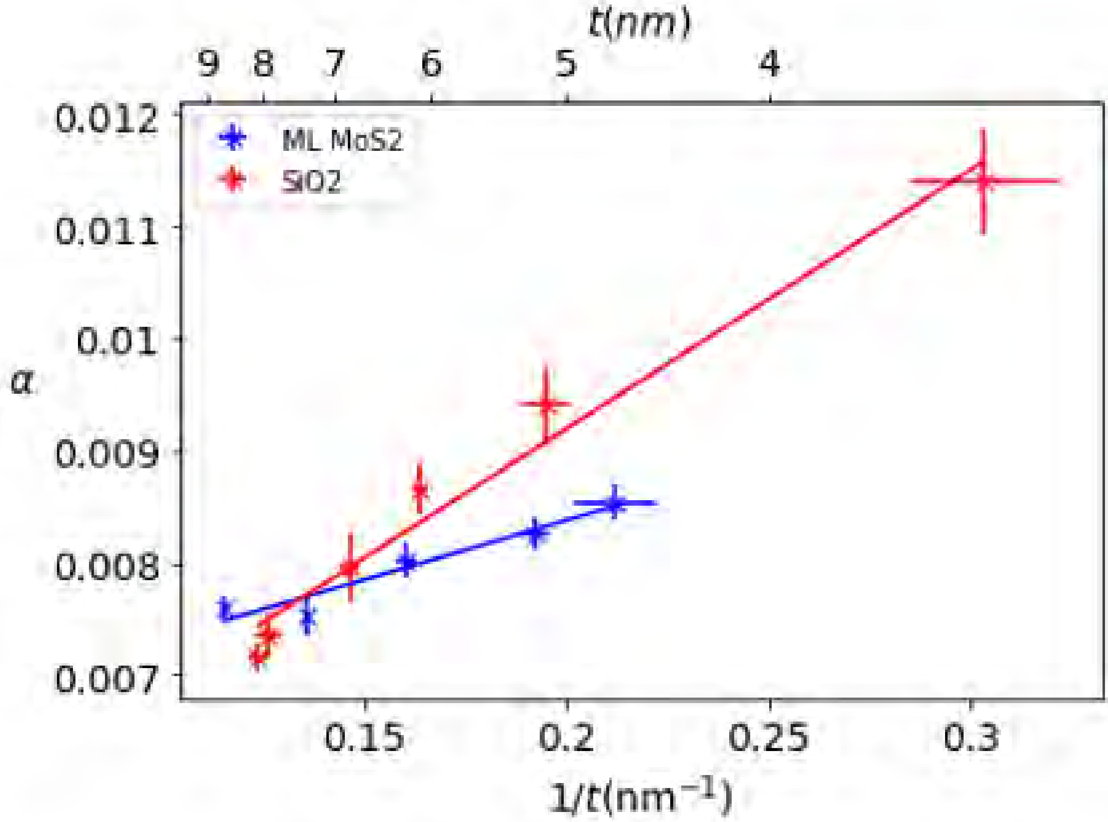
t(nm)
9
8
7
6
5
4
0.012
0.011
0.01
0.009
0.008
0.007
α
ML MoS2
SiO2
0.15
0.2
0.25
0.3
1/t(nm⁻¹)

Current driven magnetisation reversal in CoFeTaB/Pt probed by X-ray magnetic reflectivity

Dhaliwal K, Fan R, Burn D, Alsaeed K, Inyang O, Bouchenoire L, Hindmarch A, Steadman P

Session 2: Thin films, April 7, 2025, 10:00 - 11:15

Electrical control of magnetisation is a promising avenue for magnetisation manipulation beyond the conventional external magnetic fields. In this work, the current driven magnetisation reversal in CoFeTaB/Pt is investigated taking advantage of the magnetisation direction and the polarisation dependence of the X-ray scattering cross-section [1]. The current is applied perpendicular to the scattering plane (refer to fig. 1a for measurements geometry) to induce magnetisation reorientation in the scattering plane (formed by incoming and outgoing X-rays) [2] and hysteresis curves are measured during the current cycle using both helicities of circular polarisation at different temperatures (100-290K). The asymmetry ratios calculated from the measured reflectivity, presented in fig. 1b, reveal transitions between two magnetic states. The XRMR asymmetries, measured at Fe-L3 resonance with both helicities show slight variations in both magnetic states. The measurements with linear polarisation (more sensitive to the out of scattering plane components of magnetisation) show significant asymmetries, suggesting a substantial perpendicular magnetisation component in the current-driven states and hence, incomplete magnetisation switching with applied current [3]. To probe the interfacial magnetism, proximity-induced magnetism in the Pt layer is measured by tuning the incident energy to Pt-L3 resonance and perform XRMR measurements with circular polarisation. The measurements confirm that the Pt magnetic moments follow the CoFeTaB magnetisation. The measurements reveal a decrease in the current-driven coercivity as well as saturation magnetisation of CoFeTaB with increasing temperature, which follows the same trend as their magnetic field driven counterparts (probed using vibrating sample magnetometry) as shown in fig. 1c and d. The critical reversal current is found to be relatively insensitive to the change in temperature.
Figure 1. (a) Schematic of the measurements geometry, (b) Asymmetry ratio calculated from circular polarised reflectivity measured during a current hysteresis cycle at different temperatures, temperature dependence of current and magnetic field driven (e) saturation magnetisation and (f) coercivity of CoFeTaB/Pt heterostructure derived from reflectivity measurements for current driven and magnetometry for magnetic field driven hysteresis curves

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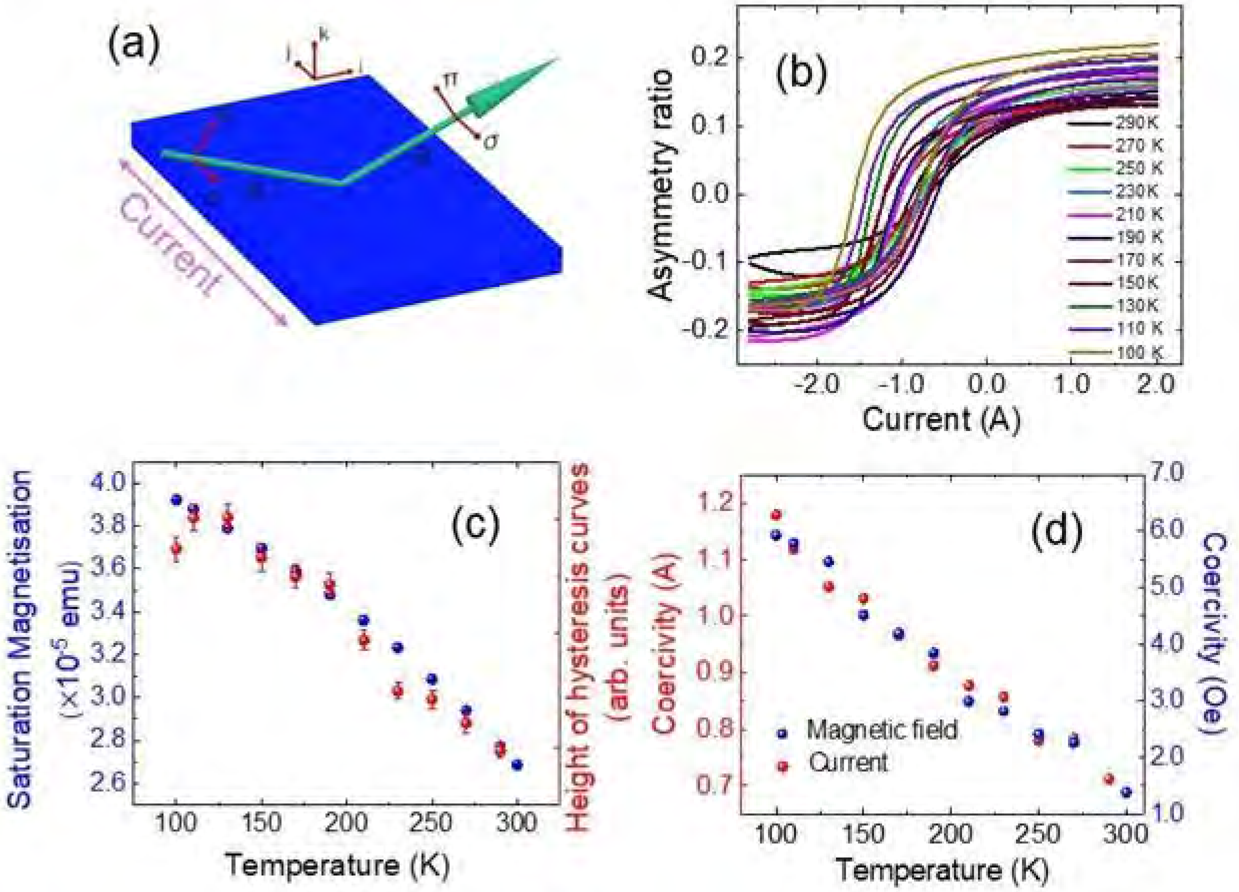
(a)
Current
(b)
Asymmetry ratio
Current (A)
290 K
270 K
250 K
230 K
210 K
190 K
170 K
150 K
130 K
110 K
100 K
(c)
Saturation Magnetisation (×10^-5 emu)
Height of hysteresis curves (arb. units)
Temperature (K)
(d)
Coercivity (A)
Coercivity (Oe)
Magnetic field
Current
Temperature (K)

Dynamics of the altermagnetic candidate compound UCr2Si2C

Biniskos N, dos Santos Dias M, Schmalzl K, Piovano A, Bengaard Hansen U, Valiska M, Cermak P

Session 12: Novel Phenomena and Techniques, April 8, 2025, 15:30 - 17:00

Altermagnets are collinear antiferromagnets where spin degeneracy of the electronic bands or twofold degeneracy of the magnon bands is not enforced by symmetry, potentially enabling an array of diverse physical phenomena. However, it remains challenging to find materials that experimentally exhibit the hallmarks of altermagnetism. UCr_2Si_2C has been recently reported as a high-temperature antiferromagnet with a rather unique crystal structure [1].

This talk will report on our combined experimental and theoretical investigation of this compound. A large single crystal was successfully grown and experimentally investigated with bulk specific heat and magnetic susceptibility measurements, and through neutron diffraction and inelastic neutron scattering. These experimental results have been interpreted with density functional theory calculations, providing a unified picture of UCr_2Si_2C and of its prospects as an altermagnet.

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Role of anisotropy in the Curie temperature of 2D vdW ferromagnets

Jenkins S, Atxitia U, Santos E, Evans R

Session 11: Computational, April 8, 2025, 15:30 - 17:00

In three-dimensional magnetic materials the magnetic anisotropy has a weak effect on the Curie temperature, which is primarily determined by the exchange interactions between the magnetic moments. However, in two-dimensional magnetic materials the effects may be different. Previously we have studied the role of finite size effects in van der Waals 2D magnetic materials and found that the well-known Mermin-Wagner-Hohenberg theorem predicting no magnetic ordering for an isotropic 2D magnetic system is only valid in the true thermodynamic limit of an infinite system [1]. Atomically large systems with a lateral size L in the micrometre range are still well-ordered, even in the absence of magnetic anisotropy. In this presentation, we extend this work to investigate the effect of magnetic anisotropy strength on the Curie temperature of 2D magnetic materials using large-scale atomistic simulations using the VAMPIRE software package [2]. We find that the anisotropy has a unexpectedly large effect on the Curie temperature as shown in Fig. 1, in contrast to a 3D sample where the effect is weak. Large anisotropies typical of permanent magnetic materials can increase the Curie temperature by as much as 60% compared to an isotropic sample, an effect which is also finite-size dependent. We will present additional calculations of susceptibility and specific heat capacity that is indicative of separate energetic and magnetic phase transitions that are unique to 2D magnetic materials, and provide new insights into their fascinating and unique thermodynamic properties.

This work used the ARCHER2 UK National Supercomputing Service (https:/www.archer2.ac.uk).

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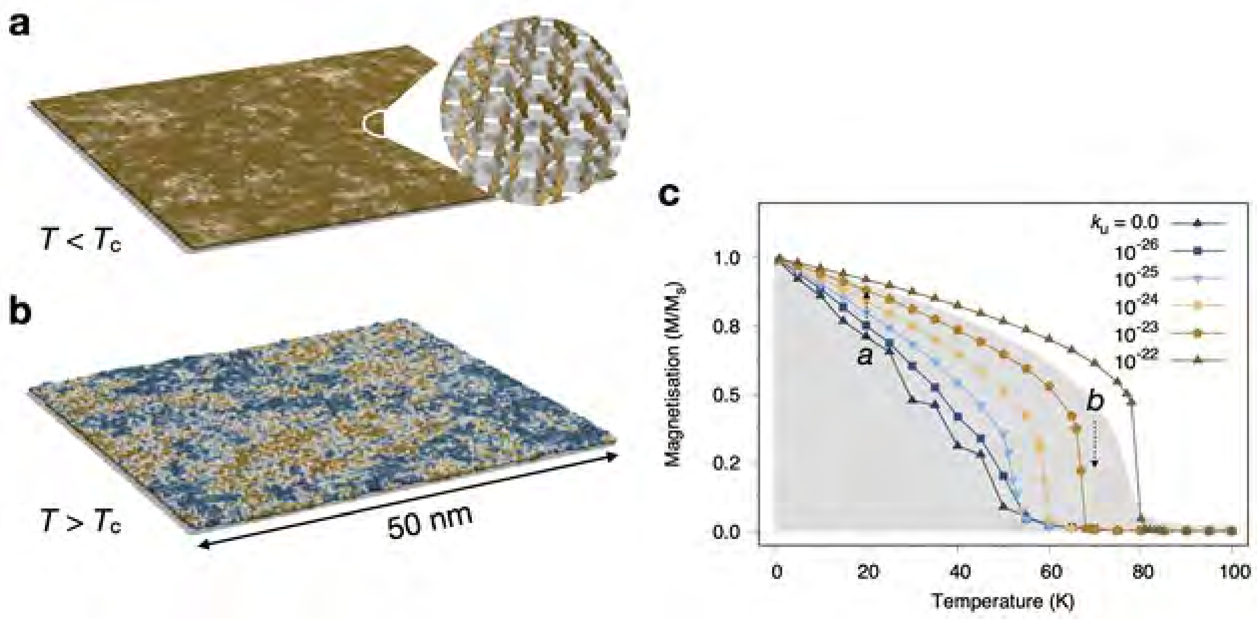

Effect of Gas Composition on Sputtered PtMn

Frost W, Carpenter R, Vallejo Fernandez G

Session 10: Antiferromagnetism, April 8, 2025, 13:45 - 15:00

Understanding of Antiferromagnetic materials (AFs) is vital for future device applications, such as SOT-AF (spin-orbit torque) spintronics. Upon annealing, PtMn with 1:1 stoichiometry crystallises in the face-centred tetragonal (fct) $L1_0$ structure which exhibits AF ordering and has a high spin-hall angle. Sputtered PtMn is usually in the paramagnetic, face-centred cubic phase prior to annealing. In this work we have varied the gas composition from 100:0 Ar:Kr to 0:100 Ar:Kr in steps of 0.25 of a PtMn layer deposited on a Pt seed layer, based on previous work [1]. By changing the sputter gas mixture, the sputter yield and kinetic energy of liberated atoms as well as their mean free path are changed once sputtered. A CoFe layer has been used to probe the magnetic ordering of the PtMn via the exchange bias effect, Hex. In all cases, the as deposited films are fcc and therefore show no exchange bias.

Figure 1a shows the effect of sputter gas composition as a function of annealing time at an optimised temperature of 400°C. The value of Hex increases monotonically with Kr content. For samples with Kr content 50% or greater, there is a peak in the value of Hex after 12 hours, implying significant transition to the fct phase has occurred. Figure 1b shows a pole figure of the PtMn {111} peak after annealing at 400°C for 90 minutes and confirms the textured growth of {111} oriented films with a 2D random distribution indicated by the uniform ring in the rotational axis, β.

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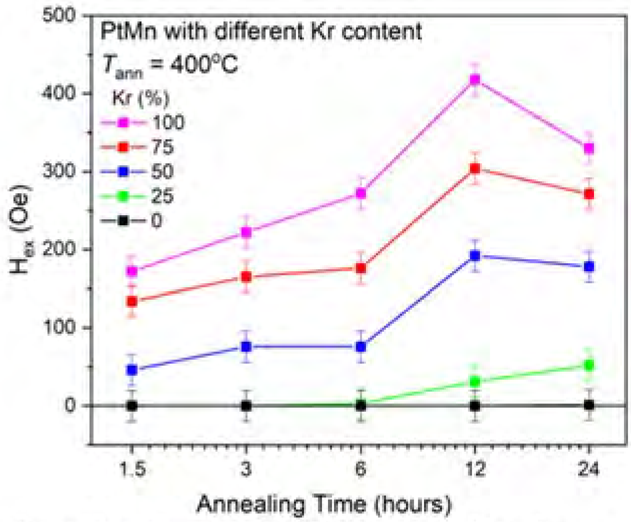

Figure **1a**: H_{ex} as a function of annealing time at 400°C for different gas compositions.

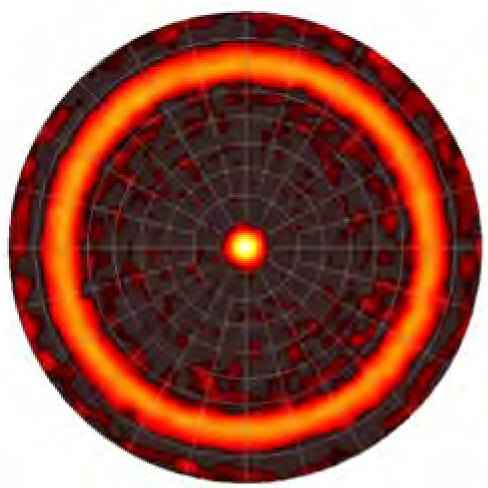

Figure **1b**: Pole figure of the Ptmn {111} reflection showing textured growth.

New Routes to Nanomagnetic Writing: a Linearly Polarised Magneto-Plasmonic Inverse Faraday Effect

Gartside J

Session 6: Patterned Thin Films and Nanomagnetism, April 7, 2025, 15:45 - 17:00

Nanomagnetic arrays are well suited for information processing, both as data storage as in hard drives, and more recently in biologically inspired neuromorphic computing systems where strong coupling between neighbouring nanomagnets allows physical realisation of neural networks.
As seen in the 2024 Physics Nobel Prize, magnetic arrays such as Hopfield networks hold substantial promise for implementing efficient physical learning. Recent experimental work by our team at Imperial College London [1-5] has implemented neuromorphic computing in nanoscale on-chip magnetic arrays, with one outstanding issue to be solved - rapid, high-dimensional data input.
Optically writing information into magnetic arrays is a promising route to explore, but existing methods require expensive exotic materials, high powered lasers and have not yet demonstrated the ability to write dense arrays of magnets - crucial for computing applications.
Here we examine magnetic writing of collinear & chiral textures in nanomagnets via an inverse Faraday effect from linearly polarised light, harnessing plasmonic resonances of NiFe nanoislands [6].
Using experimental data supported by optical & magnetic simulations, we demonstrate ps-scale optical writing in nanoarrays.

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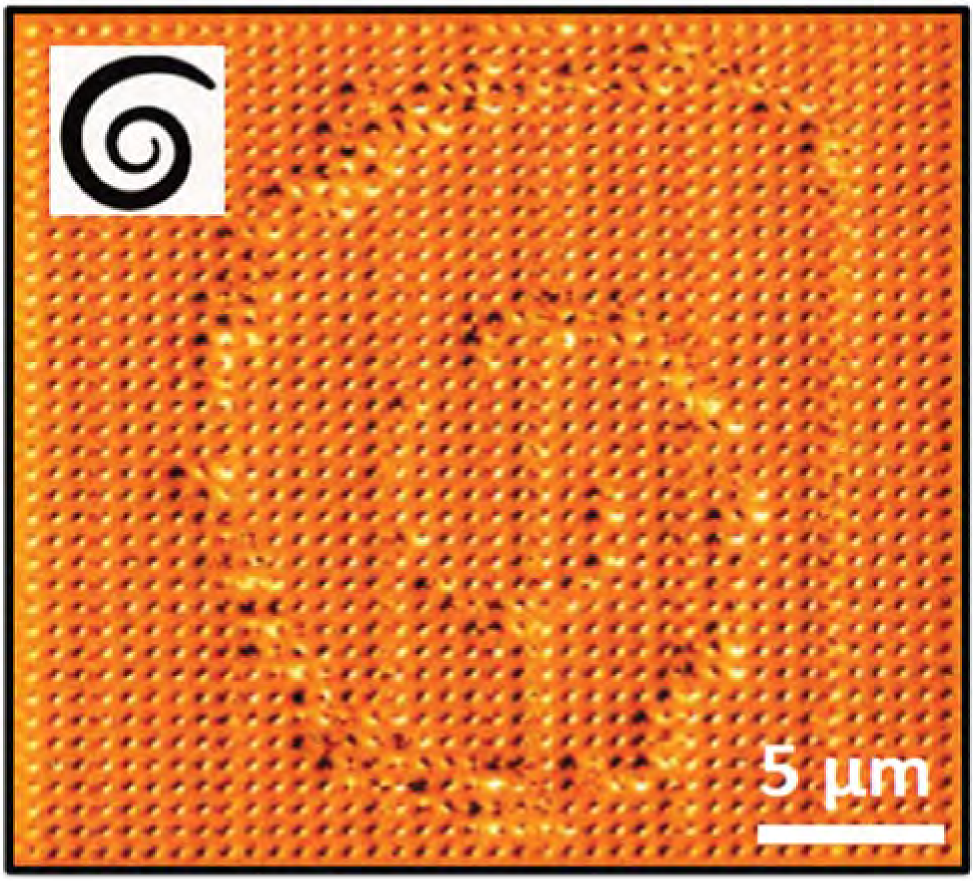

Multiscale micromagnetic / atomistic modeling of heat assisted magnetic recording

Gija M, Dobrynin A, McNeill K, Gubbins M, Mercer T, Bissell P, Lepadatu S

Session 2: Thin films, April 7, 2025, 10:00 - 11:15

Heat-assisted magnetic recording (HAMR) is an advancement in magnetic recording, significantly increasing the areal density capability (ADC) of hard disk drives (HDDs) compared to current perpendicular magnetic recording (PMR) technology. This is enabled by high anisotropy FePt media, which needs to be heated through its Curie temperature (TC) to facilitate magnetization reversal by an electromagnetic write pole. HAMR micromagnetic modelling is therefore challenging, as it needs to be performed in proximity to and above TC, where a ferromagnet has no spontaneous magnetization. An atomistic model is an optimal solution here, as it doesn't require any parameter renormalization at any temperature. However, a full track atomistic recording model is extremely computationally expensive. Here we demonstrate a true multiscale HAMR modelling approach using BORIS [1]. The simulation region consists of a central atomistic modelling window for accuracy at high temperatures near Tc, and adjacent micromagnetic modelling windows for low temperatures. The simulation windows are exchange coupled across the boundaries and the stray field contributions fully computed while the simulation region moves along the track at a set velocity. The advantages of this approach include natural emergence of TC and anisotropy distributions of FePt grains. Efficient GPU optimization of the code provides very fast running times, with a 60 nm wide track of twenty-five 20 nm - long bits being recorded in several hours on a single GPU. The effects of realistic FePt L10 vs simple cubic crystal structure is adressed, with the latter providing further running time gains while keeping the advantages of the multiscale approach.

[1] Serban Lepadatu; Boris computational spintronics—High performance multi-mesh magnetic and spin transport modeling software. J. Appl. Phys. 28 December 2020; 128 (24): 243902.

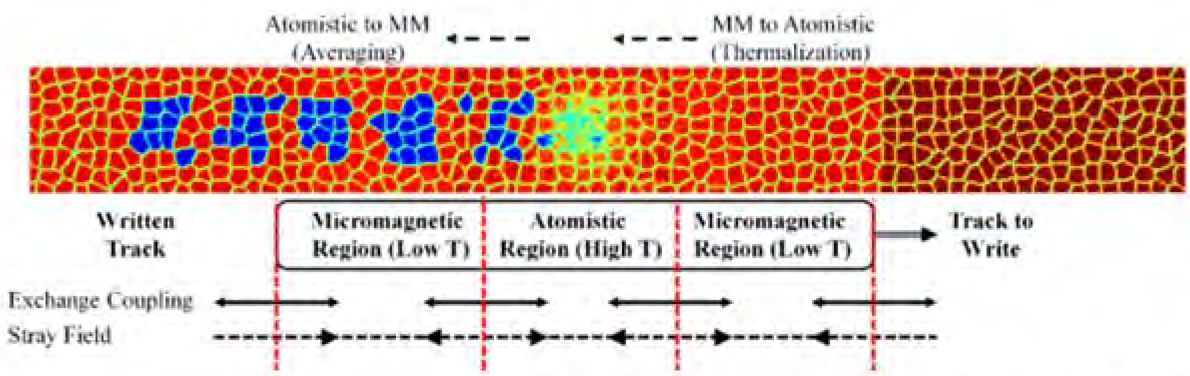

Figure 1. Diagram of the multiscale HAMR modelling track writing algorithm, with a simulation region embedded within a granular magnetic track.

Temperature control of interfacial ferrimagnetic coupling in NiFe/Tb bilayers

Gilroy R

Session 2: Thin films, April 7, 2025, 10:00 - 11:15

Magnonic technology is a key pathway towards developing novel, high performance and low-energy magnetic-logic devices. In these devices the Gilbert damping parameter is crucially important, controlling energy dissipation within the system. Low damping provides ultrafast magnetic switching, whereas higher damping simplifies magnetisation dynamics, making magnetic switching more reliable [1].

In magnetic multilayers damping can be engineered via spin pumping effects by interfacing low damping magnetic materials such as Ni80Fe20 with heavier elements with large spin orbit coupling [2]. Typically, transition metal elements such as Pt or Ta are used. However, there is also interest in using 4f rare earth (RE) metals such as Tb, where interactions are complicated by antiparallel coupling between the RE and TM [3,4]. Whilst the physics of damping enhancement in RE-TM alloys are is well understood [5], the mechanisms in multilayer systems are less clear. Previously, enhancements in the damping have been observed NiFe/Tb bilayers that are over an order of magnitude larger than those observed in NiFe/Pt systems [6,7]. This has been hypothesised to arise from the enhancement in spin-mixing conductance g↑↓ due to ferrimagnetic coupling of Tb and NiFe in the intermixed region at the interface [6].
Here we study the at the influence of temperature on the magnetic switching and damping in NiFe/Tb bilayers systems. Differences in the variation of magnetisation of the NiFe and Tb layers with temperature allow interfacial coupling to be modulated. Magneto-optical measurements illustrate this via changes in coercive field with increasing temperature as in fig.1a. When looking at the magnetic damping as a function of temperature (fig1b), there is a clear decrease in α with increasing temperature, indicating that the ferrimagnetic coupling plays an important role in the magnetisation dynamics of the system. Polarised neutron reflectivity measurements are used to allow probing of the interfacial coupling at the NiFe/Tb interface.

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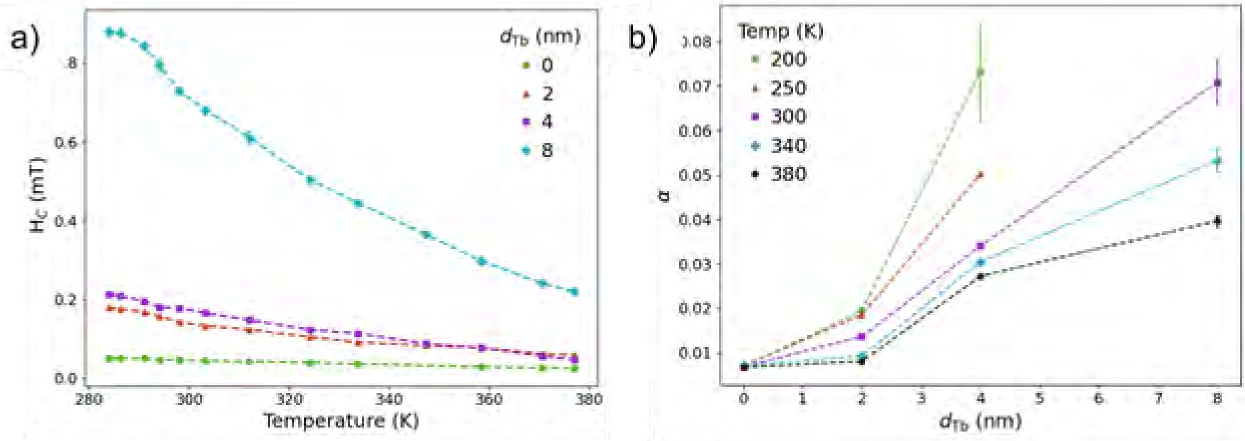

Figure 1 Temperature dependent behaviour of NiFe/Tb (0-8 nm) bilayers for a) magnetic switching and b) magnetic damping.

Magnetic imaging of thermally switchable antiferromagnetic/ferromagnetic modulated thin films

Griggs W, Peasey A, Schedin F, Anwar M, Eggert B, Mawass , Kronast F, Wende H, Bali R, Thomson T

Session 6: Patterned Thin Films and Nanomagnetism, April 7, 2025, 15:45 - 17:00

Here we report on the spin textures formed in antiferromagnetic (AF)/ferromagnetic (FM) thin film stripes of width 100 nm formed via ion irradiation nanopatterning [1]. We exploit the sensitivity of the temperature-induced AF to FM phase transition in FeRh thin films to local damage, thereby creating a series of thermally switchable AF/FM stripes which are embedded in a 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 of the patterned FeRh 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 likely to be 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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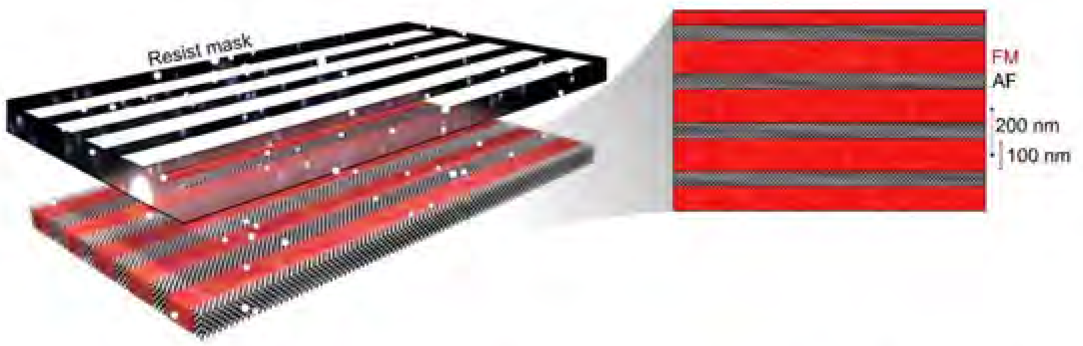

Fig. 1. Three-dimensional representation of the irradiation of an FeRh thin film through a lithographically patterned resist mask, with complementary plan view. At room temperature the irradiated regions (width 100 nm) are uniformly FM throughout the film depth, while the unirradiated regions remain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

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

Hait S, Brereton B, Yagmur A, Kinane C, Sarpi B, Maccherozzi F, Dhesi S, Langridge S, Marrows C

Session 5: Spin Textures, April 7, 2025, 15:45 - 17:00

Efficient and optimized skyrmion formation and controlled motion are essential for skyrmion-based spintronic memory and logic applications [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) with high CSC efficiency offer promising alternative [3]. However, hosting skyrmion in ultrathin magnetic multilayer (MM) structures is not straightforward, and the structural quality of the TM layer and the buffer layer between the TM and MM is crucial.

Here, we investigated skyrmion formation in an optimized MM ([Pt/CoB/Ru]x6) and over two TMs (Bi2Se3 and WTe2) with varying 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 effect of buffer layer thickness on the effective anisotropy of the MM, saturating at ~2 nm. While looking for skyrmions in these optimized MMs on SiO2, a maze domain was observed, which eventually collapsed into skyrmions under applied magnetic field (Figure 1(d, e and f)). However, on Bi2Se3 with 1.5 nm Ta buffer layer displays worm domains (even with 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.

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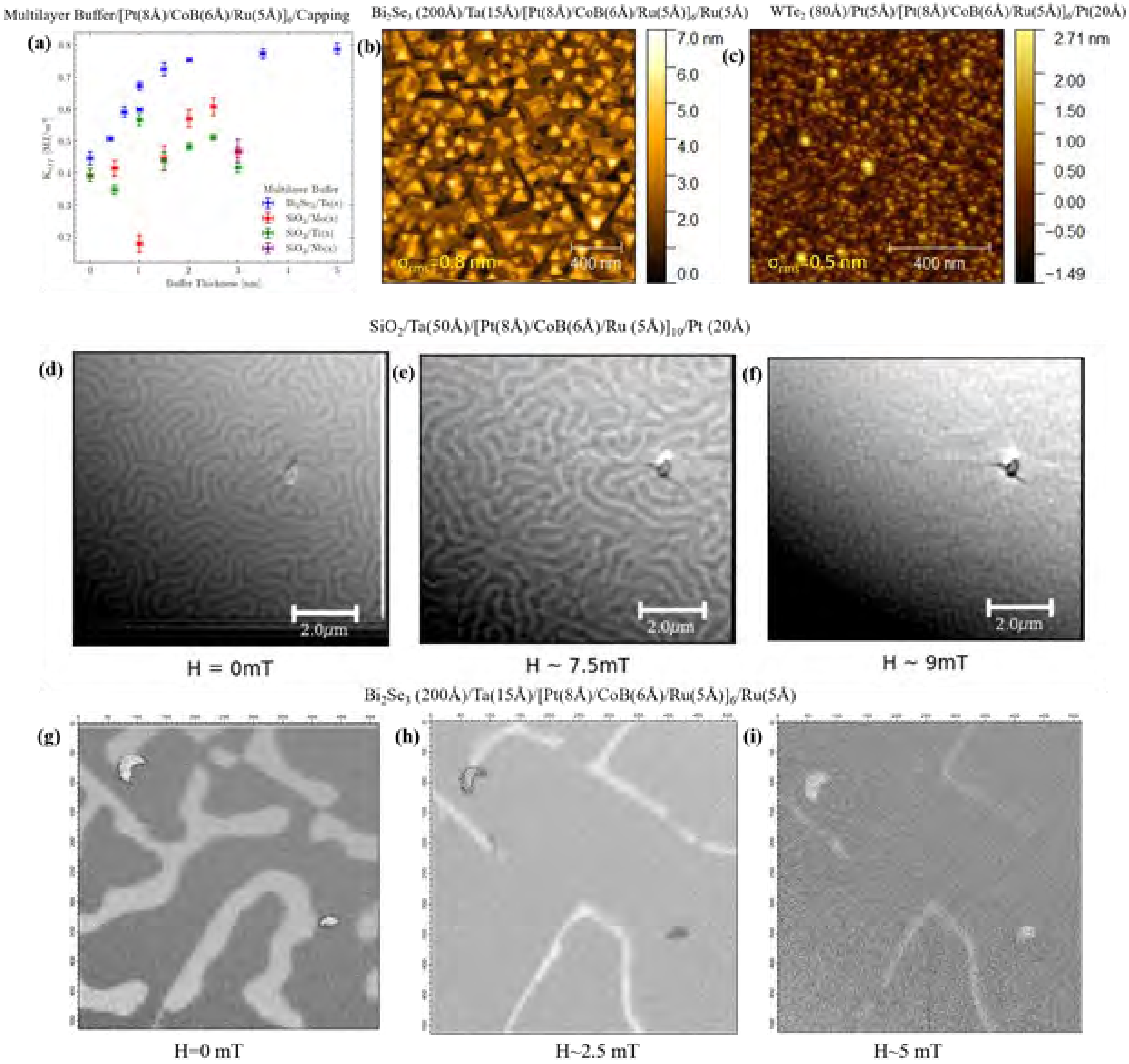
Multilayer Buffer/[Pt(8Å)/CoB(6Å)/Ru(5Å)]6/Capping
Bi2Se3 (200Å)/Ta(15Å)/[Pt(8Å)/CoB(6Å)/Ru(5Å)]6/Ru(5Å)
WTe2 (80Å)/Pt(5Å)/[Pt(8Å)/CoB(6Å)/Ru(5Å)]6/Pt(20Å)
(a)
(b)
(c)
Multilayer Buffer
Buffer Thickness [nm]
σrms=0.8 nm
400 nm
7.0 nm
6.0
5.0
4.0
3.0
2.0
0.0
σrms=0.5 nm
400 nm
2.71 nm
2.00
1.50
1.00
0.50
0.00
-0.50
-1.49
SiO2/Ta(50Å)/[Pt(8Å)/CoB(6Å)/Ru (5Å)]10/Pt (20Å)
(d)
(e)
(f)
2.0μm
2.0μm
2.0μm
H = 0mT
H ~ 7.5mT
H ~ 9mT
Bi2Se3 (200Å)/Ta(15Å)/[Pt(8Å)/CoB(6Å)/Ru(5Å)]6/Ru(5Å)
(g)
(h)
(i)
H=0 mT
H~2.5 mT
H~5 mT

Current-induced Néel vector switching in synthetic antiferromagnet probed by magnetic resonance

Hao Y, Brierley J, Sud A, Che Z, Yang C, Freeman C, Xue Z, Cubukcu M, Fukami S, Mizukami S, Kurebayashi H

Session 7: High Frequency / Ultrafast Dynamics, April 8, 2025, 10:30 - 12:00

Synthetic antiferromagnets (SyAFs) are multi-layer structures consisting of two ferromagnetic (FM) thin films coupled antiferromagnetically through a non-magnetic spacer [1]. SyAFs combine the advantages of zero stray field and high stability from antiferromagnets, as well as easy reading and writing characteristics from ferromagnets due to its relatively weak exchange coupling strength, making it a promising candidate for studying the fundamental aspects of AFMs for spintronic applications [2]. Current-induced switching behaviors have been studied for SyAFs with the out-of-plane easy axis [3, 4], where the planer Hall effect in Hall bar device geometry, is often exploited for sensing its Néel vector states controlled by electric current. In this study, we have been motivated to explore a new sensing mechanism of Néel vectors and here introduce our method of utilising spin-torque ferromagnetic resonance (ST-FMR) techniques to probe the Néel vector state via the amplitude of FMR voltages.

We fabricate SyAF devices with the structure of Ta(5nm)/NiFe(5nm)/Ru(0.4nm)/NiFe(5nm)/Ta(5nm) having the magnetic easy plane for both magnetic layers. Some measured ST-FMR spectra for the acoustic mode are shown in Fig. (a), where an application of dc current with the amplitude (Idc) drastically changes the spectral shape. To further reveal its current dependence, we plot the anti-symmetric component (Vasym) as a function of Idc in Fig. (b) which displays a clear hysteresis. We attribute this Vasym amplitude switching to the Néel vector by supporting with our analysis with a macro-spin model as well as micromagnetic simulations. The model and simulation results serve as a powerful tool to explain the angular dependence data shown in Fig. (c)-(e) measured with different Idc, pointing to two current-induced metastable states which we will explain more in detail during the presentation. We will also discuss the non-volatility nature of the Néel vector states.

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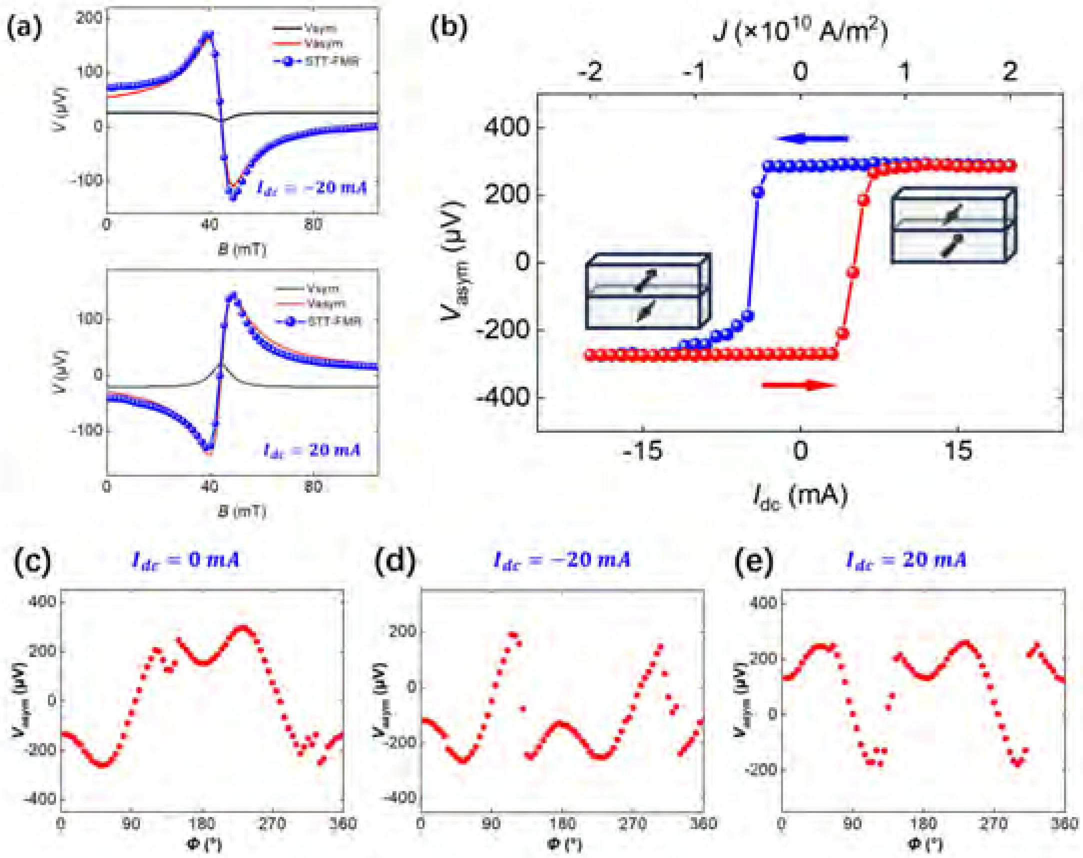

Fig. (a) Spin torque ferromagnetic resonance (ST-FMR) spectra for acoustic mode of each state, with the corresponding V_{sym} and V_{asym} derived by fitting with the Lorentzian function. (b) Hysteresis loop of V_{asym} versus I_{dc} measured by ST-FMR at 240° in-plane. All points in this hysteresis loop were measured using a switch-off measurement of ST-FMR. (c)-(e) Angular dependency of V_{asym} measured for ground state (0 mA), state induced by negative I_{dc} (-20 mA) and positive I_{dc} (20 mA), respectively.

Effects of Ni81Fe19 material quality on optical and magnetic properties towards device-based optical influence on magnetic textures

Holder H, Bromley D, Vanstone A, Bai H, Stenning K, Gartside J, Xiao X, Branford W, Oulton R

Session 7: High Frequency / Ultrafast Dynamics, April 8, 2025, 10:30 - 12:00

Studying the use of visible light to influence and control magnetism is an active topic of interest in fundamental & applied research. While much research concerns complex & exotic magnetic alloys, opto-magnetic effects in simple ferromagnetic alloys such as Ni81Fe19 (Permalloy) are of particular interest due to its low cost, high earth abundance and amenability to nanopatterning. Permalloy can be patterned into interacting arrays of nanoislands (including Artificial Spin Ice) to harness emergent computational phenomena [1,2]. Optical manipulation of the state of such Permalloy nanoarrays could afford flexible input of memory and computational data, increasing the technological prospects of future devices.

Characterisation of the material quality of such systems is crucial for ensuring the robustness and reproducibility of future devices. We investigate the impact of the vacuum pressure of the thermal evaporation system used during fabrication, comparing a variety of material characterisation, magnetic, and optical measurements between continuous Permalloy deposited at a higher and lower chamber pressures. Material characterisation is performed via X-ray Photoelectron Spectroscopy, X-Ray Diffraction, and Atomic Force Microscopy scans, with magnetic properties assessed using Vibrating Sample Magnetometry. Absorptive properties are measured with Fourier Transform Infrared spectroscopy, and finally, time-resolved optical pump-probe results provide a window through which system excitation and time dependent decay dynamics are analysed. Relevant previous studies are discussed, and our findings discussed in the context of application-focussed nanomagnetic optical manipulation

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FIB patterning of MnSb(1-101) based spintronic devices

Holmes S, Dommett E, Bell G

Session 3: Spintronics 2, April 7, 2025, 11:40 - 13:00

The integration of ferromagnetic MnSb with reduced dimensional devices fabricated in InSb and InAs-based structures is now possible [1] with spin-injection into these high spin-orbit systems an attractive proposition for the enhancement of Topological phases.
In the present work, transport measurements (ρxx and ρxy) in perpendicular magnetic fields (B) are presented of MBE-grown MnSb/GaAs(001) devices. Patterning ferromagnetic properties is achieved using a Ga+ focused ion beam-FIB at 30 keV. FIB patterning also introduces disorder and this is quantified in this work through the effect on ρxx and the anomalous Hall effect (AHE) contribution to ρxy. The MnSb structural phase is the niccolite phase in the (1-101) orientation and this is known to have a stable surface state distinct from the bulk [2]. The temperature dependence of ρxy and ρxx confirm a reduction in the surface state influence in the FIB patterned devices.
ρxx shows a log(B) dependence after the magnetization has saturated with the anisotropic magnetoresistance (AMR) contribution ~ 0.12%. The conductivity ($\Delta\sigma xx$) change is ~ e2/h in the magnetic field range of log(B) behavior. This is an indication of strong hole-hole interactions (p-type behavior) in this system and is considered in detail in this presentation.
A FIB dose of 1E13 Ga+ ions/cm2 reduces the AMR signal but increases the size of the AHE in out-of-plane magnetic fields. This is in general agreement with [1] when comparing the Sb-terminated and the Mn-terminated surfaces. ρxx shows a reduced fit to a log(B) dependence and is a useful parameter in quantifying the uniformity of the FIB damage.

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Surface energy model to predict effect of Co on twin formation and magnetic properties of Sm(Fe,Ti, V)12 alloys

Hrkac G, Sepehri-Amin H, Tozman P, Sasaki T, Staunton J, Patrick C

Session 11: Computational, April 8, 2025, 15:30 - 17:00

Transferring the excellent intrinsic magnetic properties of SmFe12-based compounds to their extrinsic properties
remains the main challenge in the development of high-performance SmFe12-based permanent magnets. Twin
formation is one of the reasons for the inability to achieve high coercivity and remanence. We investigated the addition of Co in Sm(Fe1-xCox)10–11M1–2 alloys, where M=Ti and V, leads to an increase in twin density.
We developed and used a surface energy optimization model, based on molecular dynamics and first principle calculations to revealed that the atomic arrangement in the twin boundary changes depending on the stabilizing element, which directly influences the local intrinsic magnetic properties.
The question we wanted to answer is whether the stabilizer element can change the grain size dependence on the twin formation energy. Molecular dynamics simulations were employed and the twin formation energy was calculated by comparing the total formation energy of Ti and V based 1:12 systems with and without twin-boundaries, as a function of grain size. The calculations show more negative twin formation energy in the Ti-stabilized alloys indicates easier twin formation compared to the V-stabilized alloys with comparable grain size. The critical grain size, below which twin formation energy becomes positive, is larger for SmFe10V2 compared to SmFe11Ti1. Therefore, use of V may be expected to increase the grain size range in which twinning is energetically unfavorable.
Our calculations are underpinned with experiments done at NIMS, see figure 4 in Scripta Materialia 258 (2025) 116491. The combined study shows that the alloy composition influences not only the intrinsic magnetic properties but also the twin formation energy and its grain size dependence, crucial
for the design of SmFe12-based permanent magnets.

Strain control of antiferromagnetic topology

Jani H, Harrison J, Hooda S, Prakash S, Nandi P, Hu J, Zeng Z, Lin J, Godfrey C, Omar G, Butcher T, Raabe J, Finizio S, Thean A, Ariando A, Radaelli P

Session 10: Antiferromagnetism, April 8, 2025, 13:45 - 15:00

Antiferromagnets hosting topological spin solitons, such as skyrmions, merons and bimerons, are promising platforms for developing terahertz spintronic applications [1,2]. However, they have only been fabricated epitaxially on specific symmetry-matched substrates, thereby preserving their intrinsic magneto-crystalline order [3,4,5,6]. This curtails their integration with dissimilar supports, restricting the scope of fundamental and applied investigations.

I will discuss how we circumvent this limitation by designing detachable crystalline antiferromagnetic nanomembranes of α-Fe_2O_3 [7]. First, using transmission-based antiferromagnetic vector mapping, we showed that flat nanomembranes host a spin reorientation transition and rich topological phenomenology. Second, we exploited their extreme flexibility to demonstrate the reconfiguration of antiferromagnetic states across 3D membrane folds resulting from flexure-induced strains. Finally, we combined these advances using a controlled manipulator to realise strain-driven non-thermal generation of topological textures at room temperature. Integration of such free-standing antiferromagnetic layers with 3D nanostructures could enable spin texture designs via magnetoelastic-/geometric-effects in the quasi-static and dynamical regimes, opening new explorations into curvilinear antiferromagnetism and unconventional computing.

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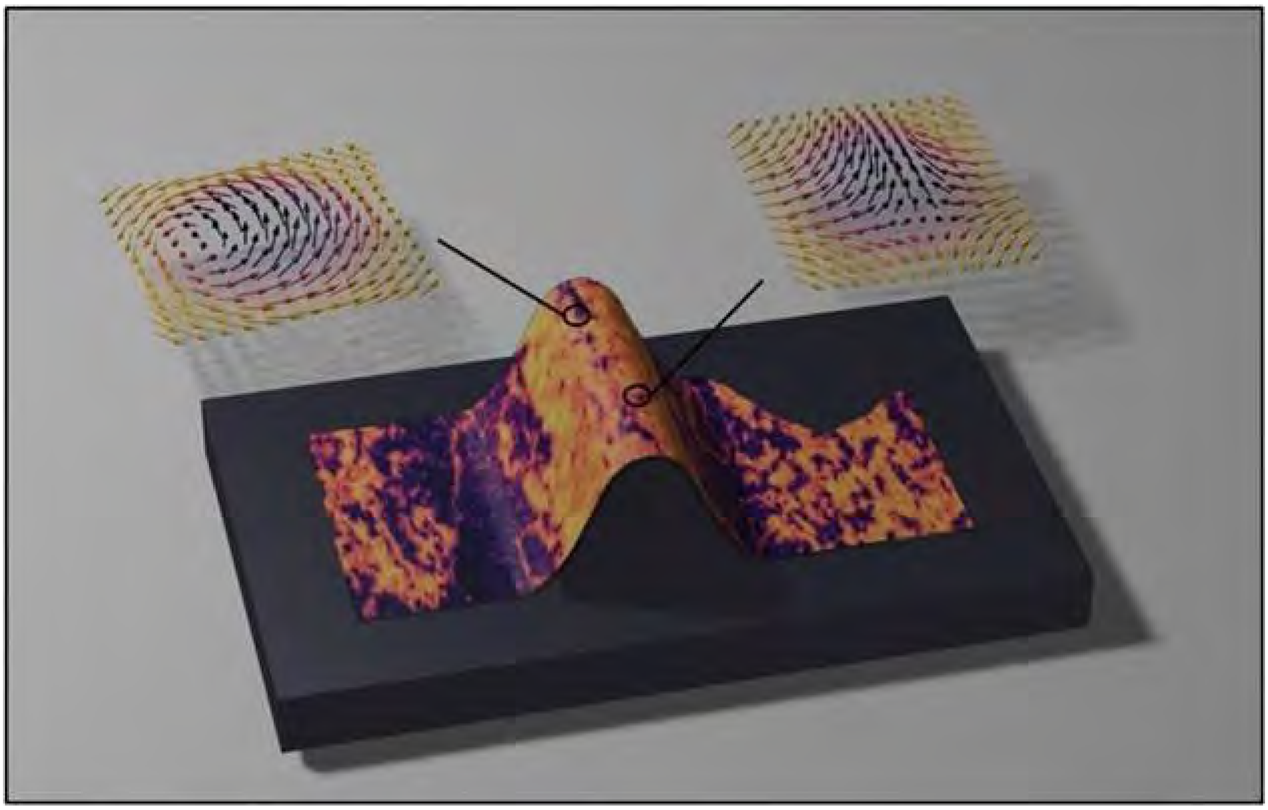

The Intriguing Properties of Non-Collinear Antiferromagnets, and the Impact of Strain and Dislocations.

Johnson F

Session 10: Antiferromagnetism, April 8, 2025, 13:45 - 15:00

Non-collinear antiferromagnetic (nc-AFM) materials present an exciting new frontier for spintronics, seeing proposed application in next-generation, energy-efficient “beyond von-Neumann” computing technologies. Unlike collinear antiferromagnets, nc-AFM possess properties reminiscent of ferromagnetic materials, such as large anomalous Hall, Nernst and magneto-optical Kerr effects, despite having vanishing magnetisation. [1] In this talk I will focus on the Mn3AN cubic antiperovskite family of materials, which possess a frustrated triangular arrangement of Mn spins in the (111) plane. This Kagome-type arrangement of spins leads to a host of magnetic phases, with sensitive dependence on externally applied stimuli – in particular, strain. [2,3] I will first provide an overview of the intriguing properties of these materials, originating from the underlying symmetry-breaking of the magnetic order. I will then discuss the strain-induced modifications of the magnetic order and its effects, distinguishing between global strain originating from lattice mismatch to the substrate and large local strain fields generated by dislocations. Finally, I will demonstrate how defects may be trapped in an interfacial layer using post-growth annealing, revealing the thickness-dependent intrinsic electronic properties of the coherent film.

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From superfluid 3He to altermagnets

Jungwirth T

Plenary: Tomas Jungwirth, April 7, 2025, 14:30 - 15:30

Pauli exclusion principle combined with interactions between fermions is a unifying basic mechanism across condensed-matter physics giving rise to spin-ordered phases. They form a common symmetry class characterized by spontaneous breaking of the continuous spin-space rotation symmetry. Ferromagnetism is a robust manifestation of spin ordering, which leads to numerous practical applications, e.g., in spintronic information technologies. In contrast, the fragility of the ordered phases of superfluid 3He makes the system unfavorable for practical applications, but it has uniquely rich physics stemming from the spontaneous symmetry breaking of both spin-space and real-space rotation symmetries. Recently discovered altermagnets [1-4] share with superfluid 3He this intriguing combination of symmetry breaking. For understanding the rich ordering physics in altermagnets, superfluid 3He thus represents a unique reference physical system. In return, altermagnetism has robust and abundant material realizations, and offers the prospect of practical utility, e.g., in ultra-scalable spintronic technologies. In the talk we will look at altermagnetism from a broad condensed-matter physics perspective by reflecting on superfluid 3He, as well as on ordered metallic phases generated by Pomeranchuk Fermiliquid instabilities, all sharing the spontaneous breaking of the spin-space and real-space rotation symmetries [5]. The Pomeranchuk instabilities, albeit experimentally elusive, serve as a bridge from the superfluids to altermagnets, and to other recently identified unconventional magnets with the combined spin-space and real-space symmetry breaking. Our broad perspective aims to provide guidance through the common symmetry classes, as well as through distinct properties of these diverse physical systems.

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Unraveling antiferromagnetic spin-waves in linear and nonlinear regimes

Lebrun R

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Conventional magnonic devices uses standard ferromagnetic materials and thus operates only at GHz frequencies [1]. Magnonic devices could thus strongly benefit from the integration of antiferromagnetic materials that brings the prospect of devices operating at THz frequencies. In low damping insulating antiferromagnets, uncoherent magnons can propagate spin-information over tens of micrometers [2,3]. However, the lack of symmetry breaking still makes it difficult to excite and detect efficiently coherent antiferromagnetic magnons [4].
In this talk, I will first discuss how antiferromagnetic materials with intrinsic symmetry breaking such as canted antiferromagnetic materials (also belonging to the recently discovered class of altermagnets) can host promising prospects for antiferromagnetic magnonic. An abundant antiferromagnetic material as hematite thus hosts non-degenerated and non-reciprocal spin-waves with group velocities > 10 km/s which are key functionalities for the development of magnonic devices [5]. Furthermore, we can efficiently detect its spin-dynamic using interfacial symmetry breaking and spin-orbit phenomena (inverse spin-Hall effect [6] or spin-Hall magnetoresistance [7]), and observe detection efficiency as large as µV/mW. In patterned microstructures, we combine thus observe antiferromagnetic spin-rectification in a single platinum stripe [7]. This approach enables accessing electrically not only the linear but also the nonlinear regimes of antiferromagnetic spin-dynamics. The presence of nonlinear frequency shift and voltage saturation together with linewidth broadening is associated with antiferromagnetic Suhl-like instabilities[8]. In a second part, I will discuss how one interfacial symmetry breaking in magnetic heterostructures enables the generation ac spin-current even in the case of compensated antiferromagnets, and the detection of their associated THz radiation using conventional THz-TDS spectroscopy[4]. These results highlight promising perspectives for the develop of magnon based THz spin-devices.

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Kinetic relaxation pathways and emergence of domains in square spin ice

Leo N, Menniti M, Vilalba P, Pancaldi M, Vavassori P

Session 6: Patterned Thin Films and Nanomagnetism, April 7, 2025, 15:45 - 17:00

The relaxation kinetics and emerging correlations of arrays of interacting Ising-like nanomagnets are governed by the switching rates of the individual magnets. These rates depend, via the Arrhenius law, on the energy barrier for moment reversal in the nanomagnets. In a recent work we demonstrated that the switching behaviour of a nanomagnet in archetypical artificial square ice is modified by the interaction with its six nearest neighbours: In particular, barrier energies for clockwise and counter-clockwise rotation can differ significantly, leading to an exponential enhancement of the transition rates compared to mean-field transitions [1,2].

Here, we use kinetic Monte Carlo simulations to show how the modified transition rates influence the demagnetisation pathways in infinite lattices of artificial square ice. We find that the relative importance of specific spin flips leads to different spatial correlations and, in particular, the emergence of coral-shaped domains with meandering boundaries [3]. Our results show that the emergence of long-range patterns, which usually are attributed to imperfections due to nanofabrication, can also be partially described by intrinsic relaxation mechanisms.

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Temperature gradient-driven motion of domains in a perpendicularly magnetised magnetic metal multilayer by entropic forces

Huang L, Barker J, Kailas L, Connell S, Burnell G, Marrows C

Session 5: Spin Textures, April 7, 2025, 15:45 - 17:00

Spin textures, such as domain walls [1] (DWs) and skyrmions [2], have been shown to move in response to temperature gradients. The flow of magnons (and electrons) induced by the spin (dependent) Seebeck effect [3] can exert spin transfer torques [4]. Entropic forces arise owing to gradients in the micromagnetic parameters [5], which can either enhance or oppose the STTs [6]. There are conflicting experimental results for skyrmions. Conventional cold to hot motion was observed in insulating $CuOSeO_3$ [7], but motion from hot to cold has been observed in Pt/CoFeB/MgO [2]. Experiments on DWs are few. In Ref. [1] a DW in the magnetic insulator YIG was reported to move towards the hot end of the system. In metals, DWs in in-plane magnetised Py wires showed this as an additional effect to current-driven motion [8].
Here we report experiments on the motion of domains in Pt/CoB/Ir metallic multilayers in a temperature gradient. The multilayers support both PMA and a chiral DMI [9] and were patterned into 10 μm wide tracks. The domain locations were determined using magnetic force microscopy (see Fig. 1) before and after a two minute heat pulse was applied to an electrically isolated Pt heater wire (purple area in schematic, SiO_2 insulator in green) crossing a magnetic track (red). The heat pulse was generated by flowing a dc current through the heater, which generates a temperature gradient along the track.
We estimate that the temperature in the region shown in Fig. 1 varies from about 340 K to 300 K across the area that was imaged during heating. After accounting for Oersted field effects by measuring average domain displacements for both directions of heater current and both senses of applied field, we find that the domains always move towards the heater. We find velocities ~1 nm/s in a temperature gradient of ~20 K/μm. Estimating the size of the various driving forces based on the measured multilayer properties including the temperature dependence of the magnetisation indicates that the motion is predominantly driven by entropic forces.

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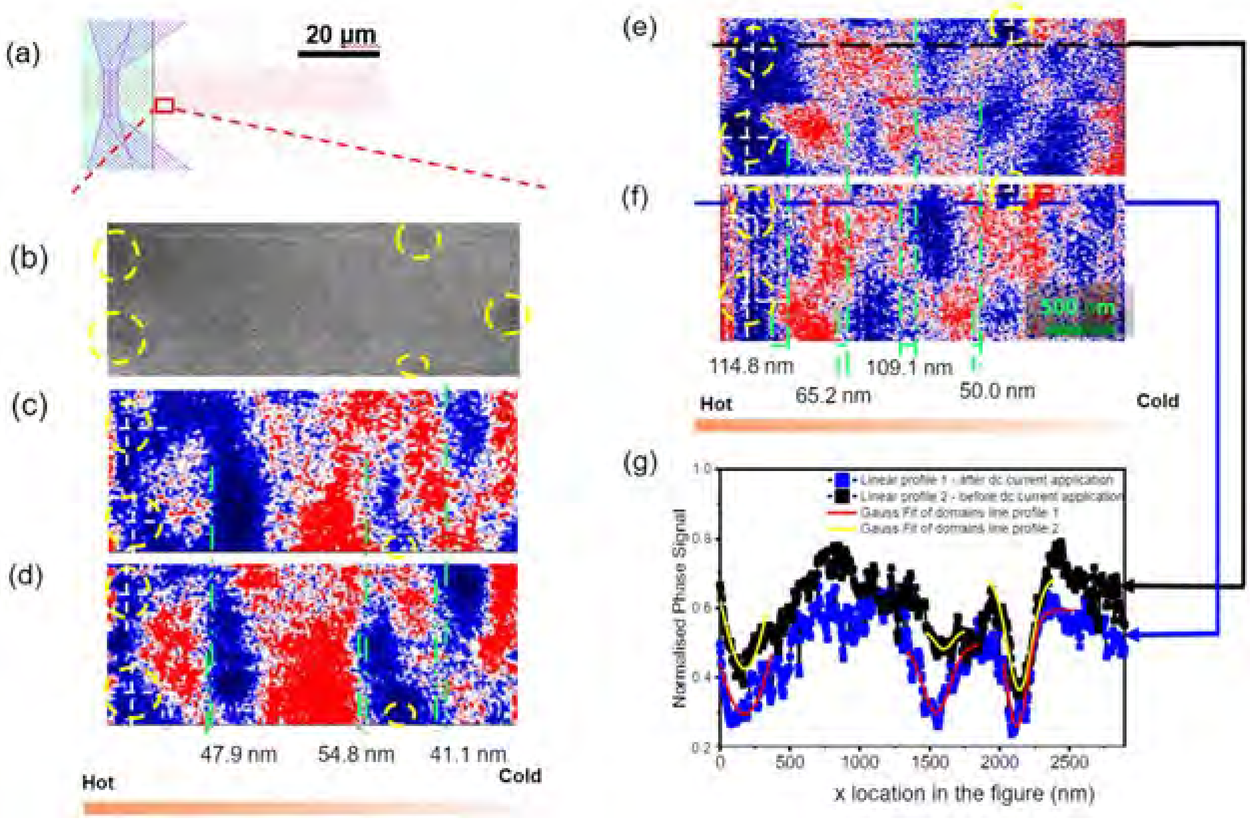
Fig. 1 caption: MFM imaging. (a) Schematic showing imaged region of track. (b) Full saturation at +600 Oe. Dark regions (marked with dashed yellow circles) are defects used as references. Example MFM images in +30 Oe field:
(c) and (d) before and after a + 30 mA current was applied to the heater. (e) and (f) Before and after a -30 mA current. Dashed green lines show domain motion. (g) MFM image line sections.


(a)
20 μm
(b)
(c)
(d)
47.9 nm
54.8 nm
41.1 nm
Hot
Cold
(e)
(f)
114.8 nm
65.2 nm
109.1 nm
50.0 nm
Hot
Cold
(g)
Linear profile 1 - after dc current application
Linear profile 2 - before dc current application
Gauss Fit of domains line profile 1
Gauss Fit of domains line profile 2
Normalised Phase Signal
x location in the figure (nm)

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

McVitie S, Villa S, Barker C, Fallon K, Barton C, Siddani R, Branford W, Reuter R, Sievers S, Rendell-Bhatti F, Kirkbride C, Almeida T, Marrows C

Session 5: Spin Textures, April 7, 2025, 15:45 - 17:00

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.

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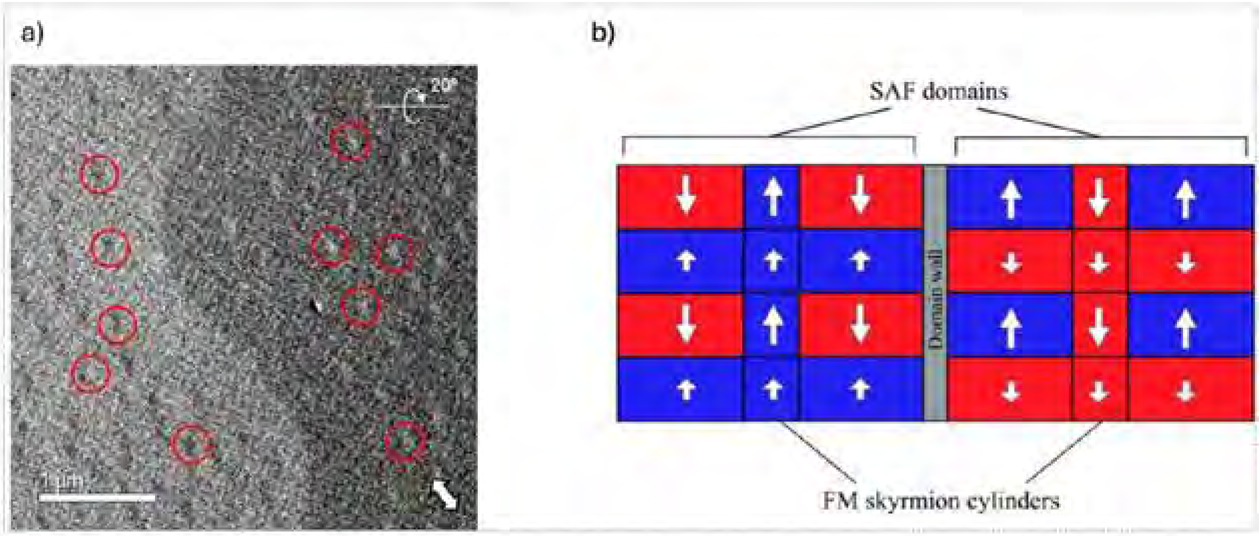

***Figure 1** a) DPC L-STEM image of a domain wall separating two SAF domains containing FM skyrmions (some of which are highlighted with red circles), b) diagram of the magnetic configuration of the multilayer.*

Coherent Magnonics in Canted Antiferromagnets

Mikhaylovskiy R

Session 7: High Frequency / Ultrafast Dynamics, April 8, 2025, 10:30 - 12:00

Magnonics aims to employ quanta of spin waves, magnons, to carry, transport and process information, avoiding the dissipation of energy inherent to electronics. Experiments on magnons in regular (ferro)magnets have yielded demonstrations of basic logic devices, albeit macroscopic (mm-scale) in size and operating at GHz frequencies. Recently, the spotlight has shifted towards the use of antiferromagnets, in which neighbouring spins are aligned antiparallel to each other. This alternating order leads to significantly higher spin wave propagation velocities and might enable devices operating at terahertz (trillion of hertz) clock-rates. However, the absence of the net magnetisation also makes antiferromagnets magnetically 'invisible': it is very hard to detect and influence the antiferromagnetic order. Yet, in some antiferromagnets strong spin–orbit coupling results in canting of the spins, thereby producing net magnetization. The canted antiferromagnets combine antiferromagnetic order with phenomena typical for ferromagnets and hold a great potential for spintronics and magnonics. In this way they can be identified as closely related to the recently proposed novel class of magnetic materials, called altermagnets. In my talk I will discuss a new functionality of canted antiferromagnets and altermagnets for magnonics and show that these materials facilitate mechanisms allowing to generate, detect and convert propagating magnons at the nanoscale [1-3].

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Probing Spinterface Physics with a Ferrimagnetic Multilayer

Moorsom T, Cespedes O, Kinane C, Caruana A, Langridge S

Session 1: Spintronics 1, April 7, 2025, 10:00 - 11:15

The term spinterface refers to a family of emergent magnetic phenomena that appear at interfaces between magnetic thin films and molecular materials. [1] Spinterfaces are important for understanding spin injection in organic spintronic devices [2] and the magnetic behaviour of hybrid organic/inorganic magnetic materials. [3] A problem with the study of spinterfaces is that the weak, emergent magnetic interface effects are in direct proximity to the much larger signal from the magnetic substrate. STM can provide insight, but only for mono or bilayers. [4] The ferrimagnetic alloy CoGd contains two magnetic sublattices, one deriving from the 3d orbitals of the Co atoms, and the other from the 4f orbitals of the Gd atoms. With changing temperature, this alloy passes through a compensation point where the magnetic moment of each sublattice cancels, but with non-zero net polarisation. [5] Using CoGd as a magnetic substrate, the spinterface can be studied in isolation. By creating a superlattice of CoGd and C60, we can tune the layer thickness to maximise magnetic contrast on a Bragg peak, which can be probed with Polarised Neutron Reflectivity. Even small changes in interfacial polarisation will then push the reflection off the Bragg condition, and result in large changes in reflected intensity. By sweeping the temperature through the compensation point, we can then determine whether the spinterface is coupled to either the Co or Gd lattice, the net polarisation or net magnetisation, figure 1.

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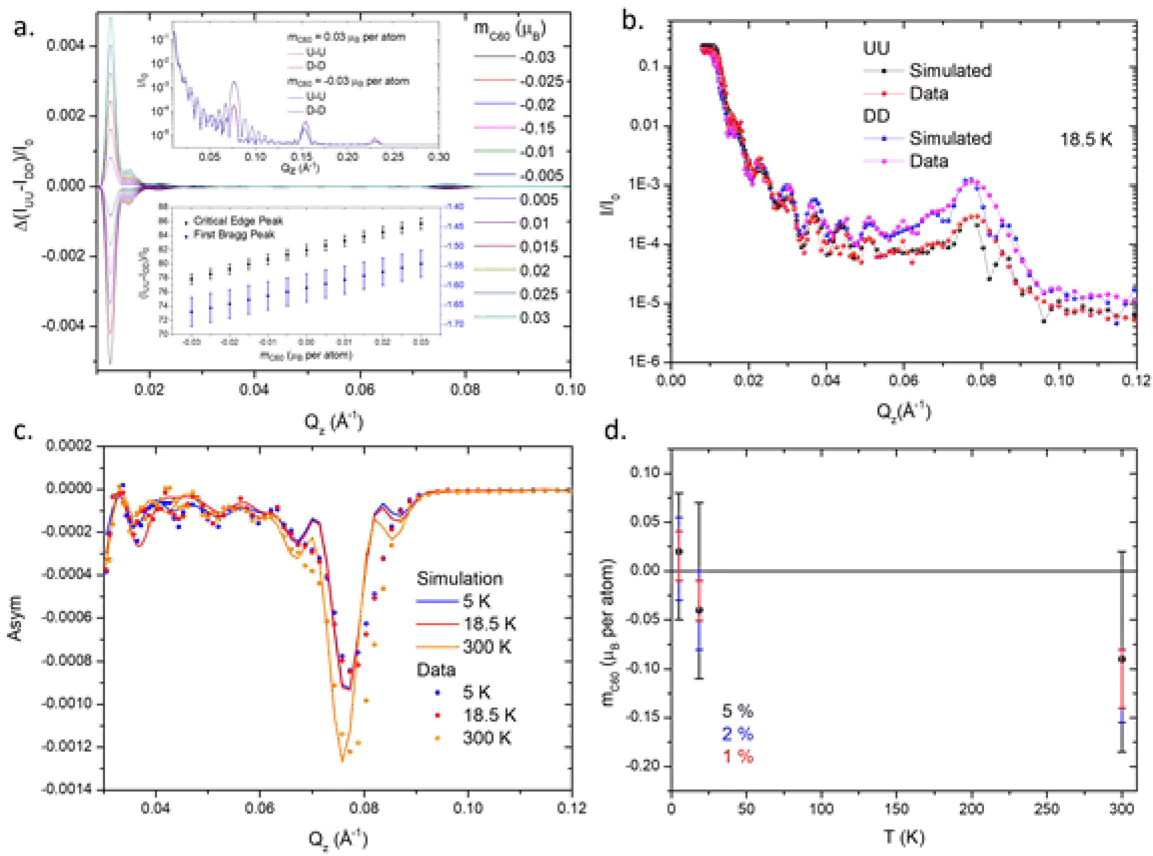
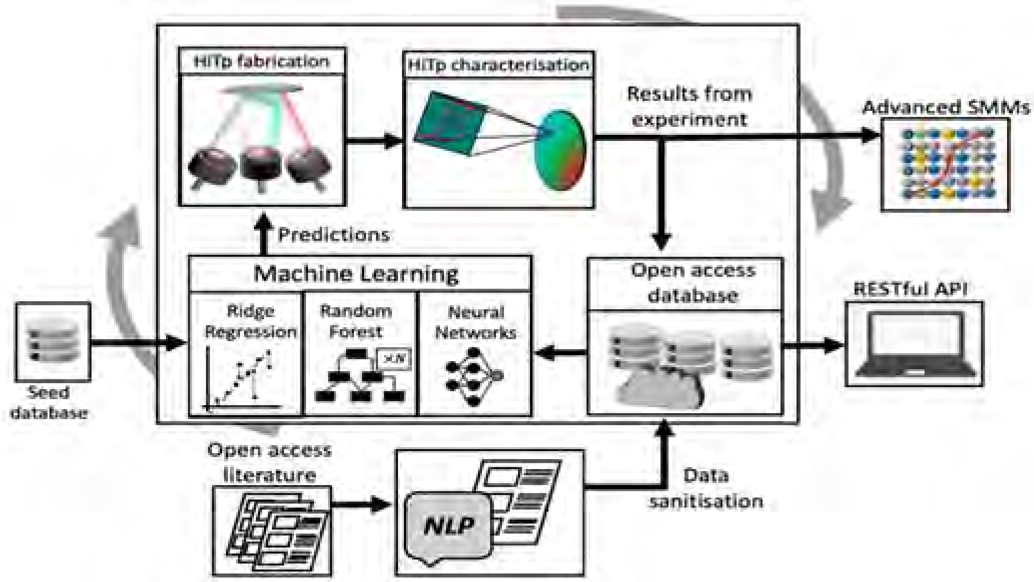


Materials Informatics for Magnetic Materials Discovery

Morley N, Read E, Rowan-Robinson R, Leong Z, Carpio S, Oh C, Liu X, Lu H, Wilkinson T

Session 9: Intelligent Computing - Devices and Materials for Applications, April 8, 2025, 13:45 - 15:00

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 required functional characteristics. Functional Magnetic Materials (FMMs) are central to new green technologies. At the present, existing hard magnets consist of critical elements, while soft magnets are limited due to processing costs and eddy losses. Thus, by improving FMMs properties, industries can capitalise on engineering advances, saving money and the environment. Traditional material discovery methods are too slow and costly. Material informatics 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), including large language models to data mine 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, with semantic networks, to allow the compositions related parameters to be correctly linked together. Having created this database, machine learning algorithms are trained on it, which are then used to observe trends within the data, along with predicting compositions with specific magnetic parameters. These compositions are then fabricated and characterised using high-throughput techniques, including combinatorial sputtering, XRD, FMR and MOKE. This allows us to verify the results from the machine learning, quickly and cheaply, discover new FMMs, plus the results are feedback into the database, allowing for a full circle discovery methodology.



Gd and Co contributions to the THz spin current produced by ferrimagnetic GdCo across magnetization compensation

Nava Antonio G

Session 7: High Frequency / Ultrafast Dynamics, April 8, 2025, 10:30 - 12:00

Guillermo Nava Antonio1, Quentin Remy2, Jun-Xiao Lin3, Yann Le Guen3, Dominik Hamara1, Jude Compton-Stewart3, Joseph Barker4, Thomas Hauet3, Michel Hehn3, Stéphane Mangin3, and Chiara Ciccarelli1
1Universtity of Cambridge, Cambridge, UK
2Freie Universität Berlin, Berlin, Germany
3Université de Lorraine, Nancy, France
4University of Leeds, Leeds, UK

Rare earth-transition metal (RE-TM) ferrimagnets are powerful and tunable sources of ultrafast spin current, capable of reversing the magnetization of an adjacent ferromagnet in spin valve devices in the picosecond time scale [1]. In this work, we elucidate the intensity and time scales of the contributions to the spin current from the Gd and Co sublattices in a ferrimagnetic GdCo alloy through THz emission spectroscopy.

By comprehensively characterizing the THz emission from GdCo/Cu/Pt heterostructures as a function of temperature and alloy composition, we determine that the net spin current is strongly supressed at the magnetization compensation point, when a bias magnetic field is applied. Static magneto-optic Kerr effect imaging reveals that this vanishing originates from the formation of a multi-domain structure due to composition inhomogeneities in the GdCo layer. Remarkably, in the absence of a bias magnetic field, the spin current persists across compensation, as illustrated in Figure 1a.

Furthermore, we analyse the THz emission spectra for various Gd concentrations and find that the spin emission is dominated by the Co sublattice at room temperature, which we explain in the framework of the superdiffusive spin transport model. On the other hand, as presented in Figure 1b, we measure a significant Gd contribution at low temperature, with markedly slower dynamics.

Figure 1. a) Integrated THz emission intensity when no magnetic field is applied. The dashed line denotes the magnetization compensation temperature. b) THz emission spectra taken at 6 K for different Gd concentrations (x).

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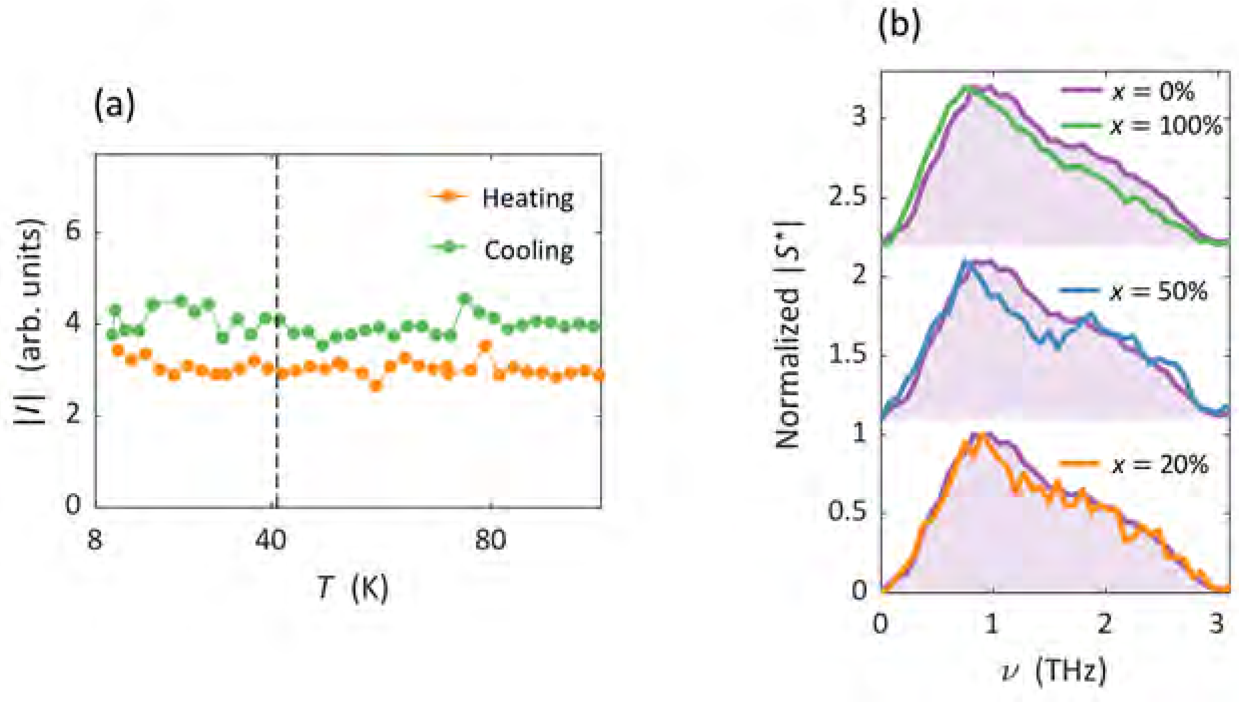
(a)
Heating
Cooling
|I| (arb. units)
T (K)
(b)
x = 0%
x = 100%
x = 50%
x = 20%
Normalized |S*|
ν (THz)

Magnetic and Transport Properties of Fe_3O_4/RGO Nanostructures: Insights into Spin-Glass Behavior and Spintronic Applications

Omran M, Eom S, Adhikari D, Kim D, Kim H, Jo Y

Session 4: Quantum Material and Devices, April 7, 2025, 11:40 - 13:00

Fe_3O_4/reduced graphene oxide (RGO) nanocomposites present a promising platform for exploring emergent quantum magnetic phenomena and advancing spintronic applications. In this study, 25 nm Fe_3O_4 nanoparticles were synthesized and integrated into an RGO matrix using the solvothermal method. Structural and compositional analyses, including X-ray diffraction (XRD), scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), and Raman spectroscopy, confirmed the high quality, uniformity, and homogeneity of the hybrid nanostructures.
Magnetization (M-H) and magnetoresistance (MR) measurements performed across temperatures from 2 K to 300 K and magnetic fields up to 9 T revealed distinct low-temperature quantum behaviors. The nanocomposites exhibited a pronounced negative-to-positive MR transition, coupled with enhanced spin-glass-like behavior and exchange bias effects, driven by interfacial coupling between Fe_3O_4 nanoparticles and the RGO matrix. Notably, slight compression during sample preparation amplified these effects, highlighting the sensitivity of magnetic and transport properties to external control and nanoscale interactions. This interplay of localized magnetic moments in Fe_3O_4 and delocalized π-electrons in RGO enables the hybrid system to balance ferromagnetic order with spin disorder, resulting in tunable quantum phases.
These findings establish Fe_3O_4-RGO nanocomposites as a versatile platform for understanding and controlling complex quantum orderings in 2D materials and demonstrate their potential in the development of next-generation spintronic devices.

Spintronic Kapitza pendulum: dynamical stability by spin transfer

Prestwood D, Youel H, Barker J, Yamazaki T, Kumar K, Stenning K, Bauer G, Yamamoto K, Seki T, Kurebayashi H

Session 1: Spintronics 1, April 7, 2025, 10:00 - 11:15

Spin transfer torques (STTs) control magnetisation by electric currents, enabling a range of spintronic applications [1–2]. STTs are in general employed in switching the magnetisation from one local energy minima to the other or in entering auto-oscillation but so far only these two have been studied as non-linear dynamics driven by STTs.

Inspired by the Kapitza pendulum [3] where a high potential energy state can be stabilised by dynamical injection of mechanical force (Fig.a), here we study the spintronic analogue of such a state achieved by nonequilibrium excitation of STTs. To achieve the same potential landscape with only one global potential minimum (Fig. c), and to maximise the efficiency of current-driven STTs, we made a dedicated CoFeB thin film layer with a characteristic property of the nearly-isotropic magnet. We use STTs generated by spin-Hall effect in the adjacent W layer to de-stabilise the energy minimum state achieved by an external field and observed the experimental signature of stabilising the state at the energy maxima, i.e. the moment pointing at the direction opposite to the external field, when the STT drive is strong enough to compenstate the material damping. One such observation is the sign reversal of ferromagnetic resonance voltage amplitude when increasing the STT drive as shown in Fig. d. Here, for a small current of 4 mA, the magnetisation precession takes place around the external field. At a higher current of 6 mA, the potential maxima condition is achieved, the moment presesses around the direction opposite to field, resulting in the peak sign reversal. We will discuss more technical details of these measurements, quantitative analysis and results by stochastic Landau-Lifshitz-Gilbert equation.

The discovery of a nano-scale rigid pendulum with dynamical stabilisation and controllable stochasticity is an ideal platform for studying dynamical systems with promising functionalities for probabilistic computing applications [4] and anti-magnonics [5].

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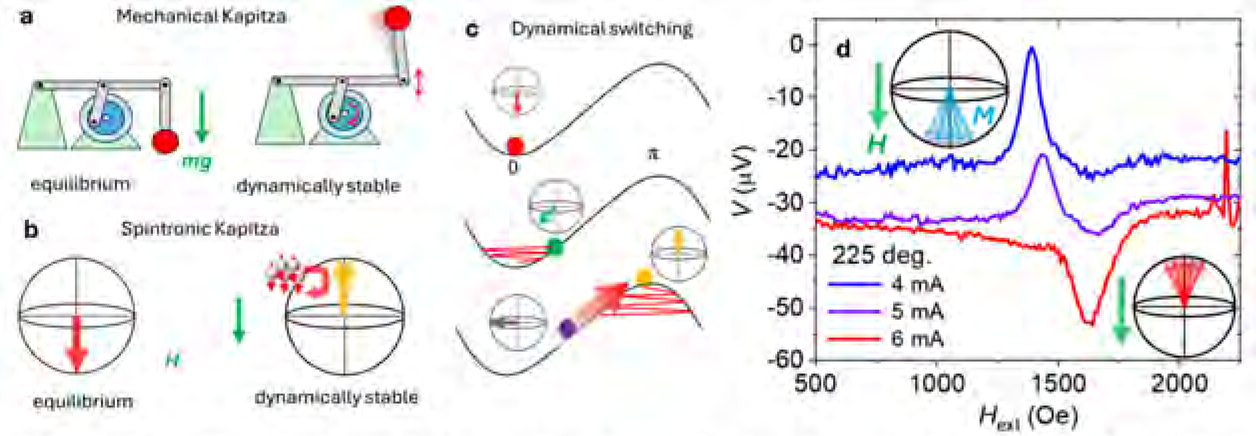

a&b: Schematics of mechanical and spintronic Kapitza pendulums. **c**: Schematic of destabilization of the state from the energy minima to stabilization of the energy maxima. **d**: FMR voltages for different STT drives by dc currents.

Extrinsic contributions to FMR line broadening in granular thin film recording media

Rannala E, Strungaru-Ruta M, Ruta S, Chantrell R

Session 9: Intelligent Computing - Devices and Materials for Applications, April 8, 2025, 13:45 - 15:00

A micromagnetic model of granular thin films was employed to investigate the ferromagnetic resonance (FMR) response of FePt as a function of temperature. Experimentally, FMR methods are used to find damping and anisotropy temperature dependencies the understanding of which are crucial to heat assisted magnetic recording (HAMR) development. Experimental FMR measurements of damping at elevated temperatures have shown an unexpected decrease of damping for temperatures within 45K of the Curie point (Tc) [1]. A decrease in damping can negatively impact HAMR performance due to worse writing speeds and bit error rates [2]. A comprehensive investigation into the damping of FePt via atomistic spin dynamics showed no decrease in damping with temperature irrespective of grain size. Additionally, a semi-analytical model accounting for parameter distributions to produce FMR results was developed, reproducing the experimental results [3]. This work expands on that model by directly simulating granular thin films with parameter distributions to, more accurately, investigate the presence of linewidth reduction at temperatures close to the system's Tc. The results obtained show the decrease in linewidth consistent with previous works (see figure). Furthermore, the model reveals that the decrease arises due to a loss in-homogeneous line-broadening occurring as grains transition to the paramagnetic state. The magnitude of the reduction and the temperature region over which it occurs is dependent on the grain size distribution. As the overall grain size decreases the strength of the effect increases showing larger reductions occurring at temperatures further from Tc. The findings of this work should aid in the future development of HAMR, specifically in media modelling, metrology and design.

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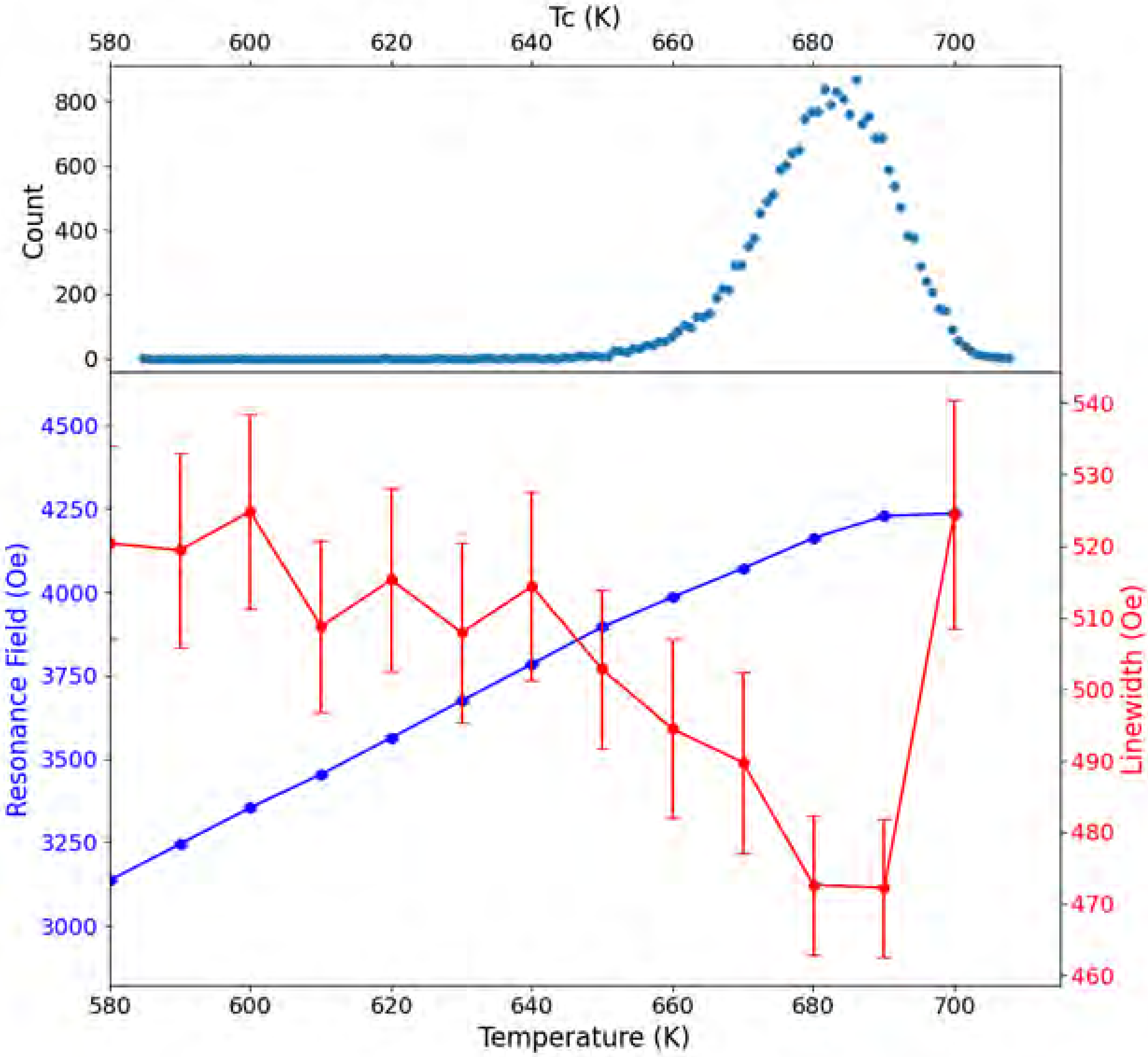
Tc (K)
580
600
620
640
660
680
700
Count
800
600
400
200
0
Resonance Field (Oe)
4500
4250
4000
3750
3500
3250
3000
Linewidth (Oe)
540
530
520
510
500
490
480
470
460
Temperature (K)

New materials and interface effects in charge and spin transport in magnetic heterostructures.

Reiss G

Session 3: Spintronics 2, April 7, 2025, 11:40 - 13:00

Magnetic heterostructures are key devices for spinelectronics. Their preparation requires thin film deposition with sub-Å control, field-annealing and nanopatterning. If fully functional, they can help fundamental research as well open applications such as sensors or memories. An introduction will present basic effects and their applications.
We then discuss several novel materials and interface induced effects in magnetic heterostructures:
- The growth of altermagnetic films and their integration in magnetic tunnel junctions using the example of RuO2. Altermagnets are at present intensively investigated due to their potentially spin split band structure and related spin currents. X-ray analysis reveals a high crystalline quality of the films with or without twinning depending on the substrate. When integrated with an MgO tunnel barrier and a ferromagnetic counter electrode, signatures of a tunneling magnetoresistance can be found that depend on the bias voltage and are not yet fully understood. When integrated with ferromagnets or heavy metals, an analysis based on the 2ω method shows the presence of torques in accordance with a spin current at the interface.
- When replacing the alter- by a ferromagnet, the heavy metal can show a proximity induced ferro-magnetism that substantially influences well-known phenomena such as the spin Seebeck, anomalous Nernst or anomalous Hall effect. Examples will be discussed using metallic as well as insulating ferro- or ferrimagnets and recipes for disentangling the zoo of effects will be given.

Mapping Rare Earth Magnetization and Anisotropy Regions in Compositionally Graded GdCoFe Ferrimagnetic Thin Films for Spintronic Applications

Rianto D, Nicholson B, Piotr Michałowski P, Bouchenoire L, Hase T, Atkinson D

Session 2: Thin films, April 7, 2025, 10:00 - 11:15

Compositionally graded amorphous rare earth (RE): transition metal (TM) ferrimagnetic thin-films have exciting potential in spintronics to enable field-free spin-orbit torque (SOT) switching [1,2]. Vertical compositional gradients in thin-films induce bulk Dzyaloshinskii–Moriya interaction (DMI) by breaking the inversion symmetry, which facilitates SOT switching without an in-plane field. This bulk DMI has also been proposed to promote canted magnetic structures, offering control over spin texture [3]. While theoretical studies highlight the gradient role in bulk DMI [4], the magnetization behaviour in RE:TM systems remain complex. They exhibit magnetization compensation, where opposing RE and TM moments cancel, and perpendicular magnetic anisotropy (PMA) within specific compositional ranges [5]. Compositional gradients have been assumed to drive transitions from in-plane to out-of-plane magnetization.

Here the magnetization profile of the rare earth was mapped through the thickness of the compositionally graded RE:TM layer to determine the in-plane and PMA regions. Films were fabricated using magnetron co-sputtering and analysed using secondary ion mass spectrometry (SIMS) and X-ray resonant magnetic reflectivity (XRMR) at the Gd L3-edge. In the figure, SIMS reveals a linear Gd gradient, while XRMR, sensitive only to in-plane moments, highlights the contrast between in-plane and out-of-plane regions. The Gd magnetic profile reveals a complex local environment, influenced not only by Gd concentration but also the local TM environment, which enhanced Gd local moments. These results advance our understanding of the magnetisation profile through such compositionally graded layers, which is key to field-free SOT switching, enabling new generations of spintronic devices.

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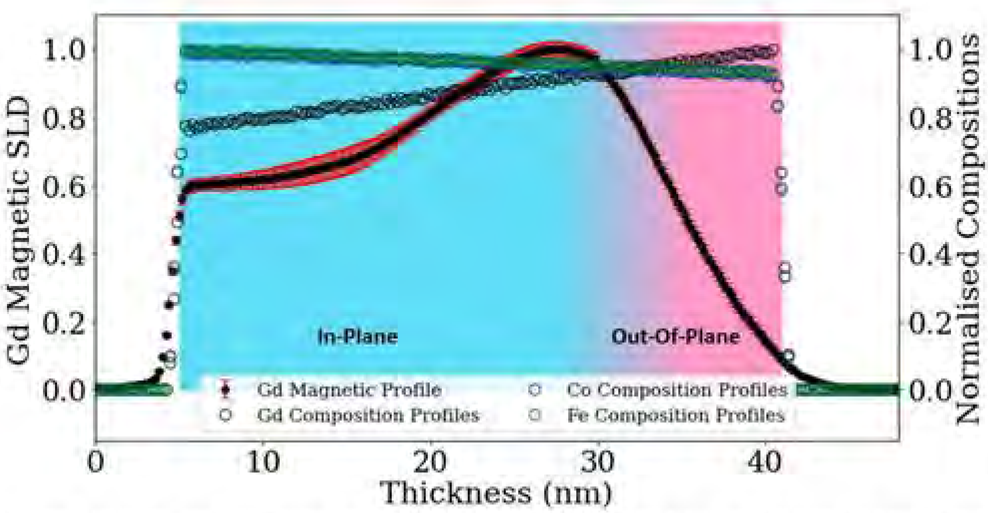

Figure. Gd Magnetic Scattering Length Density (mSLD) plotted with Gd, Co and Fe compositional profiles within GdCoFe layer.

Nanoscale quantum sensing of novel magnetic memories

Rickhaus P, Makarov D, Celano U, Pylypovskyi O, Munsch M, Nordmann M, Carpenter R, Couet S, Maletinsky P

Session 4: Quantum Material and Devices, April 7, 2025, 11:40 - 13:00

Magnetism exhibits fascinating and complex behavior at the nanoscale that has intrigued researchers for the past two decades. To study these phenomena, advanced tools are required to resolve the magnetic textures that emerge. One promising solution for this challenge is scanning NV magnetometry, a diamond-based quantum sensing technique.
This technology leverages nitrogen-vacancy (NV) centers in diamonds, which are highly sensitive to magnetic fields at the nanoscale. I will explain how scanning NV magnetometry operates and showcase its applications in uncovering magnetic textures, particularly in materials used for advanced magnetic memory technologies. These range from well-established memory types like magnetic random-access memory (MRAM)[1,2] to cutting-edge research areas involving multiferroic materials[3] and antiferromagnets[4].
Through these examples, I will demonstrate how quantum sensing can reveal previously hidden magnetic structures, offering insights that drive both fundamental research and technological innovation in the field of magnetism.

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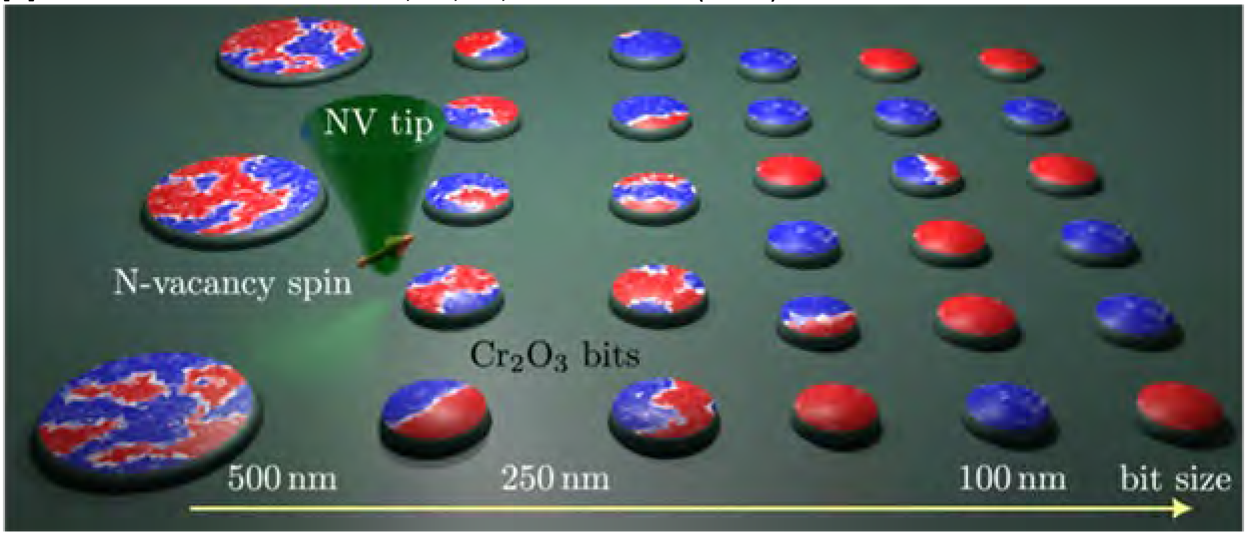

Non-Relativistic Anisotropic Magnetoresistance

Ritzinger P, Vyborny K

Session 11: Computational, April 8, 2025, 15:30 - 17:00

The anisotropic magnetoresistance (AMR) has been the subject of extensive research since its discovery in 1857 by William Thomson. While classically, it has been understood in terms of anisotropic s-d-scattering on magnetic impurities by spin-orbit coupling (SOC) [1], recent studies expanded the horizon to antiferromagnets (AFMs) [2], or investigated the much less known intrinsic mechanism [3,4], which is scattering-independent.

In all of these settings, SOC is a crucial component, rendering AMR a relativistic effect. In this study, we show how employing non-collinear magnetic order, inspired by real materials such as CrSe, δ-FeMn, Mn3Ge, or RbFe(MoO4)2, allows to generate AMR even in absence of SOC, allowing for a previously overlooked non-relativistic AMR.
We explore various types of lattices on a toy model level, including trigonal, parallelogram, and kagome lattice, as well as examples of non-collinear materials. Magnetic moments can be arranged in many different ways on such lattices, and small changes can alter the Fermi surface symmetry, spin texture, and transport properties. We systematically investigate the influence of magnetic ordering on these properties, which allows us to predict general features of spin texture and transport by only considering the symmetry of the underlying system. We show how non-relativistic AMR is possible for both the classical scattering-dependent extrinsic AMR and for the scattering-independent intrinsic AMR.
We will also propose a way to experimentally confirm our findings, which may have important implications for the development of future spintronic devices. Our findings shed light on the complex interplay between magnetic order, crystal symmetry, and electronic transport properties in magnetic materials.

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Fluctuating local moments from itinerant d- and localised f-electrons in magnetic materials: permanent magnets, caloric effects and magnetic phase diagrams.

Staunton J

Wohlfarth: Julie Staunton, April 8, 2025, 09:00 - 10:00

On the sub nanoscale, a material's magnetic properties come from spin correlations of its septillions of interacting electrons. In many cases, this collective electron behaviour can be characterised in terms atomic-scale, relatively long-lived magnetic moments. The moments' behaviour determines the overall magnetisation and its resilience and response to magnetic fields as well as affecting temperature dependent spin-polarised electronic structure. At high temperatures, the moments disorder so that there is no overall magnetisation in the paramagnetic state. As the temperature is lowered, they order into patterns describing magnetic phases whose structures and topologies depend on the nature of the local moment interactions. At T=0K, where magnetic order is complete, computational calculations using the first-principles spin-polarised Density Functional Theory (DFT) describe magnetic properties well and can be predictive. This talk will describe how the disordered local moment (DLM) theory extends DFT to finite temperatures for magnetic materials and, together with experimental investigations, enables quantitative modelling of properties and input for further modelling and experimental analysis. The talk will describe some of the early DLM theory work on the electronic structure of ferromagnetic metals above their Curie temperatures [1] and go on to discuss a range of applications: the magnetic anisotropy of FePt [2], magnetic order of the heavy rare earths [3], skyrmion lattices in centrosymmetric Gd intermetallics [4], caloric effects in La(Fe1-x Six)13 [5] and the hard magnetic properties of the ubiquitous permanent magnet Nd2Fe14B [6].

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Phonon-driven magnetisation dynamics using spin-lattice modelling

Strungaru M, Ellis M, Ruta S, Evans R, Chantrell R, Chubykalo-Fesenko O

Session 11: Computational, April 8, 2025, 15:30 - 17:00

In magnetic systems, relaxation is governed by the coupling of the magnetic modes (given primarily by the atomic spin/magnons) with the non-magnetic modes (lattice vibrations/phonons and electrons) which can mutually influence one another. A complete picture of a magnetic material would hence involve three sub-systems: spins, lattice and electrons, with the transfer of energy and angular momentum between them. Since electrons relax at faster timescales, a unified model of molecular and atomistic spin dynamics, called Spin-Lattice dynamics(SLD), can offer a deeper understanding of, relaxation processes[1] and phonon-driven switching mechanism[2], which can lead to the development of next-generation magnetic devices.
To model the effect of phonon excitation on magnetic systems, we apply a periodic external force to each atom and for specific k-vectors with corresponding THz frequencies we observe precessional switching caused by the generation of magnetoelastic fields of spin-lattice coupling origin. Analysis of the angular momentum transfer between sub-systems demonstrates that the angular momentum generated during phonon excitation is not able to solely account for switching and contains contributions from the internal sub-systems. By computing the switching phase diagram we observe that ferromagnetic materials that present a flat phonon spectral region, where a large number of phonon modes can be efficiently excited, are good candidates for THz-assisted, 'cold' switching. The key factor is excitation with THz phonons with frequencies and k points at a maximum in the phonon density of states and no spin excitations. In this case, the heating from the switching process is low (order of mK). Our prediction serves as an important route for the next generation of eco-friendly storage devices since heat production is a major problem for large data storage centers. Finally, the SLD framework is now freely available via the VAMPIRE software[3].

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Three-Dimensional Topological Spin Textures in Curved Chiral Magnets

Turnbull L, Birch M, Di Pietro Martínez M, Neethirajan J, Yamamoto R, Belkhou R, Finizio S, Mayoh D, Balakrishnan G, Weigand M, Wintz S, Abert C, Donnelly C

Session 5: Spin Textures, April 7, 2025, 15:45 - 17:00

Nanoscale topologically non-trivial magnetization configurations have garnered significant interest due to both the fundamental properties of their knotted structures [1], and their potential applications in ultra-efficient computing devices [2]. While such textures have been widely studied in two dimensions, three-dimensional (3D) systems can exhibit more complex configurations [3], resulting in richer topologies and dynamic behaviors [4]. However, reliably nucleating these 3D textures has proven challenging and so far, 3D configurations, such as vortex rings and hopfions, can often only be observed forming spontaneously in relatively uncontrolled manners. Here, we will demonstrate that through the 3D nanopatterning of chiral single crystal helimagnets into nano-tori, the controlled formation of three-dimensional topological spin textures can be achieved. Specifically, by employing focused ion beam patterning, we create nanoscopic tori of single-crystal helimagnets, introducing confinement, curvature, and non-trivial topology to the sample geometry. By investigating their magnetic configuration via resonant soft X-ray imaging, we observe a strong geometric influence at remanence, leading to a double helical texture that, with finite element micromagnetic simulations, we can attribute to the presence of non-trivial three-dimensional chiral configurations [5]. Our work highlights the impact of curvature on chiral helimagnetism, offering opportunities to tailor chiral magnetic textures within curvilinear geometries.

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Weak anti-localization in Bi implanted Cu devices

Vashisht G

Session 3: Spintronics 2, April 7, 2025, 11:40 - 13:00

Garima Vashisht1, M.M. Martinez Cameros1, Y. Huang2, M. Ali1, Maddison Coke2, R.J. Curry2, Jessica L. Boland2, G. Burnell1, B.J. Hickey1
1School of Physics and Astronomy, University of Leeds, Leeds, LS2 9JT, UK
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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 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, t = 10 nm) implanted with Bi ions with a dose of 1015 ions/cm2 over the length scale of 35 µm ? 10 µm (figure 1a and 1b). 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 1c). Despite a classical 3-dimensional system (mean free path is less than thickness before and after implantation), modelling the magneto-resistance curves HLN theory provides strong evidence of the quantum interference effects prevailing in 2-dimensions only, since the phase coherence length was 74 nm which is much larger than the thickness of devices. The 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. The contrast variation in the third order optical amplitude detected using scanning near field optical microscopy (SNOM) measurements reveals that the conductivity of the Cu devices at the area of Bi ion exposure is considerably decreased (figure 1d). 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.

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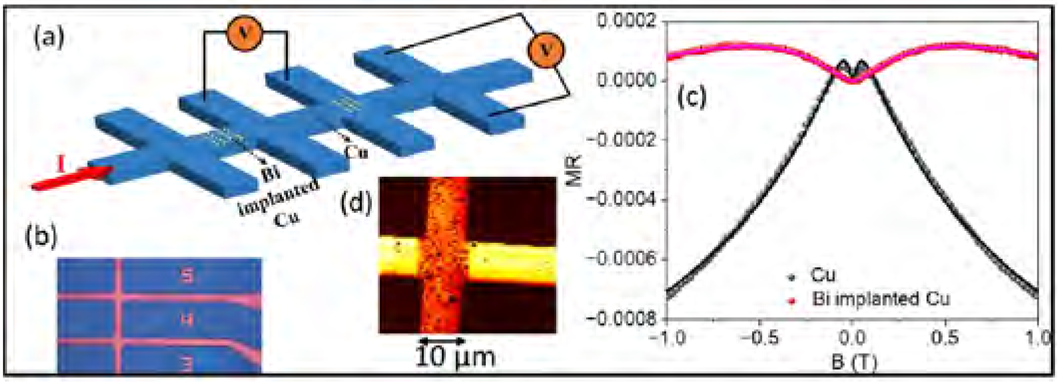

Figure 1: (a) Schematic for Bi ion implanted Cu devices (b) microscopic image of Cu devices (c) magneto-resistance curves at 2 K for pure and Bi-implanted Cu devices (d) 2D photocurrent mapping of Bi implanted Cu devices using SNOM.

Electronic structure and X-ray Magnetic Circular Dichroism in Topological Insulator/Molecular Diode

VASILI H, Rogers M, Parkin Z, Li W, Valvidares M, Ali M, Burnell G, Hickey B, Cespedes O

Session 4: Quantum Material and Devices, April 7, 2025, 11:40 - 13:00

Molecular thin films offer a promising platform for engineering novel spintronic devices by tailoring electronic properties at interfaces via charge transfer and hybridization [1,2]. Combining organic semiconductors such as C_{60} and phthalocyanines (CuPc) with topological insulators (TI) can create hybrid interfaces where emergent spin-dependent phenomena such as spin transport and spin photovoltaics may arise. Importantly, this approach holds potential for controlling spin Quantum bits, as phthalocyanines with their S=1/2 spin states can be influenced by the interfacial environment [3]. However, accessing coherent spin superposition states in thin layers of atomic and molecular spins on virtually arbitrary surfaces remains elusive for emergent quantum technologies.

We have grown the thin film multilayers of C_{60}(5,50)/CuPc(20) and CuPc(5,50)/C_{60}(20) on Bi_2Se_3(20) thin films grown on sapphire substrates (thicknesses are in nm). The spin and orbital configuration of Cu ions in CuPc deposited on either TI or C_{60} surfaces are strongly influenced by the rehybridization of molecular states with the underlying layer, despite the formation of long-range ordered CuPc chains. Element-specific X-ray magnetic circular dichroism and linear dichroism (XMCD and XLD) at the Cu-$L_{2,3}$ absorption edges reveal that the orbital and spin orientation of Cu^{2}+ ions are significantly modified upon CuPc adsorption on the surfaces, particularly when the orbitals responsible for the magnetic moment are involved in the interactions. The distinct responses can be attributed to the $3d^9$ e_g symmetry and orientation of the d_(x²-y²) and d_(z²) orbitals. A complete description of the orbital, spin, and spin-orbit operators is provided based on the XMCD sum rules. Our measurements demonstrate an extraordinary orbital moment anisotropy and anisotropic spin dipole moment exceeding twice the isotropic spin in the metal-organic layers.

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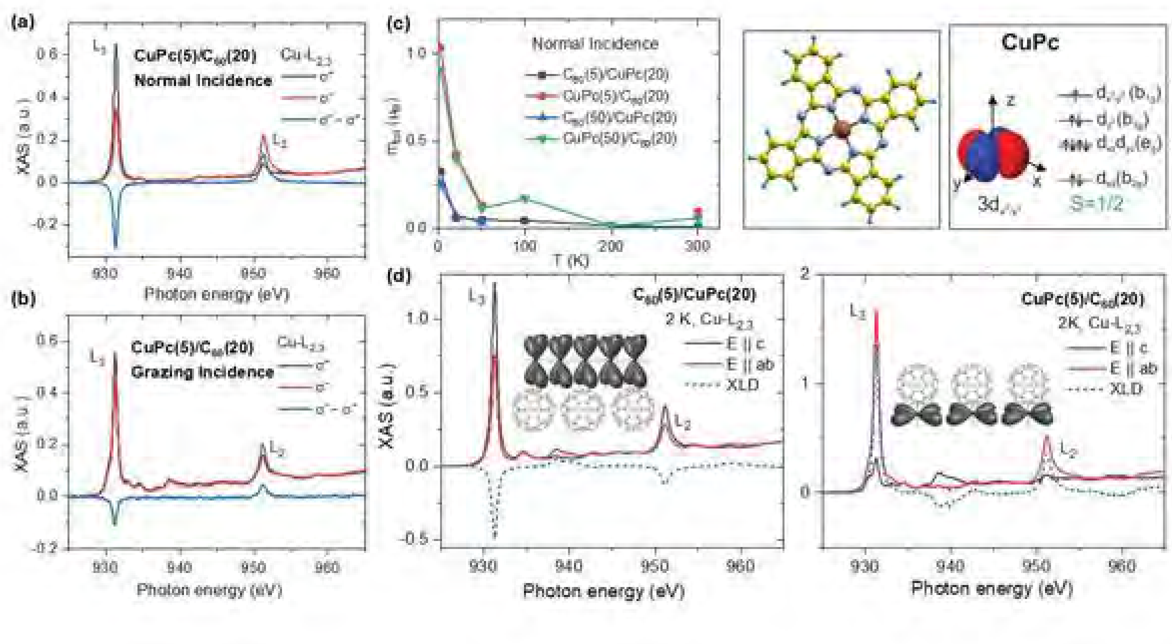

Altermagnetism imaged and controlled down to the nanoscale

Wadley P

Session 12: Novel Phenomena and Techniques, April 8, 2025, 15:30 - 17:00

Altermagnetism imaged and controlled down to the nanoscale

Peter Wadley – University of Nottingham

Altermagnetism is a newly identified class of magnets which combines properties from both ferromagnets and antiferromagnets, making them highly promising candidates for spintronic applications[1,2]. We recently demonstrated the spin split nature of the altermagnetic electronic band structure in MnTe[3]. In this work, we demonstrate that the unique resultant properties of altermagnets can be used to image them in unprecedented details, and also to control them in unique ways.

Utilising a combination of linearly and circularly polarised x-rays, in a single instrument, we generate a full Neel vector map of the magnetic domain in MnTe, showing all 6 domain types and revealing vortices and their vorticity. In addition, we utilise a combination of patterning and field cooling to nucleate single domains of our choosing from the micron to nanoscale. We also show generation and control of the position and vorticity of single vortices. These experiments showcase the unique properties of altermagnets and also provide a platform for the next stages of research and application[4].

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3. Altermagnetic lifting of Kramers spin degeneracy
J. Krempaský, L. Šmejkal, S. W. D'Souza, M. Hajlaoui, G. Springholz, K. Uhlířová, F. Alarab, P. C. Constantinou, V. Strocov, D. Usanov, W. R. Pudelko, R. González-Hernández, A. Birk Hellenes, Z. Jansa, H. Reichlová, Z. Šobáň, R. D. Gonzalez Betancourt, P. Wadley, J. Sinova, D. Kriegner, J. Minár, J. H. Dil & T. Jungwirth
Nature 626, 517–522 (2024)
https://doi.org/10.1038/s41586-023-06907-7

4. Altermagnetism imaged and controlled down to the nanoscale
O. J. Amin, A. Dal Din, E. Golias, Y. Niu, A. Zakharov, S. C. Fromage, C. J. B. Fields, S. L. Heywood, R. B. Cousins, J. Krempasky, J. H. Dil, D. Kriegner, B. Kiraly, R. P. Campion, A. W. Rushforth, K. W. Edmonds, S. S. Dhesi, L. Šmejkal, T. Jungwirth, P. Wadley
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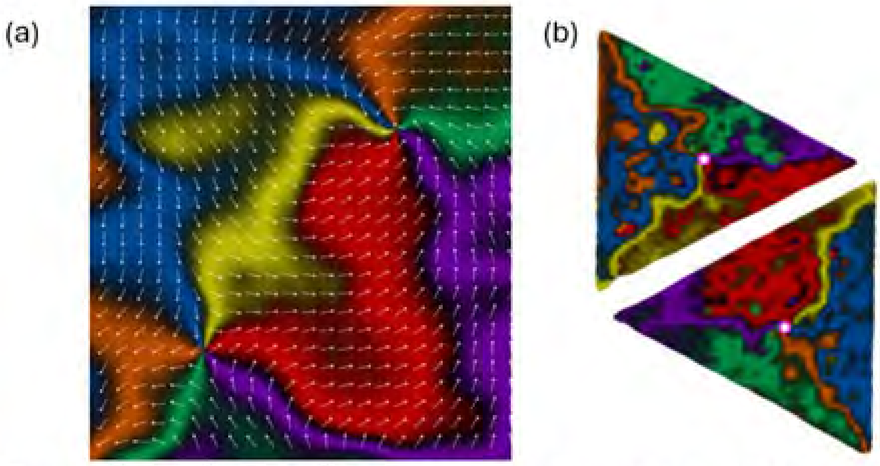

Figure1 – Altermagnetic domain structure in open space (a) showing a vortex antivortex pair and (b) in micro-fabricated field-cooled triangles showing single vortices with opposite vorticity. Adapted from [4].

Maze Solving with Stochastic Racetrack Neural Networks

Welbourne A, Ellis M, Gilroy E, Chambard M, Kyle S, Drouhin M, Haigh L, Keogh A, Mullen A, Fry P, Maccherozzi F, Forest T, Allwood D, Vasilaki E, Hayward T

Session 9: Intelligent Computing - Devices and Materials for Applications, April 8, 2025, 13:45 - 15:00

Non-volatile logic and memory devices based on domain wall (DW) motion have significant technological potential, with concerted efforts to realise technology such as magnetic racetrack memory [1,2]. Additionally, there is increasing demand for alternative computing paradigms that can address the limitations of traditional CMOS logic [3]. However, stochastic behaviour considerably impedes development [4]. We have previously demonstrated how tuneable stochastic pinning sites (Fig. 1(a)) can be used as stochastic magnetic synapses in hybrid CMOS/magnetic Neural Networks (NNs); we achieved handwritten digit recognition with performance comparable to a standard NN [5]. Here, we go a step further, linking the stochastic pinning site with magnetic DW logic gates to perform maze-solving in a reinforcement learning framework with our all-magnetic racetrack neural networks.

A simple NN is shown in Fig. 1(c). The highlighted regions demarcate inputs and outputs of a synaptic unit. Fig. 1(d) demonstrates this synaptic performance arising from coupling of an AND gate with stochastic input notches. Varying a weighting field tunes the passing probability of DWs through the notches. Binary inputs are encoded as DWs pinning (0) or passing (1) the notch. Analogue values arise as the average values of DW bit-streams, which tend to the passing probability of the notch. The AND gate acts to multiply these probabilities (the input and the weight), performing the analogue weighting of a synapse in a neural network. The later stage in the network performs the action of a neuron: computing (in materio) the non-linear weighted sum of two inputs with two weights.

This presentation will demonstrate how the stochasticity intrinsic to DW motion has enabled realisation of all-magnetic “Racetrack Neural Networks”, as evidenced by a maze solving task in a reinforcement learning framework (fig 1(d)). Although further research is necessary, magnetic NNs could be pivotal in high-radiation environments requiring autonomous decision-making capabilities.

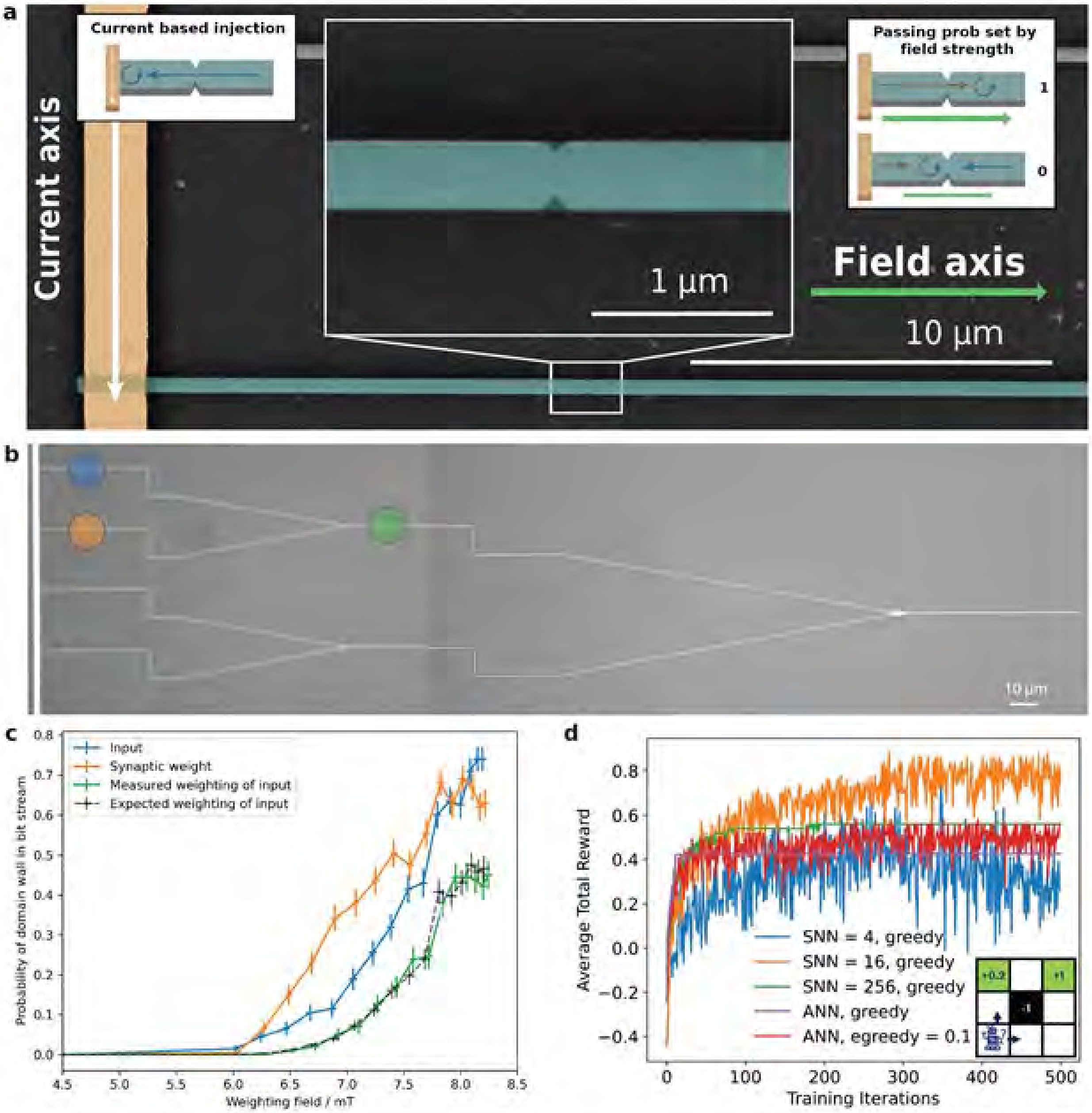

Fig. 1: **(a)** SEM of a notch defect in a 400 nm wide (54 nm thick) permalloy nanowire that provides a site with tunable pinning probability. Injection with an increasing field increases the probability of a domain wall (DW) passing the notch. This can be used to provide bit streams where the probability of a DW provides the analogue values required for a neural network. **(b)** Image of a full perceptron (synapses and neuron). The highlighted sections correspond to the data in (c); input (via a notch) and output of an AND gate. The network pictured computes (in materio) the output of a perceptron subjected to two inputs with two weights. **(c)** Synaptic operation with an AND gate and input notches. Multiplication of an input probability (notch one) with a weight (notch two) through an AND gate. By comparing the measured output and the predicted output, it is shown that the gate weights the input as expected, functioning as a synapse. **(d)** Maze solving using reinforcement learning. The curves for the Stochastic Neural Network (SNN) represent performance using a model based on the experimental network in (b) with increasing number of samples of the network (higher reward is better). The curves for the Artificial Neural Network (ANN) demonstrate performance in a comparable "traditional" NN. The SNN outperforms the control (ANN) approach for the optimum number of samples.

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Chiral-soliton-mediated tunnelling magnetoresistance in van der Waals homo-junctions

Yang C, Xue Z, Hao Y, Youel H, Freeman C, Nakagawa K, Cubukcu M, Cothrine M, Mandrus D, Kurebayashi H

Session 8: Low Dimensional Magnetism, April 8, 2025, 10:30 - 12:00

The mechanical exfoliation of layered van der Waals (vdW) materials offers a fascinating playground to explore novel nano-electronic device structures that are not thermodynamically accessible by conventional growth techniques such as sputtering and molecular beam epitaxy. This is true for the field of spintronics and nano-magnetism where the low-symmetry of vdW materials and their heterostructures generate spin textures in both momentum and real spaces for unconventional spin-orbit torques, and magnetic skyrmions together with other topologically defined objects. One such real-space spin texture is a magnetic soliton, initially theorized in 1964 and recognized for their monoaxial spin alignment, quasi-particle nature, and topological durability [1-2], One-dimensional magnetic solitons were experimentally realized in CrNb3S6 (CNS) [3] which has been since actively studied to explore monoaxial chiral helimagnetism and its spintronic applications [4].

This present study leverages the unique properties of CNS via mechanical exfoliation and 2D material transfer techniques, leading to the first fabrication of CNS/CNS vdW homo-junctions (Fig.(b)). By controlling the thickness of single CNS nanoflakes, we modulate the topological sectors of magnetic solitons [5], facilitating their controlled annihilation and creation, detectable via magneto-transport measurements. The constructed CNS/CNS spin valve homo-junctions demonstrate pronounced tunnel-magnetoresistance (TMR) like behaviour at low magnetic fields (Fig.(c)). Notably, the vdW gap within these homo-junctions effectively decouples the ferromagnetic layers, unlike typical magnetic layers with strong interface exchange coupling [6]. This decoupling facilitates varied coercivities and stabilizes the chiral soliton interaction states, enhancing device functionality. Our analysis of angular-dependent magnetoresistance further reveals the TMR sensing of magnetic soliton dynamics, which will be elaborated upon alongside quantitative results and micromagnetic simulations.

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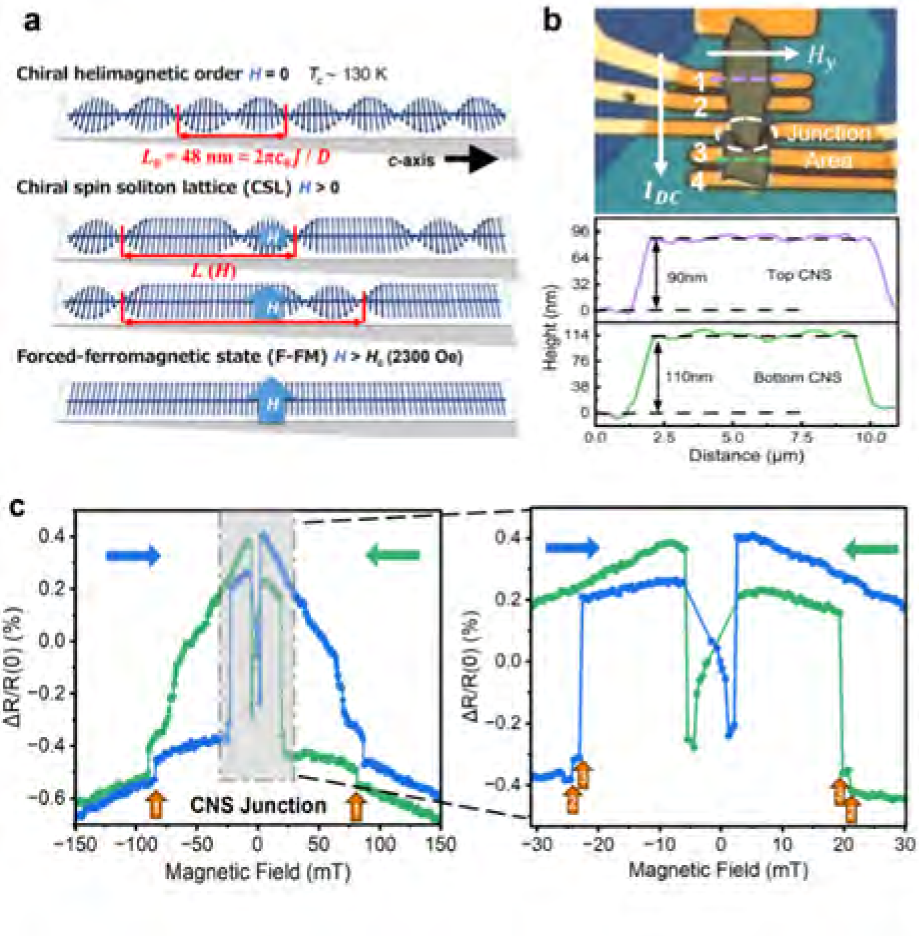

Fig (a). Schematic Diagram: Spin configurations in $CrNb_3S_6$. Adapted from [5]. (b). Optical Microscope Image: CNS vdW homo-junction device, showcasing height profiles of the top and bottom CNS nanoflakes. (c). Magnetoresistance Curve: MR response of the CNS homo-junction, with detailed magnification on the right panel.

Demonstration of ultrastrong coupling of magnon polaritons in on-chip thin ferromagnetic films

Yoshii S, Müller M, Ohshima R, Ando Y, Althammer M, Heubl H, Shiraishi M

Session 4: Quantum Material and Devices, April 7, 2025, 11:40 - 13:00

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 exploring 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 multiple reports on the realization of ultrastrong coupling in magnon polaritons, most 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 YBa2Cu3O7 (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) and apply the magnetic field in the plane. Figure 1 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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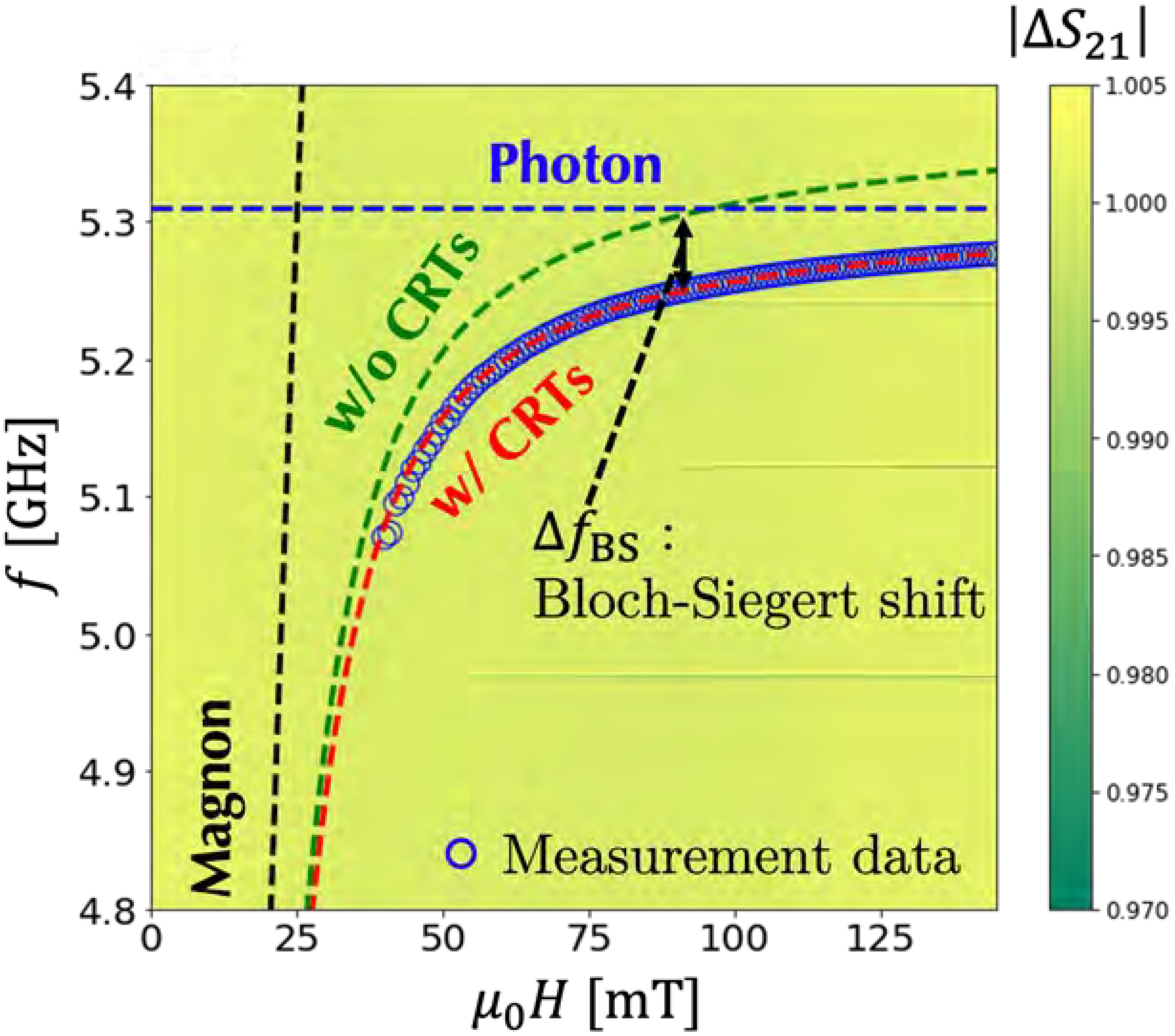

$|\Delta S_{21}|$
1.005
1.000
0.995
0.990
0.985
0.980
0.975
0.970
5.4
5.3
5.2
5.1
5.0
4.9
4.8
f [GHz]
Photon
w/o CRTs
w/ CRTs
Δf_{BS} :
Bloch-Siegert shift
Magnon
Measurement data
0
25
50
75
100
125
$\mu_0 H$ [mT]

Probabilistic computing using an isotropic magnet

Youel H, Prestwood D, Barker J, Yamazaki T, Kumar K, Stenning K, Bauer G, Yamamoto K, Seki T, Kurebayashi H

Session 4: Quantum Material and Devices, April 7, 2025, 11:40 - 13:00

Probabilistic computing is an unconventional computing framework that leverages true randomness to sample from distributions and has previously been demonstrated using stochastic magnetic tunnel junctions [1]. The base unit of probabilistic computing, the probabilistic bit (p-bit), bridges the gap between the classical bit and the qubit [2], offering a promising route for simulating quantum algorithms at room temperature [3]. So far, p-bits that have been proposed and experimentally developed, randomly fluctuate between two states due to finite temperature, and can be externally biased to either state for more functional operations.

In this study, we focus on a new type of p-bit that has a continuous variable in its state vector, rather than conventional binary behavior i.e. it is capable of sampling values on the interval [-1, +1] instead of discrete binary states {-1, +1}. The increased number of accessible states for p-bit operations is expected to empower its architecture on a range of probabilistic computing problems. Building on experimental work [4], we simulate a MgO/CoFeB/W stack with interfacial perpendicular magnetic anisotropy, where the shape anisotropy has been approximately cancelled through precise annealing. Spin orbit torques arising from the W layer modulate the damping parameter, enabling biasing of the magnetization.

We demonstrate that this isotropic magnet serves as a continuous p-bit (Fig. a), exhibiting a random walk on the axis parallel to the applied field (Fig. b), which can be applied to probabilistic computing tasks. Using numerical stochastic Landau-Lifshitz-Gilbert equation simulations, we showcase its capability to perform invertible logic operations (Fig. c) and explore its continuous nature to solve problems requiring more than two states [5].

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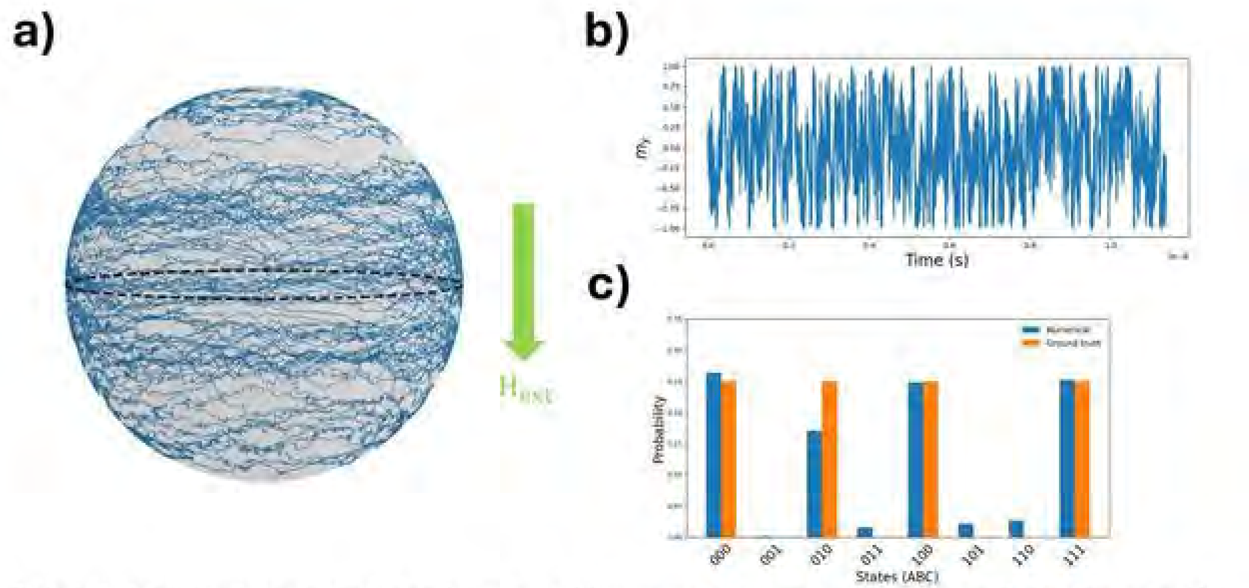

Probabilistic computing using an isotropic magnet. a) Compensated magnetization random walk visualization and **b)** y-component magnetization output. **c)** Results for a probabilistic AND gate using a stochastic Landau-Lifshitz-Gilbert simulation.

Barium Hexaferrite Nanoplatelet Deposition and Functionalization

Zabek D, Ladak S

Session 6: Patterned Thin Films and Nanomagnetism, April 7, 2025, 15:45 - 17:00

Unlike spherical nanoparticles, anisotropic geometries such as rods and platelets are of particular interest because their aspect ratio influences magnetic properties, which can be precisely controlled for the desired application. In this field, scandium-substituted barium hexaferrite magnetic nanoplatelets (MNPs) are of significance due to their strong geometric and magnetocrystalline anisotropy. With only one or two unit cells stacked (~2 - 5 nm thick) perpendicular to their basal plane, barium hexaferrite MNPs can be approximated as a two-dimensional (2D) material with strong magneto crystalline anisotropy. Here, the synthesis [1] as well as their structural and magnetic properties are discussed at the nanoscale [2] opening the way for macroscopic two-dimensional (2D) and three-dimensional (3D) structures with tuned magnetic ordering.

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Localized Magnetization Control in Ferromagnetism Nano-systems

Zheng T

Session 11: Computational, April 8, 2025, 15:30 - 17:00

Recent advances in all-optical magnetisation switching (AOMS) in ferromagnetic nanoarrays have highlighted the potential for precise, field-free manipulation of magnetic textures. AOMS uses lasers to achieve magnetisation control at the nanoscale, offering transformative possibilities for reconfigurable magnetic systems and applications such as energy-efficient data storage and neuromorphic computing. While AOMS has been demonstrated experimentally, the underlying mechanism remains an active area of investigation [1]. Theoretical modelling by Yang et al. (2023) [2] suggests that the inverse Faraday effect (IFE) induced by linearly polarised light in metallic nanostructures could generate plasmonically-enhanced magnetic fields, and play a key role in AOMS. Yang et al demonstrated in simulation on Au nanoislands that linearly polarised light can generate strong, out-of-plane magnetic fields through IFE from linearly polarised light, with peak effects observed at specific polarisation angles. Building on these findings, this work explores AOMS-driven mechanisms for controlling magnetisation textures in ferromagnetic nanoislands (NiFe). Using Mumax3 micromagnetic simulations and experiments, we investigated precessional magnetisation dynamics induced by the IFE-generated Bz-field under varying island geometries, field parameters, and thermal conditions. Key simulation outcomes reveal energy landscapes and magnetisation state evolution, highlighting potential benefits for such plasmonically-enhanced IFE effects from linearly-polarised light on AOMS performance. This work paves the way for a deeper understanding and experimental verification of the physics behind AOMS, and it provides a powerful framework for scalable, ultrafast manipulation of magnetic states.

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Magnetism 2025 – Posterboard allocations

Poster board no.	First Name	Last Name	Paper Title
1	Aly	Abdeldaim	The materials and magnetism beamline, I16 at Diamond Light Source
2	Stefano	Agrestini	I21 RIXS beamline as powerful tool to investigate quantum and magnetic materials
3	Shoug	Alghamdi	Manipulating the Magnetic Properties of 3d Transition Metals with C60 Thin Films
4	Dkhilallah	Alsebaie	Impact of Increasing Aluminium Content on the Magnetic, Electrical, and Structural Properties of FeCoNiMn Thin Films
5	Peter	Bencok	Beamline for Advanced Dichroism Experiments
6	Luke	Benson	Spin-polarised currents in topological insulators due to the acousto-electric effect
7	Ben	Brereton	Growth of chiral magnetic multilayers on topological insulator Bi2Se3 epilayers and observation of hosted spin textures
8	David	Burn	Time-resolved and 3-dimensional vector imaging of magnetic materials with coherent soft x-rays
9	Andrew	Caruana	Refl1d: Advanced Neutron and X-ray reflectivity modelling with Bayesian Uncertainty analysis
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20	Emily	Heppell	Room-temperature in-plane ferromagnetism in Co-substituted Fe5GeTe2 investigated by magnetic x-ray spectroscopy and microscopy
21	Emily	Heppell	Search for proximity-induced magnetism in CrTe2/Bi2Te3 ferromagnet-topological insulator heterostructures
22	Angus	Hodgkiss	Platinum/Gold Alloys for Spintronics: Investigating Spin Orbit Torque and Spin Pumping Reciprocity
23	Dirk	Honecker	Nanomagnetism seen with neutrons: Small-Angle Neutron Scattering
24	Lin	Huang	The alternative antiferromagnetism of Mn doped ferrite C4AF
25	Mae	Jankowski	Bismuth ferrite-lead titanate thin films for an investigation of the effects of the morphotropic phase transition on magnetic properties
26	Paul	Keatley	Exploring ultrafast magnetic processes of low-dimensional ferromagnets using EXTREMAG

27	Christy	Kinane	Structural and Magnetic Depth Profiling of Magnetic Thin Films with the POLREF Reflectometer
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29	Maria Magdalena	Martinez Cameros	Enhancing spin signals in pure spin currents
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31	Noora	Naushad	Developing novel magnetic L10 alloys for spintronics
32	John	Osborne	Optimisation of magnetic multilayers for surface acoustic wave-driven skyrmion motion
33	Manikantha	Panda	Experimental and theoretical study on quaternary Heusler alloy FeRuVSi: Anti-site disorder effect study
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35	Jack	Pearce	Applying Soft X-Ray Resonant Magnetic Diffraction to Elucidate the Magnetic Ordering of the W-Type Hexaferrite SrCo2Fe16O27
36	Sergiu	Ruta	Spin-wave implementation within the VAMPIRE software package
37	Abhirami	Saminathan	The search for spin-polarised edge states in InAs/GaSb quantum well devices
38	Rishi	Siddani	All-Electrical Magnetisation Switching of Connected Nanomagnets
39	Sehwan	Song	Correlation Between Local Structural Symmetry and Magnetic Anisotropy Energy: Insights into the Morin Transition in α-Fe_2O_3 Films
40	Harvey	Stanfield	Beyond Room Temperature Magnetic Order in Low Dimensional van der Waal Crystals for use within Magnetic Tunnel Junctions
41	Nick	Surtees	Large Bandgap Oxide Topological Insulators
42	Gonzalo	Vallejo Fernandez	MnN As replacement for IrMn
43	Jing	Wu	Ultrafast magnetization enhancement via the dynamic spin-filter effect of type-II Weyl nodes in Co3Sn2S2

The materials and magnetism beamline, I16 at Diamond Light Source

Abdeldaim A, Scatena R, Porter D, Nisbet G, Vibhakar A, Bombardi A

I16 is a high flux, high resolution x-ray beamline based at the Diamond Light Source. The beamline operates in the 2.7-15 KeV range and it is a diffraction facility optimized for the study of resonant and magnetic scattering processes from single crystal samples [1]. Resonant elastic X-ray scattering is ideal to characterize electronic, magnetic, and structural properties of materials thanks to the enhanced sensitivity to otherwise weak scattering processes providing spectroscopic information and chemical selectivity. I16 main instrument is a large 6-circles K-diffractometer able to accommodate a variety of ancillary environment. The beamline offers full control of the incident photon polarization over most of its energy range. This is combined with large photon counting area detectors and an in vacuum linear polarization analyser installed on the K diffractometer that is used to isolate and enhance specific scattering processes related to ordering phenomena.

Using circular light of opposite helicity allows the investigation of chiral magnetic structures, inversion domain in multiferroic materials and permits to separate collinear and non collinear magnetic textures in real and reciprocal space. Other phenomena routinely investigated on I16 include charge density wave, metal-insulator transitions, orbital ordering, and subtle structural transitions. The beamline has been highly successful in examining weak scattering phenomena in small crystals, films, and multilayers between 6-800 K, often in combination with other generalised thermodynamic variables like electric or magnetic fields, and strain [2-5]. X-ray Bragg Coherent Diffraction Imaging is also possible at the beamline and allows researchers to peer into the inner structure of nanocrystals, with unparalleled detail and resolution by recording the interference patterns resulting from the interaction of a coherent beam with the lattice.

In this poster presentation, some of the new capabilities and features of the beamline will be shown, and recent results establishing the capabilities of the beamline will be highlighted.

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I21 RIXS beamline as powerful tool to investigate quantum and magnetic materials

Agrestini S, Zhou K, Garcia-Fernandez M

Resonant inelastic X-ray scattering (RIXS) is a photon-in photon-out spectroscopic technique utilising highly intense and monochromatized X-rays to probe the excitations in materials of interest. By selectively working at the resonant thresholds of an element, RIXS can probe in the energy-momentum space a wide variety of local excitations, collective excitations or ordered states, such as d-d excitations, magnons, orbitons, plasmons, phonons, and charge-density waves. Thanks to its high cross-section and focused X-ray beam, RIXS is capable of measuring micron-size samples and nanometre-thick films, too small to be accessible to neutron scattering. The full control of the polarisation of the x-ray beam in I21 beamline in Diamond Light Source allows to probe the chirality of materials by using circularly polarised light. In this poster, I will briefly introduce the principle of the technique, I21 beamline unique capabilities, and discuss some recent science cases in quantum and magnetic materials.

Manipulating the Magnetic Properties of 3d Transition Metals with C60 Thin Films

Alghamdi S, Al Ma'Mari F, Moorsom T, Ali M, Hickey B, Céspedes O

Organic semiconductors (OSCs) is a fascinating topic for essential scientific research and for future applications. Recent theoretical and experiment developments in the interaction between organic and ferromagnetic metals have intensified studies focusing on hybridisation between ferromagnetic metals and molecule orbitals that can lead to big interfacial spin polarisation and magnetic moment in carbon-based spintronics [1] [2]. This study explores the modification of magnetic properties in 3d transition metals through interactions with hybrid nanocarbon and molecular carbon interfaces. Specifically, it examines the magnetic behavior of Fe/C60 bilayers at room temperature and assesses the effects of annealing at 100°C, 150°C, and 200°C. C60 was used due to its straightforward deposition on metal surfaces, its simple molecular structure, higher spin-orbit coupling, and potential for significant charge transfer [3]. Magnetic moments were measured using SQUID-VSM magnetometry at 300 K. Our findings show changes in both Ms and Hc when the metallic layer is coupled with C60 before and after annealing. The findings emphasis the critical role of hybridization effects between nanocarbon molecular orbitals and the 3d bands of metals in influencing interface magnetic properties before and after annealing.

Fig.1: Changes in Ms for Ta(5 nm)/Fe(t)/C60(20 nm)/Ta(10 nm) and control samples Ta(5 nm)/Fe(t)/Ta(10 nm) measured by SQUID magnetometer at room temperature. The samples show dependence of the magnetisation on the Fe film thickness before and after annealing. The uncertainty in Ms that could be due to sputtering parameters such as growth pressure or substrate alignment or to variations in volume.

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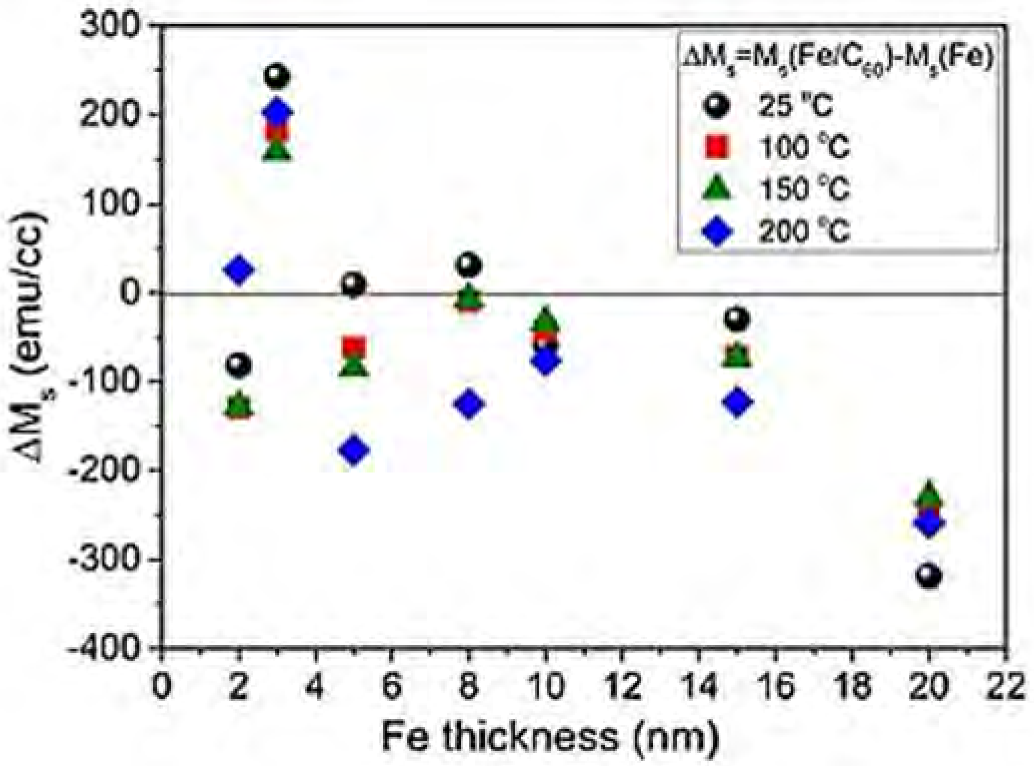

Impact of Increasing Aluminium Content on the Magnetic, Electrical, and Structural Properties of FeCoNiMn Thin Films

Alsebaie D, Morley N

The prospective uses for soft, high-moment magnetic films are within storage devices, high frequency applications and sensors due to their considerable saturation magnetisation (>800 kA/m) and minimal coercivity (<0.2 A/m)[1]. The growing interest in miniaturising device size has driven the investigation into producing and characterising new soft magnetic films [2]. In this research, FeCoNi, FeCoNiMn, and FeCoNiMnAlx thin films were prepared using DC sputtering, with a thickness of 100 nm under a chamber pressure (PAr) of 5 mTorr. How the structural, magnetic, and electronical properties changed with the additional of Mn and Al to FeCoNi was determined.
The X-ray diffraction (XRD) patterns reveal a structural transformation from a FCC phase in FeCoNi to a BCC phase in FeCoNiMnAlx. However, FeCoNiMn exhibits an amorphous structure, likely due to the addition of Mn. The magnetic properties exhibit significant changes with the addition of Mn and Al to FeCoNi. Adding Mn to FeCoNi results in a noticeable increase in remanence (Mr) and coercivity (Hc) However, with the introduction of Al to FeCoNiMn, both remanence and coercivity gradually decrease as the Al concentration increases from 0.6 to 2 (Figure 1a). The saturation magnetization (Ms) for FeCoNi is approximately 1025 kA/m. This value decreases with the addition of Mn, but then remains relatively constant with the further addition of Al; however, when the Al concentration reaches 2, a noticeable decrease in Ms is observed (Figure 2b). The electrical resistivity (ρ) of the film set was studied, revealing a significant increase from approximately 0.06 mΩ·mm for FeCoNi to 2.9 mΩ·mm for the film with a high aluminum content.
Thus taking account of the decrease in saturation magnetisation, with the increase in electrical resistivity, the Fe1.4Co1.1Ni1.1MnAl1.3 film is a promising candidate as a new soft magnetic material.

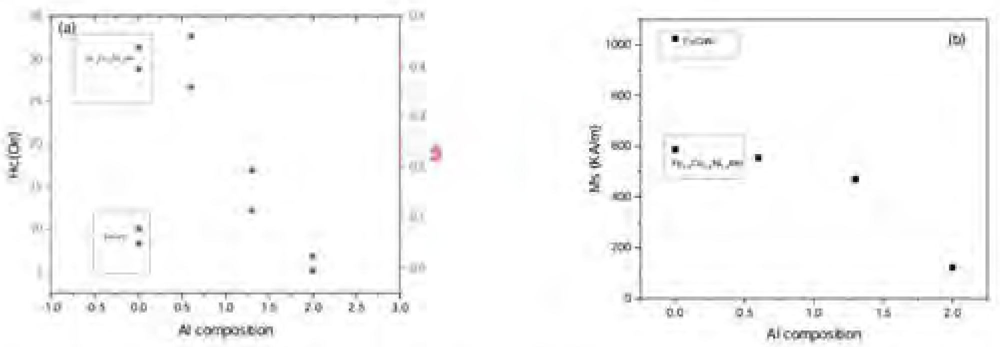

Figure 1. (a) show the hysteresis loop, coercivity, and remanence for all the FeCoNiMnAl films as a function of Al composition. (b) show the saturation magnetisation (M_s) of all the films as a function of Al composition.

Beamline for Advanced Dichroism Experiments

Bencok P, Steadman P, Fan R, Kiranjot K

The Beamline for Advanced Dichroism Experiments delivers soft X-ray beam in the energy range from 0.4 to 1.6 keV. The research focuses on the magnetisation and the magnetic structure of novel nanostructured systems. These magnetic properties can be probed thanks to high dichroic effects in the soft X-ray region. The dichroic effect can be studied both in scattering and absorption experiments.

The scattering branch is housing a 2-circle diffractometer. Our diffractometer is equipped with a full polarisation analyser and low temperature capabilities (down to 12K). Sets of various magnets can be used to apply a magnetic field up to 0.2T in different geometries. The scattered beam can be detected by a point detector or by one of two area detectors (fixed or movable).

On the absorption branch, using the high field magnet, the sample can be exposed to a magnetic field up to 14 T and cooled down to a temperature of 3K. For lower fields and moderate temperatures down to 20K, the electromagnet end station can be used. Both stations are optimized for the measurement of the x-ray magnetic circular dichroism in absorption. The signal, which is proportional to the absorption, can be detected in the total electron mode or fluorescence mode.

The beamline has been in operation since 2011. The research is focusing on topics like skyrmions, multiferroic materials, topological insulators, molecular magnets and many more.

Spin-polarised currents in topological insulators due to the acousto-electric effect

Benson L, Sasaki S, Cunningham J

Topological insulators (TIs) have attracted a lot of attention in recent years due to potential applications in spintronic devices [1]. TIs have an energy gap between the highest occupied and lowest unoccupied bulk bands which is partially inverted due to strong spin-orbit coupling. A characteristic property of TIs is their topological surface state – a gapless surface state that occurs at the interface between a TI and a trivial insulator such as vacuum. In these surface states, charge carriers are helically polarised with the spin orientation locked perpendicular to its momentum [2], hence carriers with opposite spins flow in opposite directions. When an external charge current is applied to a TI the momentum direction becomes determined, hence current is spin-polarised which enables applications in high-efficiency spintronics.

Rayleigh surface acoustic waves (SAWs) are mechanical quasi-two-dimensional waves that propagate along the surface of a substrate, with the amplitude of oscillation decaying exponentially into the bulk over one or two wavelengths. SAWs can be launched and detected on a piezoelectric substrate using comb-like electrodes known as interdigitated transducers (IDTs). The piezoelectric field generated by the SAW can interact with charge carriers on an adjacent two-dimensional sample. The carriers are trapped in the extrema of the energy potential and, as a result, dc current can be generated in the sample [3]. This is known as the acousto-electric effect.

Using molecular beam epitaxy (MBE), thin-film bismuth selenide samples have been grown on ST-cut quartz substrates, which support Rayleigh SAWs parallel to the X crystallographic direction. Aligning IDTs to this direction, TI samples can be etched into Hall bars such that low-temperature magneto-transport measurements can be performed. We aim to demonstrate the acousto-electric effect in TIs for the first time, providing a novel technique to manipulate carriers within the topological surface state, enabling applications in spintronic devices.

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

Brereton B, Hait S, Yagmur A, Kinane C, Sarpi B, Maccherozzi F, Moore T, Dhesi S, Langridge S, Marrows C

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 Bi2Se3 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 1c). These textures appear to be affected by terracing effects from the underlying TI as shown by AFM (fig 1d) which can limit skyrmion nucleation compared to similar multilayers grown on silicon (fig 1e). Potential solutions to this problem are proposed for future skyrmion dynamics experiments.

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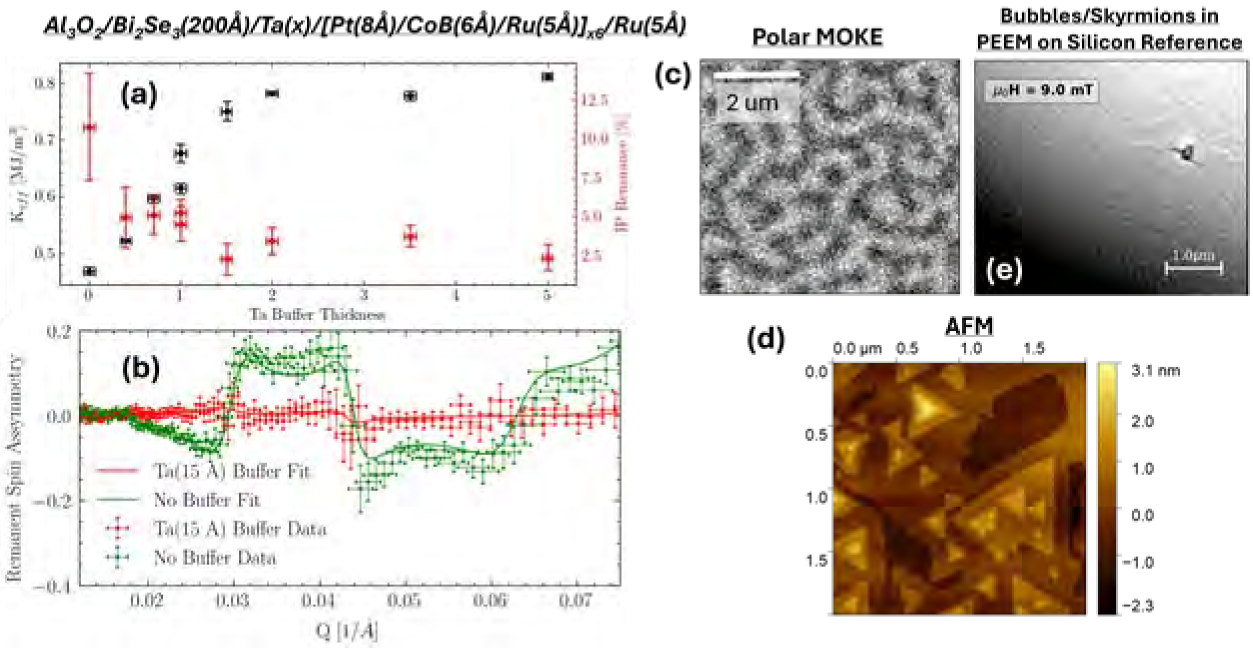
Al3O2/Bi2Se3(200Å)/Ta(x)/[Pt(8Å)/CoB(6Å)/Ru(5Å)]x6/Ru(5Å)
(a)
Ta Buffer Thickness
(b)
Ta(15 Å) Buffer Fit
No Buffer Fit
Ta(15 A) Buffer Data
No Buffer Data
Remanent Spin Asymmetry
Q [1/Å]
Polar MOKE
(c)
2 um
Bubbles/Skyrmions in
PEEM on Silicon Reference
μ0H = 9.0 mT
(e)
1.0μm
(d)
AFM
3.1 nm

Time-resolved and 3-dimensional vector imaging of magnetic materials with coherent soft x-rays

Burn D, Walters A, Dhesi S

Magnetic ordering in nanostructures and in chiral materials gives rise to interesting phenomenon such as the formation of skyrmions, chiral spin structures, domain and domain walls geometries. These features are a key area of research at the forefront of innovation as they provide potential building blocks for future technological devices for data storage, processing and novel computing applications.

The majority of research to date is based on two-dimensional systems, however, the behaviour in the third dimension promises a wealth of opportunities for scientific advancement and technological development[1]. Techniques are now available for experimental fabrication of structures in 3D, along with readily available theoretical and modelling frameworks, however, full understanding is limited by the availability of suitable experimental techniques to measure such systems in 3D.

Here we will outline an instrument which is currently under development at the Coherent Soft X-ray Imaging and Diffraction (CSXID) beamline at Diamond Light Source. This instrument will be dedicated towards exploring the three dimensional spin structuring in nanoscale quantum materials. We will show how cutting-edge developments in synchrotron technology can provide high resolution 3D imaging using coherent soft x-rays[2] with mechanisms to explore temporal resolution in dynamic time resolved processes[3]. Furthermore, we will show how the imaging can be provided along with magnetic fields, temperatures and electrical contacts for a wide variety of relevant research.

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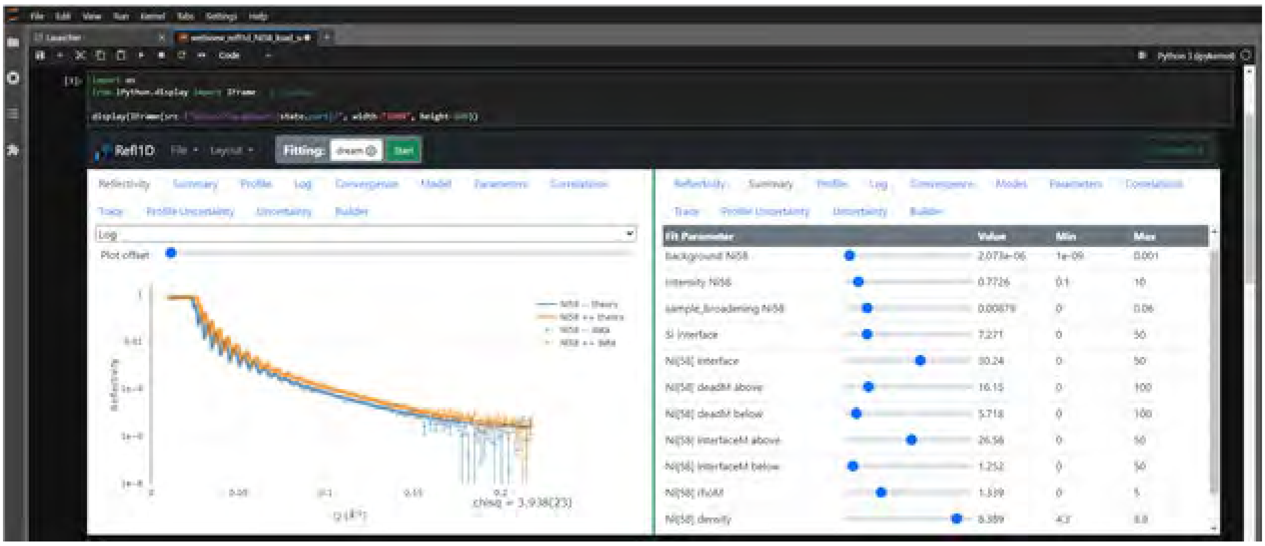
Refl1d: Advanced Neutron and X-ray reflectivity modelling with Bayesian Uncertainty analysis

Caruana A, Maranville B, Kienzle P, Doucet M, Elsarboukh G

Refl1d is an advanced reflectivity modelling and fitting python package than can be used to fit both Neutron (Non-Polarized – NR, Polarized – PNR and with Polarization analysis – PA) and X-ray scattering data. Basic slab-based models can easily be constructed with additional magnetic properties, such as dead layers or decoupled magnetic interfaces, which are readily integrated into the basic modelling. Beyond the standard slab-based modelling, Refl1d allows for the use of custom functional profiles to describe complex structural and magnetic scattering length density (SLD) profiles – e.g., helical magnetism (see Figure below). Refl1d has many other modelling features such as mixed area models, multi-data set fitting and free interface spline profiles, to name a few.

With the fitting engine supplied by bumps, Markov Chain Monte Carlo (MCMC) Bayesian un-certainty analysis can be performed, providing information on parameter uncertainties, correlations, and model uncertainties, by using the DREAM algorithm. Furthermore, the DREAM algorithm can be used as a very robust fit engine, with the ability to minimize very complex fit spaces.

Here we will show some examples of simulating and fitting X-ray, NR, PNR and PA data and further describe the features of Refl1d including the new web browser-based GUI – Webview. Finally, future developments, including the inclusion of a GUI model builder and integration of a nested sampler for model selection, will be discussed.



Microscopic magnetic modelling of manganese-based olivines Mn_2AX_4

Davies M, Rousochatzakis I, Tsirlin A

Manganese-based olivine compounds with the stoichiometry Mn_2AX_4 (A=Si, Ge; X=S, Se) have attracted significant interest (see e.g., [1-3]) due to their intriguing magnetic properties, in particular, the sharp peak of the magnetization in the vicinity of the Néel temperature TN. This study [4] aims to explore the interplay of the geometrical frustration and magnetic anisotropy in these compounds, as well as their corresponding H-T magnetic phase diagrams, using microscopic insights from ab initio Density Functional Theory calculations and various numerical and analytical semi-classical approaches. By analysing several key magnetic parameters (including the Néel and Curie-Weiss temperatures, the saturation and spin-flop re-orientation transition fields) and comparing with reported experimental data, we arrive at a minimal microscopic model, common for all Mn-based olivines, that sheds light into the impact of the sawtooth-like chain structure of Mn ions in the crystallographic a-b plane, the non-trivial inter-plane exchange pathways, as well as the crucial role of magnetic anisotropy. We also aim to make predictions for the spin-wave excitation spectrum, thus setting the stage for further experimental and theoretical exploration of the transition-metal olivine compounds.

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Magnetic and Electrical Characterisation of α-MnTe films grown by Molecular Beam Epitaxy (MBE)

Dawa E

Altermagnets are collinear, fully compensated materials with spin sublattices that are connected by crystal rotation symmetries in real space, leading to broken time symmetry. Their electronic band structure is characterised by momentum-dependent spin splitting, while preserving a net-zero magnetisation [1-2]. This unique property leads to a combination of the ultra-fast dynamics associated with antiferromagnets together with spin polarised currents associated with ferromagnets, making altermagnets ideal for future memory devices.

α-MnTe (0001) is a prototypical example of a g-wave altermagnet, as confirmed by several recent studies [2-5]. Here, we report on detailed structural, magnetic and electrical characterisation of α-MnTe films grown by molecular beam epitaxy (MBE) on InP(111) substrates. The α-MnTe films are p-type and semiconducting, with a carrier concentration of typically 10^{18} cm^(-3) at room temperature, and they exhibit a spontaneous anomalous Hall resistivity below around 250 K. Magnetometry measurements reveal that a weak ferromagnetic moment of the order of 10^(-3) μ_B appears around the same temperature.

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Magnetism of Hole Doped Néel Antiferromagnet La2-xSrxNiO4 x = 0.12.

Freeman P, Komarek A, Braden M

Since the discovery of charge-stripe order in hole doped cuprates the role of charge-stripes in high temperature superconductivity has been under intensify investigation[1]. To aid these investigations, the study of charge-stripe order in insulating, non-superconducting hole doped La2-xSrxNiO4 and La2NiO4+? have been undertaken across a range of doping levels[2,3], with doping by oxygen excess leading to a variety of structural distortions[4]. Hole doping of the cuprates from undoped has been reported to cause electronic phase separation into part Néel Antiferromagnet and part charge-stripe order that increases in volume with doping level [5]. Unlike the cuprates the phase diagram of La2-xSrxNiO4 has not been studied from the Néel Antiferromagnet phase into charge-stripe ordered phase[2,3,6].

We studied the magnetic order and magnetic excitations of the Néel Antiferromagnet La1.88Sr0.12NiO4 by neutron scattering which enable the completion of the structural and magnetic phase diagram of La2-xSrxNiO4 in combination earlier results[2,3,6]. The effect of hole doping by Sr in the Néel phase have been determined. Unlike the cuprates there is no electronic phase separation, yet we observe the magnetic excitation spectrum is consistent with a host and an impurity mode as reported for the Néel phase of La2NiO4.11[7]. Our results have important implications for exploiting the dielectric properties of the nickelates[8].

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Thermal scanning probe lithography for nanoscale magnetic hybrid devices

Gabbitas A, Leo N, Coveney A, Morrison K

Hybrid thermoplasmonic-magnetic devices, combining key ideas from the fields of both photonics and magnetism, can be used to create optically-controlled temperature distributions for immediate control of magnetic material properties such as anisotropy, saturation magnetisation, and dynamic responses [1,2]. The development of such hybrid devices requires fabrication of plasmonic particles with precise sizes and aspect ratios which determine the peak position and shape of plasmonic resonances.

Here, we apply thermal scanning probe lithography (t-SPL) using a Heidelberg NanoFrazor system. This approach allows for writing of high-resolution patterns (down to 20 nm pixel size) via a heated AFM tip [3]. Unlike traditional techniques such as e-beam lithography (EBL), the NanoFrazor provides simultaneous writing and reading in situ, allowing for real-time control in a 'closed-loop lithography' process. We use this method to pattern noble-metal, nanoscale ellipses onto glass substrates, which enable plasmonic excitation for light-controlled targeted heating.

Post-deposition and lift-off, we characterise the morphology and optical response of the patterned nanoellipses. Specifically, optical extinction spectroscopy is used to identify the spectral position and amplitudes of the plasmonic excitation peaks, giving insight into device performance as light-controlled nanoscale heaters.

This work is a first step towards the development of novel hybrid thermoplasmonic spintronic devices. Thermal scanning probe lithography allows for patterning of intricate morphologies and precise control of nanoscale features, which is critical to tuning the hybrid light-controlled magnetic properties.

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The role of cluster geometry in magnetic hyperthermia.

Gleadhall S, Fernández-Afonso Y, Páez-Rodríguez A, van Zanten T, Fratila R, Moros M, del Puerto Morales M, Satoh A, Chantrell R, Serantes D, Gutiérrez L, Ruta S, Cleaver D

Cancer is one of the leading causes of death globally with current treatments causing great discomfort and unpleasant side effects to patients. A possible novel and non-invasive alternative is magnetic hyperthermia. Magnetic hyperthermia is a therapeutic process where magnetic nanoparticles (MNPs) are inserted in a cancerous region and applying an external AC magnetic field leads to a local temperature increase and destroys the cancer cells [1]. In an ideal case, when the MNPs are injected, they will be evenly distributed throughout the cancerous region however, this is not usually the case.

Within this work, using a combination of experimental techniques and computational simulation we have found that it is more likely that when an AC field is applied to the MNPs, they will form aggregates and chains that impact the effectiveness of the treatment by impacting the amount of energy lost from the system of MNPs into the surrounding tissue, the specific loss power (SLP) [2]. Based on our simulation, the SLP can vary by a factor of 3 (figure 1B) or 5 (figure 1A) depending on cluster geometry, indicating the importance of cluster configuration.

I will present a systematic investigation of how key cluster parameters effect SLP. This will include cluster geometry, easy axis orientation and cluster orientation with respect to the applied field direction.

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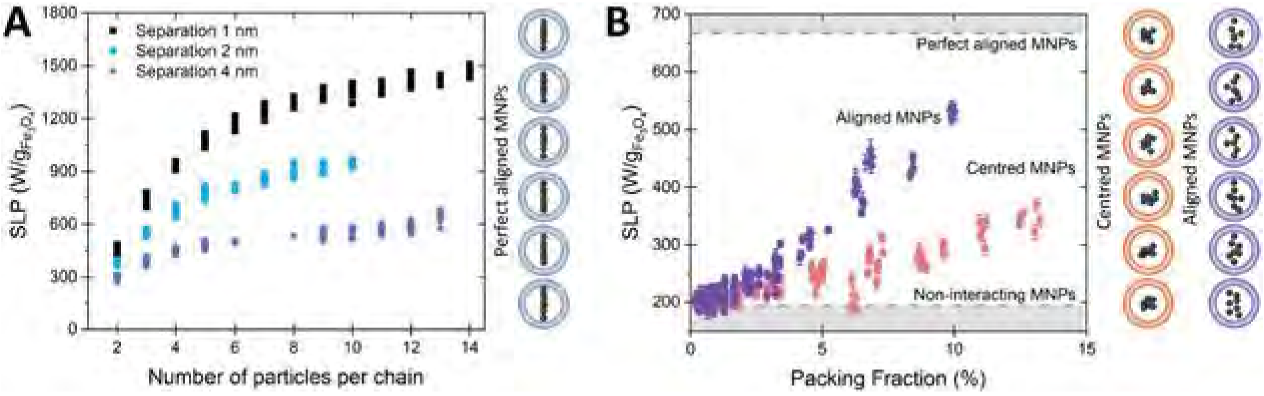

Skyrmionic Abacus for Neuromorphic Edge Computations

Griggs W

Over just a few years, AI systems have become capable of beating humans at strategic games, coordinating autonomous driving, and learning to recognise and generate complex text, images, and videos. However, these advances been achieved at the expense of vast energy consumption. For example, OpenAI's GPT-3 model is estimated to have required 1300 MWh to train 175 billion parameters [1], approximately equivalent to the energy needed to circumnavigate the Sun in a Volkswagen ID3 twice. There is hence a real need to curb the energy consumption of AI models, especially for edge devices with limited battery power budgets.

Here we propose skyrmion-based multibit memory devices which may be deployed as synapses in brain-inspired computing hardware. The device structure resembles that of a traditional abacus, wherein numerical states are encoded by stacking beads on a guide rail. In our nanoscale device concept, skyrmions are stacked throughout different numbers of layers in a multilayer nanodisk system. To achieve this, we exploit the spin memory loss effect as a spin-current passes through successive interfaces of the multilayer (Fig. 1a and b).

Using micromagnetic simulations, we investigate the effects of current pulse length and amplitude (Fig. 1c), Dzyaloshinskii-Moriya interaction, and external magnetic field on the ability of the multilayer nanodisk to hold distinct 'abacus' states, and explore their stability. We use the results of these micromagnetic simulations as input to simulations of shallow feed-forward neural networks, convolutional neural networks (CNNs), deep CNNs, and deep spiking neural networks based on the synaptic characteristics of the 'abacus' devices, and explore their performance on several widely used benchmark tests such as the MNIST handwritten digit recognition test and the ImageNet Large Scale Visual Recognition Challenge [2].

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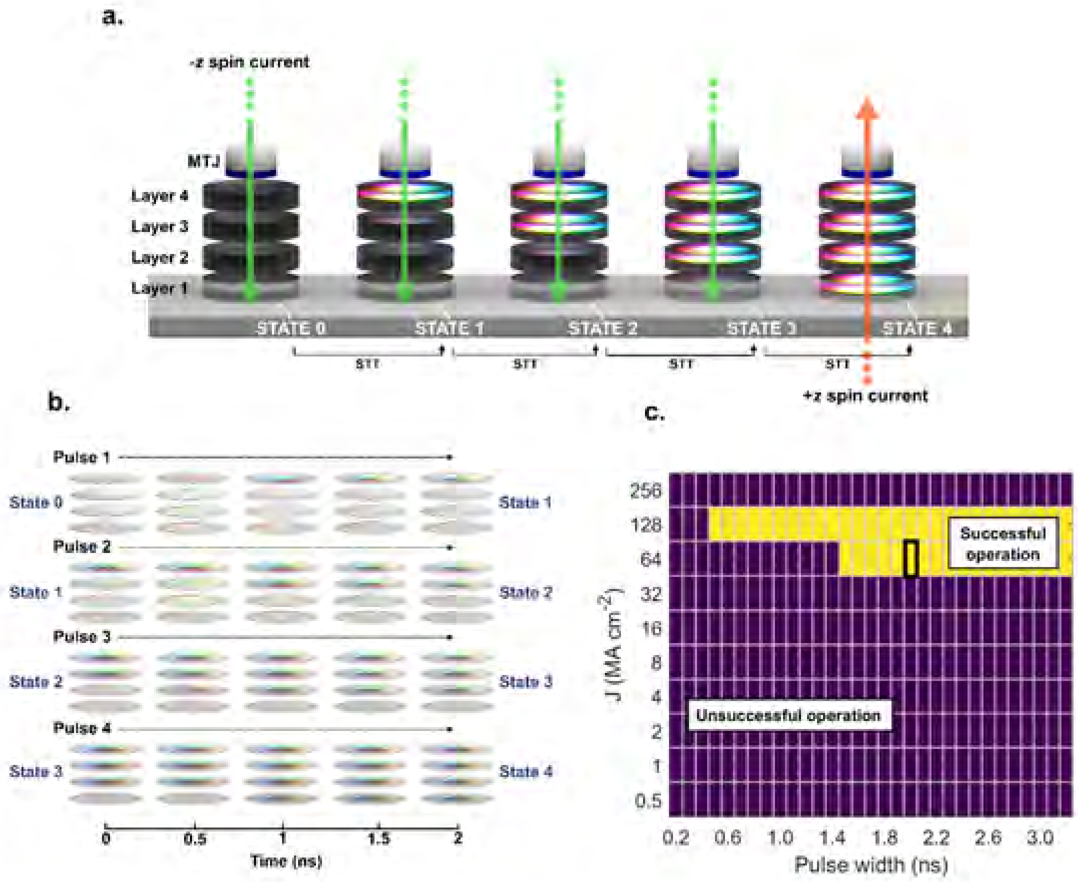

Fig. 1: **a.** Schematic illustration of the 'abacus' device. Successive spin-polarised current pulses from a magnetic tunnel junction (MTJ) nucleate skyrmions in individual layers of the multilayer structure. Spin current depolarisation the interfaces ensures that a skyrmion is nucleated only in the layer directly beneath the bottommost skyrmion in any given state. **b.** Micromagnetic simulations of the nucleation process for current pulses of amplitude J = 64 MA cm^{-2} and width 2 ns. **c.** Pulse amplitude vs. pulse width phase diagram showing the parameter space over which the device can operate.

Towards experimental realization of skyrmionic artificial synapses

Griggs W, Boukaert W, Chiliquinga J, Reyren N, Cros V, Pavlidis V, Thomson T, Moutafis C

The recent and rapid rise of resource-intensive artificial intelligence (AI) has created an unprecedented need for innovative computing hardware which couples superior performance with improved efficiency. This is especially critical in healthcare, automation, and robotics, where data privacy and low latency are essential. In many respects, the gold standard for computational versatility and efficiency remains biological; the human brain is extremely efficient, consuming only ~20 W of power, and performs well across a diverse set of tasks. Thus, in neuromorphic computing next-generation hardware is developed by taking inspiration from the brain.

In our previous work, we numerically demonstrated the use of magnetic skyrmions to encode synaptic states in an artificial synapse comprising a thermally stable magnetic multilayer [1]. The device consists of a nanotrack partitioned into pre- and post-synaptic regions by a “barrier” region of locally modified magnetic properties [2]. By driving skyrmions either side of the barrier using spin-orbit torques (SOT), the conductance of the post-synaptic region can be modulated, emulating long-term potentiation and depression processes observed in the brain.

Here we present our progress towards experimental verification of our synapse design. We have nanofabricated skyrmionic racetracks from [Pt(2.4)/CoFeB(1.0)/Ir(0.5)]8 multilayers (thicknesses in nm inside parentheses), which are characterised via magnetic force microscopy (MFM) and magneto-optic Kerr effect (MOKE) imaging (Fig 1a). We show that skyrmions can be thermally nucleated at notch-like constrictions in the device and characterise their SOT-driven transport (Fig. 1b). We furthermore propose two approaches to implementing the central barrier region via light ion irradiation, enabling the modification of skyrmion transport without compromising the homogeneity of the driving electrical current (Fig. 1c). Additionally we show progress towards experimental demonstration of ion-irradiated skyrmionic synapse devices.

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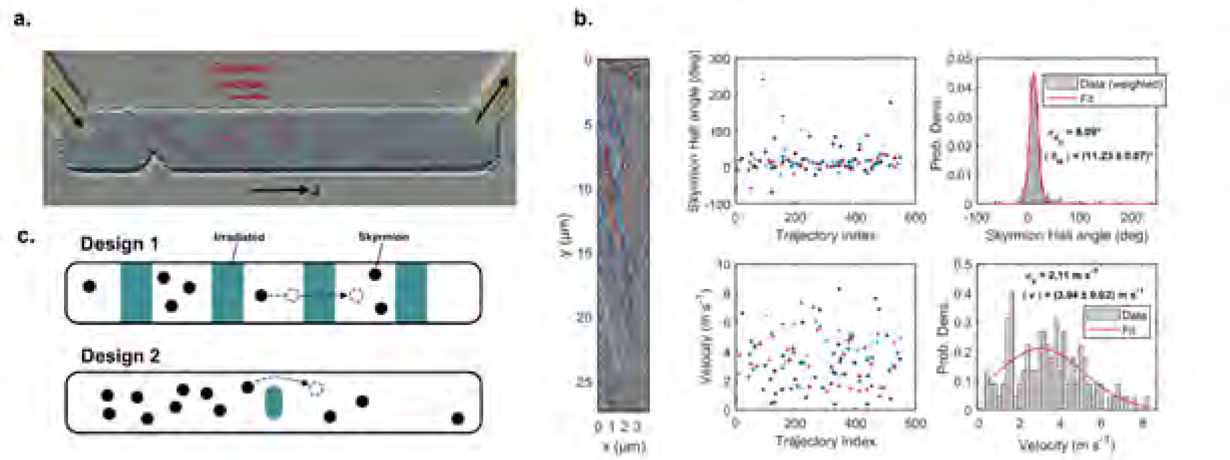

Fig. 1. **a.** MOKE microscope magnetic image of our patterned skyrmionic multilayer device. Skyrmions can be nucleated via Joule heating at a notch-like constriction. **b.** Analysis of skyrmion trajectories within the device, indicating the skyrmion Hall angle and velocity. **c.** Two approaches to modifying the skyrmion transport via light ion irradiation, enabling the racetrack to exhibit long-term potentiation and depression processes observed in biological synapses.

Electrically switchable ferromagnetic Josepshon Junctions for cyrogenic memory

Gupta S

Storage systems in data centres are requiring an ever increasing amount of energy to be maintained. A solution for this would be in the form of a superconducting memory bit utilizing the quantum properties of superconductivity and magnetism.

Design would be in the form of a pseudo-spin valve ferromagnetic Josephson junction, utilizing the 0-pi transition to store information and a dc-squid readout. We are currently investigating candidate materials for the soft layer of the stack, including the 3d ferromagnets and amorphous alloys.

Further to this we will investigate possible magnetisation switching methods that maintain superconducting nature for energy efficient operation. These include spin-orbit torque, spin-transfer torque and local superconducting write-line mechanisms.

Phonon-Driven Spin Dynamics in Rare-Earth Orthoferrites across Spin-Reorientation Temperatures

Hales M, Kovalenko O, Kimel A, Afanasiev D, Mikhaylovskiy R

The pursuit of energy efficient alternatives to conventional electronic devices has become a central focus of scientific research. One promising approach employs spin waves (magnons) as a means of information transfer to avoid Joule-heating. Additionally, all-optical magnetisation switching holds the potential to enhance magnetic data-storage technology, offering high speed operation and improved efficiency.

Spin dynamics in rare-earth orthoferrites have been extensively studied due to their canted antiferromagnetic structure, strong spin-lattice coupling and very high magneto-optics. Also of interest is a phase transition during which the antiferromagnetic vector undergoes a spin reorientation. For thulium and erbium orthoferrites, $TmFeO_3$ and $ErFeO_3$, this occurs from about 80K to 90K. Recently, a phononic pathway to excite spin dynamics has been discovered in rare-earth orthoferrites [1][2], while phonon-driven switching was observed in an iron garnet [3].

To study phonon-driven responses in a single crystal, 60 µm-thick sample of $TmFeO_3$ we performed a time-resolved pump-probe spectroscopy experiment, shown in Fig.1a. Mid-infrared pump pulses were tuned at resonance with optical phonons, distorting the crystal lattice which induced a torque on the spins, thereby driving them into precessional motion. The spin dynamics were measured by polarisation rotation of an 800 nm probe as a function of time-delay with respect to the pump pulse.

Polarisation rotation signals reveal the quasi-ferromagnetic magnon mode over the spin reorientation temperature region, shown in Fig.1b. A complementary experiment performed on the $ErFeO_3$ sample provided similar evidence for phonon-driven excitation by an observed increase in the magnitude of magnon oscillations approaching resonant excitation of infrared phonons. While the frequency dependence in $TmFeO_3$ (Fig.1c) agrees with prior experimental results which used another non-thermal excitation [4], the pump polarisation dependence differs from expectation. Further investigation into the interesting behaviour of phonon-driven spin dynamics will yield a better understanding of how the mechanism differs between rare-earth orthoferrites.

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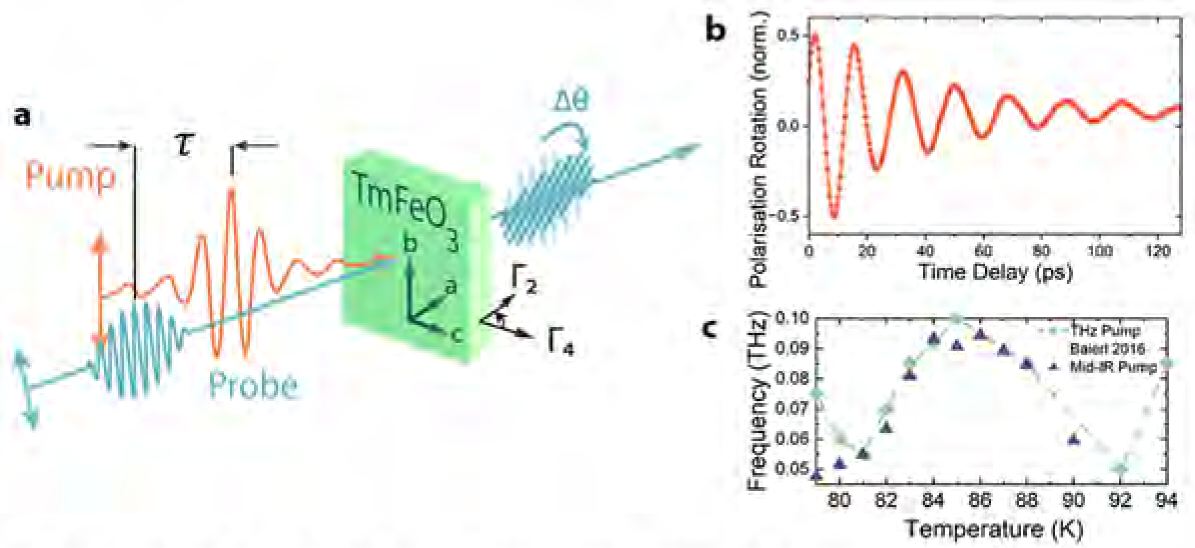

Fig.1 a Schematic of the pump-probe experimental setup. The antiferromagnetic vector reorients itself from the *c* to *a* crystallographic axis as the temperature is increased. **b** The normalised polarisation rotation signal measured at 82K with exponential offset removed. **c** Frequency dependence calculated from Fourier transforms of the rotation data across the spin reorientation region. Good agreement is observed between our experimental data and previous resonant THz excitation measurements [4].

Hybridization-Driven Optical and Spintronic Properties of Phthalocyanines on Cobalt

Harikumar P, O'Regan D

Phthalocyanines (Pc) on ferromagnetic cobalt (Co) surfaces exhibit intriguing electronic, optical, and magnetic behaviors, making them highly attractive for spintronic and optoelectronic devices. In this study, we explore the electronic hybridization, charge transfer dynamics, optical properties, and reflectivity of Pc molecules adsorbed on Co using density functional theory (DFT). Our findings reveal a strong interaction between Pc molecular orbitals and the Co dd-states, leading to spin polarization in the molecular system and modifying its electronic structure [1].

Charge density analysis shows significant redistribution of electrons at the interface, further quantified through Bader charge analysis, confirming charge transfer from the Co surface to the Pc molecule. Optical absorption spectra exhibit characteristic redshifts due to this hybridization, highlighting the molecule's potential as a tunable optoelectronic component [2].

Reflectivity R(ω), calculated from the dielectric function, offers deeper insights into the material's optical response. The results show high reflectivity at lower frequencies, driven by enhanced molecular hybridization and absorption, followed by a steady decline with increasing frequency. This behavior is indicative of energy dissipation mechanisms that could influence spin transport in hybrid molecular systems. The accompanying reflectivity plot demonstrates these trends, underscoring the potential for tailoring optical and electronic properties by modifying molecular orientation or substrate interactions [3].

These findings not only provide a detailed understanding of the Pc/Co interface but also point to its potential as a building block in molecular spintronics. By harnessing hybridization-induced spin polarization and controllable optical properties, Pc/Co systems could pave the way for energy-efficient spintronic devices such as molecular-based spin valves and optospintronics.

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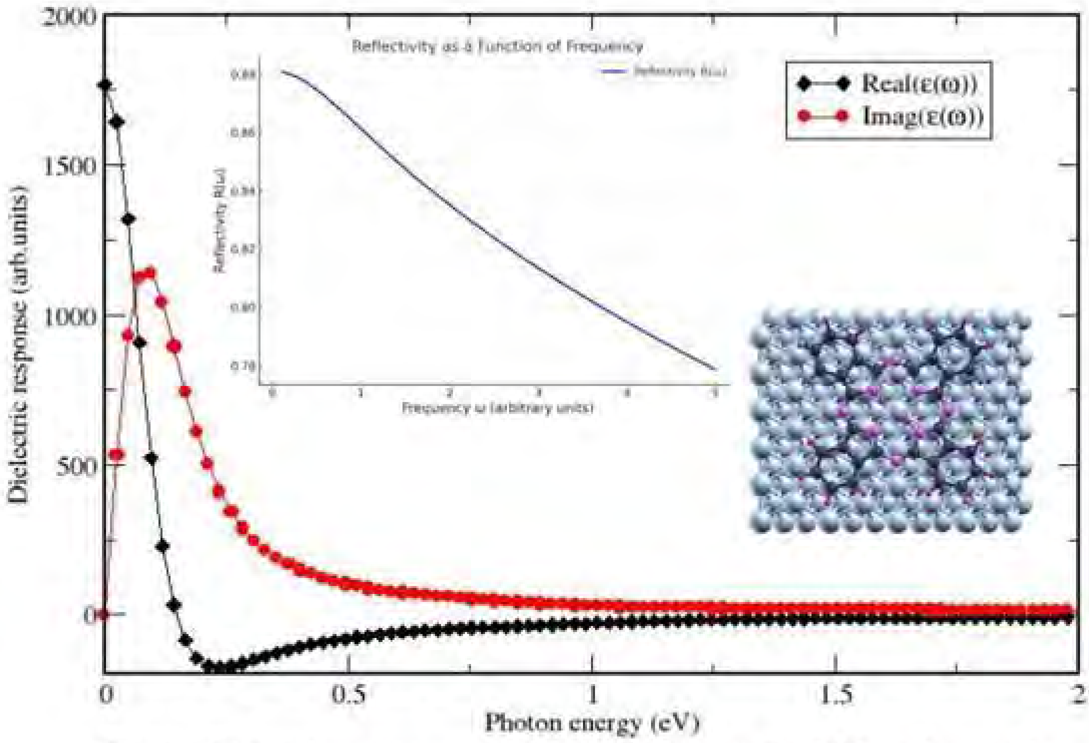

Figure: Dielectric response of Phthalocyanine on Co(111) surface with insets showing the top side of the molecule structure and reflectivity as a function of frequency.

Room-temperature in-plane ferromagnetism in Co-substituted Fe5GeTe2 investigated by magnetic x-ray spectroscopy and microscopy

Heppell E, Fujita R, Gurung G, Lin J, May A, Foerster M, Khaliq M, Ninõ M, Valvidares M, Herrero-Martín J, Gargiani P, Watanabe K, Taniguchi T, Backes D, van der Laan G, Hesjedal T

The exploration of two-dimensional (2D) van der Waals (vdW) ferromagnets has revealed intriguing magnetic properties with significant potential for spintronics applications due to their ability to retain magnetic order down to monolayer thicknesses and their ease of integration into functional heterostructures [1]. Fe3GeTe2 was one of the first materials in which a persistent long-range magnetic order down to the monolayer limit was demonstrated, possessing a high Curie temperature, Tc, of 230 K in the bulk [2] and 130 K in the monolayer limit [3]. The recently discovered 2D vdW ferromagnet Fe5GeTe2, however, exhibits ferromagnetic ordering with a Tc of ~270-310 K [4-6] and magnetic and electronic behaviour that can be enhanced and tailored through chemical doping [7-9].

We examine the magnetic properties of Co-doped Fe5GeTe2 using x-ray photoemission electron microscopy (XPEEM) and x-ray magnetic circular dichroism (XMCD), complemented by density functional theory calculations [10]. Our XPEEM measurements, figure 1, reveal that the Tc of a bilayer of (CoxFe1−x)(5−δ)GeTe2 (with x=0.28) reaches ~300 K - a notable enhancement over most 2D ferromagnets in the ultra-thin limit. Interestingly, the Tc shows only a small dependence on film thickness (bulk Tc ≈ 340 K) in line with the observed in-plane (IP) magnetic anisotropy and robust IP exchange coupling. The XMCD measurements indicate that the spin moments for both Fe and Co are significantly reduced compared to the theoretical values. The XMCD measurements also highlight the orbital moment anisotropy of the elemental constituents, demonstrating that the introduction of Co redirects the easy magnetisation direction due to its preference for IP anisotropy. These insights highlight the potential of Co-doped Fe5GeTe2 for stable, high-temperature ferromagnetic applications in 2D materials and underscore the potential of chemical doping to tune the magnetic properties of 2D vdW ferromagnets.

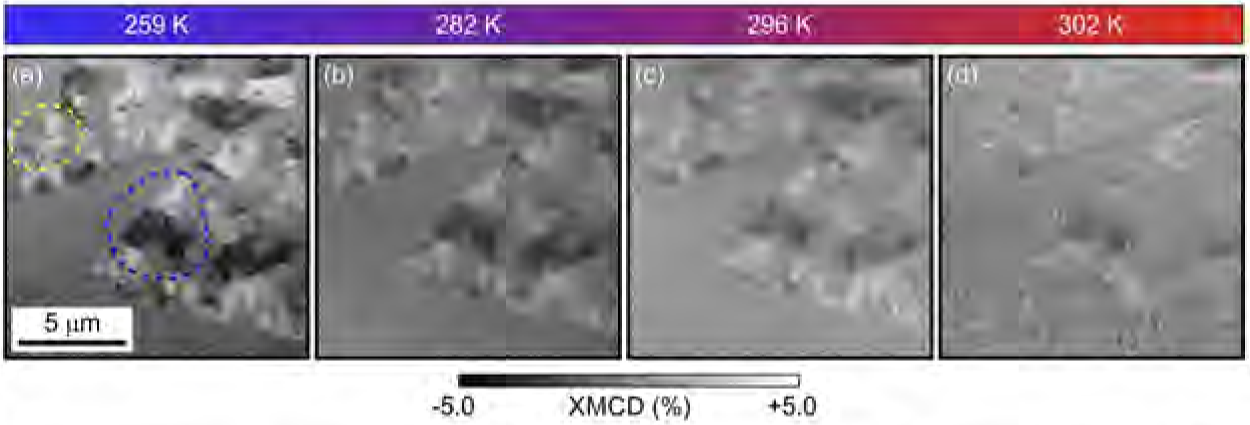

Figure 1: XPEEM measurements as a function of temperature. The magnetic contrast at (a) 259 K and (b) 282 K is dominated by larger, µm-sized domains. (c) At 296 K, the magnetic contrast is reduced and at (d) 302 K, it has almost completely vanished, except for larger domains. Examples of both larger (blue) and smaller (yellow) domains are indicated in panel (a).

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

Heppell E, Liu X, Kinane C, Caruana A, Langridge S, van der Laan G, Backes D, Kou X, Hesjedal T

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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Platinum/Gold Alloys for Spintronics: Investigating Spin Orbit Torque and Spin Pumping Reciprocity

Hodgkiss A, Rianto D, Hase T, Atkinson D

The spin Hall effect in nonmagnetic heavy metals (HM) leads to a spin accumulation at the interface with ferromagnetic (FM) layers that enable the propagation of spin current into the ferromagnet, creating spin-orbit torque (SOT) that produce oscillations and switching of the magnetization. SOTs offer a promising avenue towards field-free magnetic switching, which is highly desirable for efficient, low-energy magnetic memory systems. Various heavy metals (HMs), such as Pt and β-W, have been shown to generate substantial SOTs in an adjacent ferromagnet, due to their relatively large spin Hall angles (ϑ_{SH}). Recent studies have demonstrated enhancement of the ϑ_{SH} in Pt via alloying [1, 2, 3]. In particular, $Pt_{0.75}Au_{0.25}$ has been demonstrated to enhance ϑ_{SH} by over a factor of 4 [1]. According to Onsager's reciprocity theorem, SOT generation and spin-current injection via spin-pumping should be reciprocal dynamical effects [4]. As such, enhanced SOT systems should also demonstrate enhanced Gilbert damping. Also, as damping involves spin transport across the FM/HM interface, details of the interface structure and HM proximity induced magnetism [5] are likely to be significant.

In this work, ferromagnetic resonance was used to investigate the damping in platinum/gold alloys in Pt_xAu_{1-x} /ferromagnet bilayer structures. Samples are produced via magnetron sputtering onto silicon wafers, with the alloy composition modulated through co-sputtering of Pt and Au from x=0 to x=1. Three different ferromagnetic materials, Co, CoFe, and NiFe, were studied, with the layer structure and interfaces of the HM/FM determined using x-ray reflectivity measurement. We see, as expected, substantial enhancement to damping for pure Pt, and minimal enhancement for pure Au. At intermediate compositions, however, an interesting trend is observed, with full results shown in the presentation. Additionally, a thickness-dependent spin diffusion length, λ_{sd}, is calculated for each composition using the approach presented in [6].

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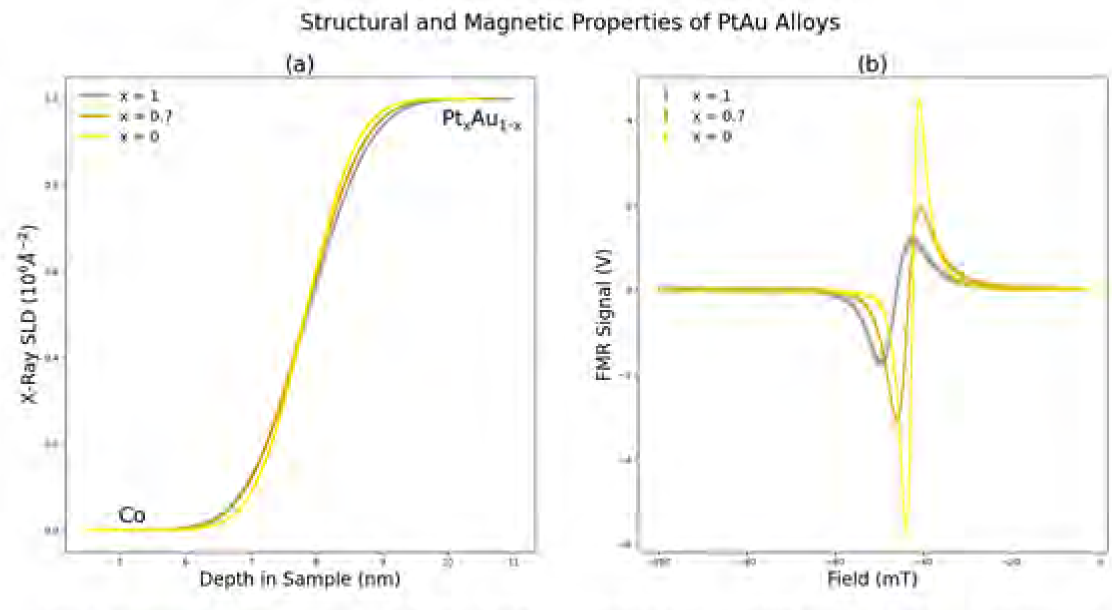

Figure 1: (a) Normalised X-Ray scattering length densities of Co/Pt_xAu_{1-x} interfaces (left) and (b) FMR spectra of Co/Pt_xAu_{1-x} structures (right)

Nanomagnetism seen with neutrons: Small-Angle Neutron Scattering

Honecker D, Alba Venero D

Small-angle neutron scattering (SANS) is a powerful experimental technique for investigating the structural and magnetic properties of condensed matter and quantum materials. The technique allows to probe structural inhomogeneities in the bulk of materials on a mesoscopic real-space length scale from roughly 1nm to the micrometer regime [1]. As the neutron has a magnetic moment, the spin of the neutron provides SANS with a unique sensitivity to study magnetism and magnetic materials at the nanoscale, like nanoparticles, long-range magnetic domain structures, skyrmion or superconducting vortex lattices. In this poster, we explore the application of SANS in studying quantum materials, focusing on its ability to probe nanostructures, study magnetic phases, and investigate magnetic excitations.

The alternative antiferromagnetism of Mn doped ferrite C4AF

Huang L, Morley N

Ca4Fe2Al2O10 (C4AF, 4CaO·Al2O3·Fe2O3) is one of the phases of cement, which is ferrite-rich and magnetic. 1, 2 Recycling the UK iron wastes for C4AF production can reduce the CO2 emissions, but other components such as MnO doping will change the magnetic properties of the C4AF products. 2 The Mn ions prefer to replace the Fe ions in C4AF crystal structure due to lower defect formation energies of Mn ions-doping.3 The antiferromagnetism is more significant when the Fe ion starting to be replaced by more Mn ion (Fig. 1a). Powder samples of ferrites C4AF with different MnO doping concentration (0 wt.% - 4.5 wt.%) were sintered at1350 °C and measured by SQUID, neutron diffraction and XRD. Higher magnetic moments were observed for higher MnO doping. In Fig. 1b, the magnetic moments at low temperatures [5 K, 100 K] show an increasing tendency to the higher MnO doped weight of C4AF. The moment of the MnO doped samples have values higher than the theoretical moment of both Fe and Mn with the low spin state but lower than the magnetic moment with all Fe ions in the high spin state at room temperature. These indicated that the doped Mn ions help the Fe ions partially change from the low spin state to the high spin state and change the alignment between spins in the crystal structure. Also, different sintering time length for 3.5 wt.% samples were studied. The magnetic moment and the Néel temperature of the samples changed with the burning hours (Fig. 1C). The heating time length affects the crystallization of the sample as well as the magnetic moment as shown in the XRD data (Fig. 1d). These adjustable magnetic properties of MnO doped C4AF can rise more potential of the application of the magnetic cements.
Fig. 1 (a) AC susceptibility of different MnO doping concentration samples. (b) Magnetic moment of the different MnO doped C4AF samples. (c) The ac susceptibility of different 1350 °C heating time length samples. (d) Part of XRD patterns of different 1350 °C heating time length 3.5% MnO doped C4AF samples.

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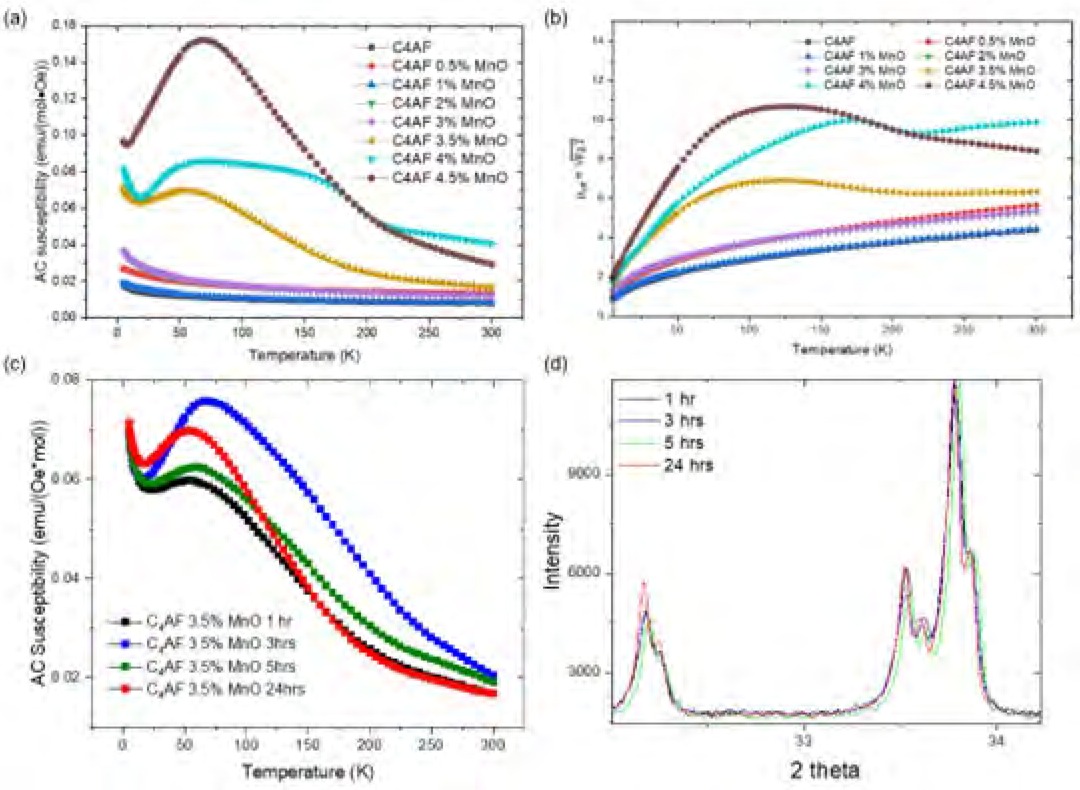

Bismuth ferrite-lead titanate thin films for an investigation of the effects of the morphotropic phase transition on magnetic properties

Jankowski M, Bell A, Moore T, Shepley P

$xBiFeO_3$-(1-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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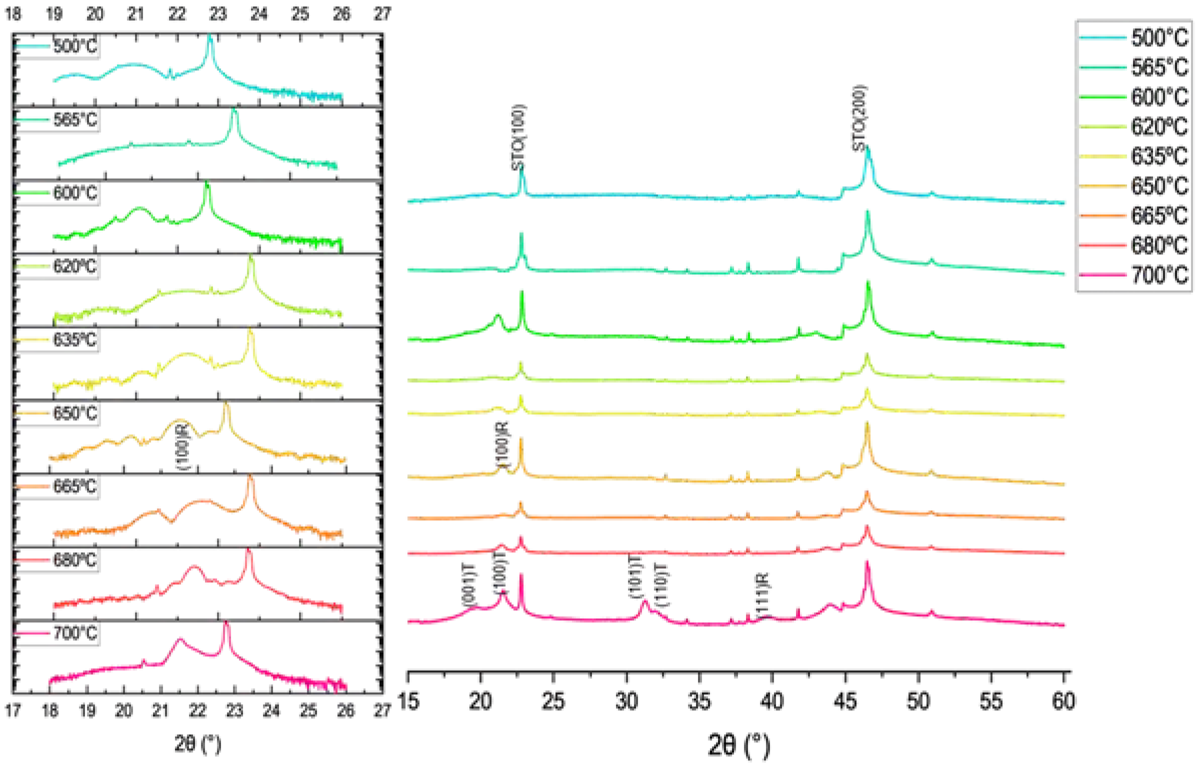

Figure 1: XRD data collected for x=0.65 (x)BF-(x-1)PT where deposition chamber temperature varied. a) shows the 2θ range of 15° to 60° and b) narrowed 2θ range, across the (100) peak, 18° to 26°

Exploring ultrafast magnetic processes of low-dimensional ferromagnets using EXTREMAG

Keatley P, Dąbrowski M, Hicken R

The Exeter Time Resolved Magnetism (EXTREMAG) Facility is an ultrafast magneto-optics user facility at the University of Exeter. Recently users have applied EXTREMAG's variable temperature and high magnetic field environments to exemplar studies of flakes of low, or 2-dimensional (2D) materials and van der Waals heterostructures (vdWh). Low temperature magnetometry and domain imaging on a $MoSe_2/CrBr_3$ vdWh using a wide field Kerr microscope allowed its magneto-photoluminescence to be understood in terms of the magnetic state of the $CrBr_3$ [1]. Combining the microscope with an ultrafast laser pump allowed all-optical switching to be studied in the CrI_3/WSe_2 [2] and $Cr_2Ge_2Te_6$ [3] vdVh where toggle switching of the magnetic state was observed. In the time domain, beam-scanning Kerr microscopy allows microscale imaging on sub-ps timescales in a superconducting magnet. In $Cr_2Ge_2Te_6$ this enabled time-resolved domain imaging and the measurement of ultrafast demagnetisation and subsequent variation in relaxation timescales for different flake thickness [4]. Finally, imaging of h-BN flakes in photoluminescence using a scanning Kerr microscope with microwave probe station opens opportunities to study the high frequency properties of devices containing such low-dimensional materials, e.g. [5]. Since the first user experiments in 2019, EXTREMAG has nurtured a growing overlap of its unique capabilities with the expertise of users exploring low dimensional magnetism. With EXTREMAG's growing use to study these materials, we will continue to develop the capability to probe ultrafast dynamic processes in these exciting materials where quantum effects may emerge.

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

Kinane C, Caruana A

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 is now 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 access the ISIS neutron facility and POLREF beamline.

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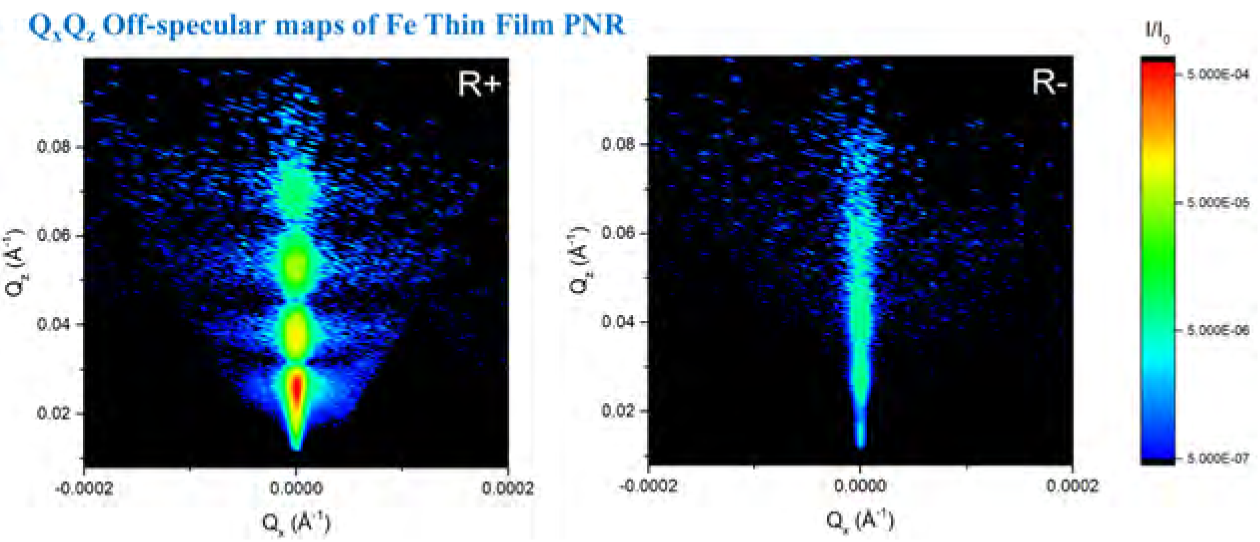

Comparison of noise removal methods in Ferromagnetic resonance

Kuninski N, Scott J, Hendren W, McCormack T, Lyle S, Lyons F, Bowman R

Broadband Ferromagnetic resonance (bbFMR) is a powerful experimental technique for investigating the dynamic magnetic properties of thin films, such as the gyromagnetic ratio, Gilbert damping parameter, magnetic susceptibility, and exchange constant. These parameters are crucial for understanding the behaviour of magnetic materials and their applications. bbFMR is particularly valuable as it allows for the differentiation between intrinsic and extrinsic damping [1]. Moreover, reliable extraction of these properties is essential for understanding phenomena like all-optical switching (AOS), an emerging data storage technique with transformative potential for information technology.

The data obtained from a typical bbFMR setup is often affected by significant noise, and while numerous noise removal methods exist, their results can vary inconsistently. For instance, when determining the gyromagnetic ratio, most methods produce comparable values [1]. However, as shown in [1], the magnetic linewidth can exhibit up to a 10% variation depending on the method used. Notably, most approaches focus solely on the transmission parameters [2], [3],[4] measured in the bbFMR setup, while only a few incorporate the reflection parameters as well [1], [5]. As of now, there is no clear consensus on the most reliable noise removal method.

Therefore, a systematic review of existing noise removal methods has been conducted, building on the work of [1] and incorporating the latest technique, derivative divide [2]. This review evaluates and compares these methods, focusing on their reliability, repeatability and ease of use. Preliminary results obtained using the method shown in Figure 1(a) yield a Gilbert damping value of 0.0047 (unitless), compared to 0.0089 (unitless) as derived from results shown in Figure 2(b). This significant discrepancy highlights the variability between methods, even when both rely solely on transmission parameters for analysis. By conducting this analysis, the study aims to facilitate a more precise and accurate determination of the aforementioned parameters.

Figure 1. The contour plots of bbFMR spectra containing the field and frequency sweeps of a 30nm permalloy thin film. a) Contour plot produced by noise removal method in [4]. b) Contour produced by noise removal method in [2].

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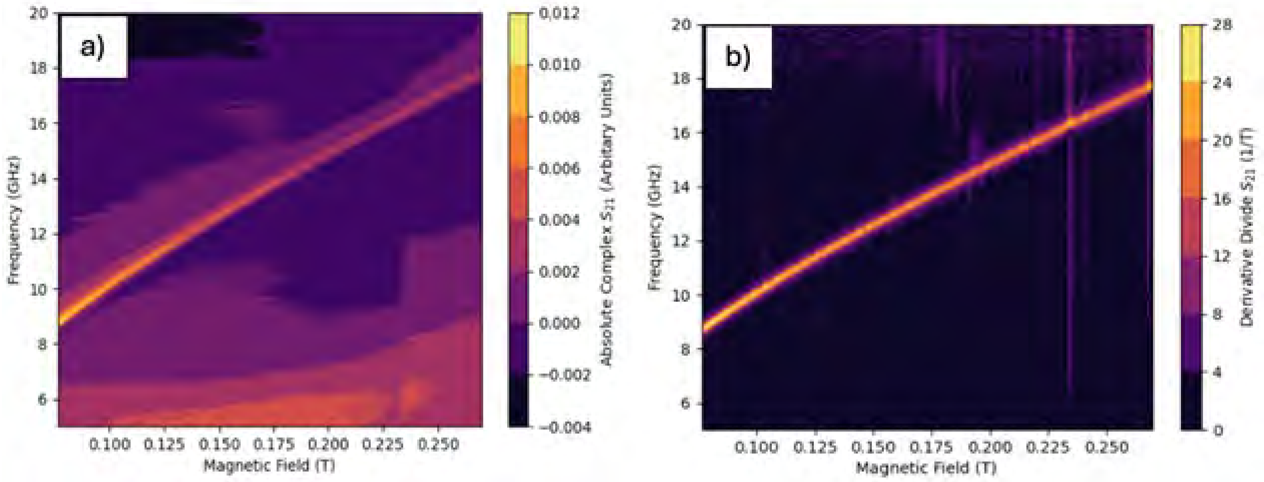


Enhancing spin signals in pure spin currents

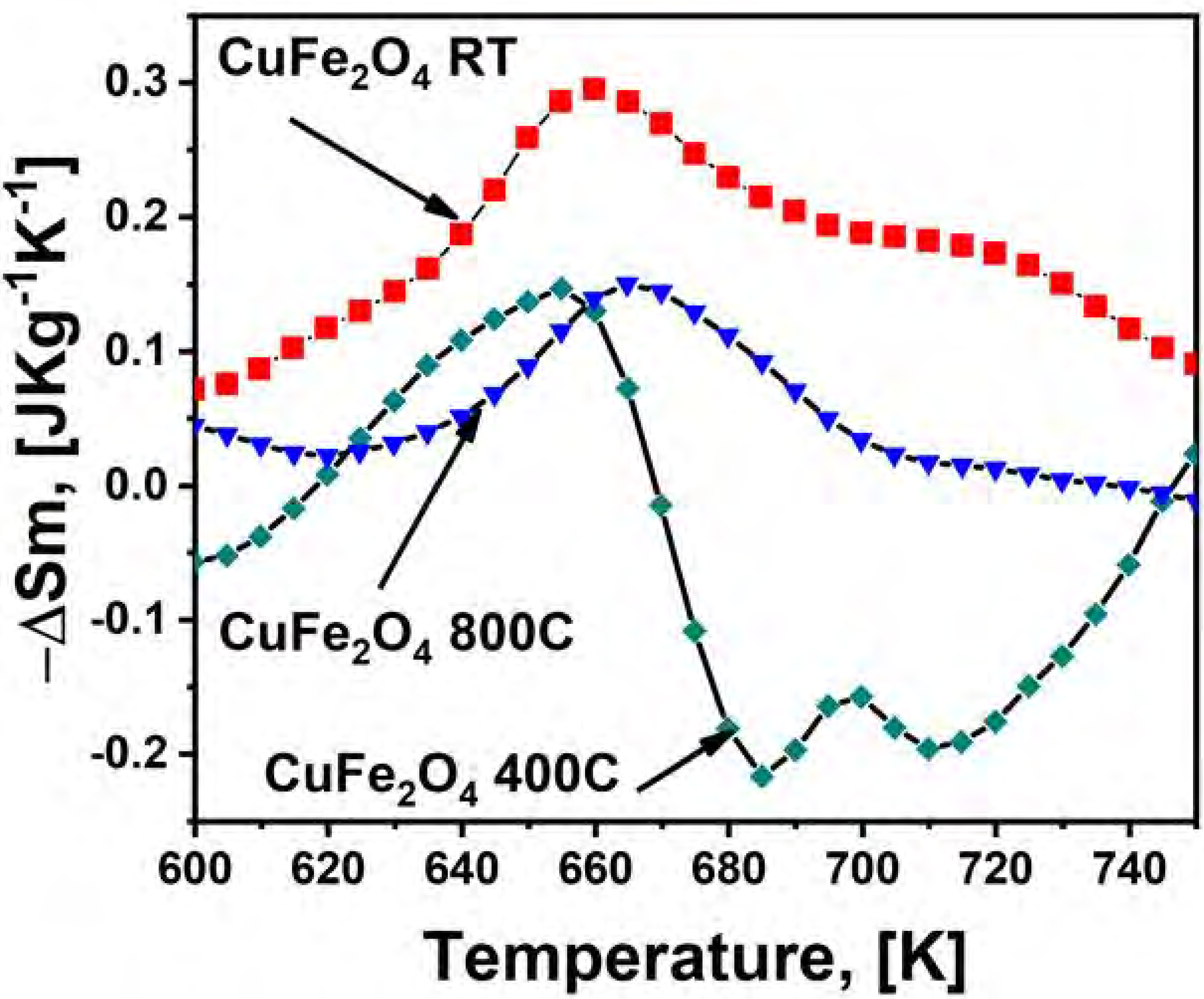
Martinez Cameros M

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. 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.

Effect of Annealing Temperature on Magnetic Properties of Nanoscale Copper Ferrite

Mazurenko Y, Kaikan L

This study investigates the influence of annealing temperature on the structural and magnetic properties of nanoscale copper spinel synthesized via the sol-gel auto-combustion method. X-ray diffraction analysis using the Rietveld method confirms that all samples crystallize into the spinel structure, with the unannealed sample belonging to the cubic Fd3m space group and annealed samples transitioning to the tetragonal I41amd group. Thermal annealing modifies structural parameters, including redistributing copper cations from tetrahedral to octahedral sites, and impacts magnetic properties, such as saturation magnetization and coercive force.
The magnetocrystalline anisotropy constant was determined using the law of approach to saturation (LAS). Variations in coercive force and saturation magnetization were attributed to the transition of magnetic particles from a single-domain to a multidomain state during annealing. The temperature dependence of saturation magnetization and coercive force is analyzed using the modified Bloch law and the Kneller relation. The switching field distribution and magnetocaloric effect are also calculated, revealing a second-order phase transition.
The phenomenological Hamad model simulates the magnetization behavior M(T), which is in good agreement with the experimental data.
Figure: Change in magnetic entropy (ΔSM) as a function of temperature.
Estimates of the change in magnetic entropy -ΔSM derived from the Hamad model and Landau theory align with experimental results obtained via Maxwell's relation above the Curie temperature TC, though discrepancies appear below TC. The compound demonstrates a relative cooling power (RCP) of 64.342 J·kg-1 under a magnetic field of 5 T, suggesting its potential for magnetic refrigeration (MR) applications. Finally, the validity of the mean-field theory is supported by the compatibility of the maximum magnetic entropy change -ΔSMMAX and RCP values derived from Maxwell's relation and the Bean-Rodbell model. This consistency further substantiates the theoretical framework applied in this study.


CuFe2O4 RT
CuFe2O4 800C
CuFe2O4 400C
−ΔSm, [JKg-1K-1]
Temperature, [K]
0.3
0.2
0.1
0.0
-0.1
-0.2
600
620
640
660
680
700
720
740

Developing novel magnetic L10 alloys for spintronics

Naushad N, Nutter P, Thomson T

Magnetic materials with significant magnetic moment and high anisotropy are essential for spintronics and data storage but often rely on scarce or expensive elements such as rare earth metals. Here, we work towards creating high anisotropy, high moment magnetic thin films made from abundant and inexpensive Mn and Al. MnAl in the $L1_0$ τ-phase is an attractive candidate with high magnetic moment, Curie temperature and magneto-crystalline anisotropy at room temperature [1]. The magnetic dynamics of this system is expected to show very low damping. The $L1_0$ phase is expected to form under a narrow range of fabrication conditions, where temperature plays a vital role [2]. This research aims to optimize fabrication methods to produce $L1_0$ MnAl thin films for spintronic applications.

The fabrication of $L1_0$-ordered MnAl thin films was investigated using two sputter deposition approaches. In the first approach, we alternately stack Mn and Al films with thicknesses of a few nm on MgO(100) and Si/SiO_2(290nm) substrates. The samples were then annealed to promote intermixing and alloy formation. In the second approach, a mosaic target comprising a perforated Al foil cap placed on a pure Mn target was used. The film composition is thus controlled by varying the Al to exposed Mn surface area ratio.

Given the narrow compositional range of the magnetic τ-phase, it is important to accurately characterise this property. We performed compositional analysis using X-ray fluorescence (XRF), Hard X-ray Photoelectron Spectroscopy (HAXPES), and X-ray photoemission spectroscopy (XPS) etching for depth profiling. The results from these techniques showed notable differences, Table-1. We discuss the origin of these differences and methods to accurately determine composition in magnetic thin films.

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	EDXRF		WDXRF		HAXPES	
SAMPLE	Mn%	Al%	Mn(%)	Al(%)	Mn 2p%	Al 1s%
Si/SiO_2(290 nm)/[Mn(3 nm)/Al (1.5 nm)]10/Pt (4nm)	34.7	65.2	61.1	38.8	34.36	65.64
Si/SiO_2(290 nm)/[Mn(3 nm)/Al (1 nm)]10/Pt (4nm)	39.6	60.3	66.9	33	35.3	64.7
Mosaic target sample	14.8	85.1	28.5	71.4	33.65	66.35

Table. 1. Comparative analysis of thin film composition using energy dispersive (EDXRF), wavelength dispersive (WDXRF) x-ray fluorescence and hard x-ray photoelectron spectroscopy (HAXPES) techniques.

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

Osborne J, Brereton B, Hait S, Khaliq M, Niño M, Foerster M, Marrows C, Cunningham J, Moore T

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 (LiNbO3) via interdigitated transducers (IDTs) have the potential to control skyrmion motion [2].

LiNbO3/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 LiNbO3 substrate (Fig .1, 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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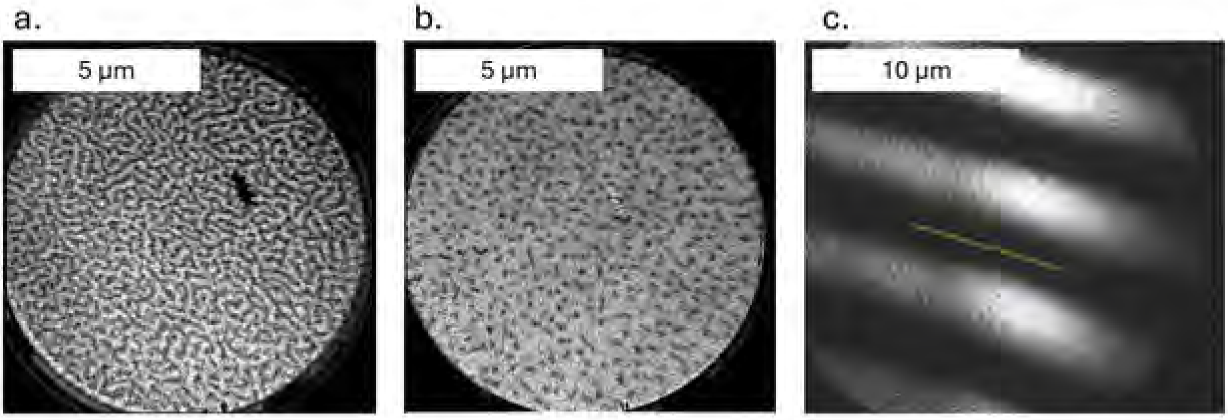

Figure 1: XMCD-PEEM images of a $LiNbO_3$/Ta(5 nm)/[Pt(0.8 nm)/CoB(0.6 nm)/Ru(0.5 nm)] x 6 magnetic thin film in states, a. Remanence field with maze-like domain wall pattern, b. At 6.11 mT where skyrmion like magnetic structures appear, c. PEEM image of surface acoustic waves in $LiNbO_3$ substrate.

Experimental and theoretical study on quaternary Heusler alloy FeRuVSi: Anti-site disorder effect study

Panda M, Paramanik T, Mondal R

Fe-based quaternary Heusler alloys including 4d elements remain relatively underexplored, despite their potential to demonstrate half-metallicity and other compelling magnetic and electrical features beneficial for spintronics and memory storage technologies. These alloys are prone to disorder owing to the similarity in electronegativity and atomic radii of their constituent elements. This structural instability frequently undermines the half-metallic ferromagnetic (HMF) characteristics of the material. This work examines the impact of disorder on the magnetic characteristics of the Fe-based quaternary Heusler alloy FeRuVSi, which includes the 4d element Ru, utilizing both experimental data and first-principles calculations. FeRuVSi exhibits ferromagnetic properties beneath the Curie temperature (TC) of 70 K. The measured effective magnetic moment for FeRuVSi is 0.7 μB per formula unit, while the Slater-Pauling principle and first-principles computations forecast a value of 1 μB per formula unit. The decrease in effective moment is ascribed to antisite disorder between Fe and Ru, as demonstrated by our first-principles calculations. These findings may guide the selection of materials appropriate for forthcoming industrial applications.

Strange metal states and optical tuning in Bi2Se3 with molecular diodes

Parkin Z

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.

Applying Soft X-Ray Resonant Magnetic Diffraction to Elucidate the Magnetic Ordering of the W-Type Hexaferrite $SrCo_2Fe_{16}O_{27}$

Pearce J, Fan R, Steadman P, Cavill S

The search for room temperature (RT) magnetoelectric materials is a keen research area constantly expanding in order to find promising candidates that could be applied in next generation low power ICT devices. To display both ferroelectricity and magnetism simultaneously, both the spatial inversion and time reversal symmetry must be broken [1]. The magnetic ordering of a material is one way that this is achieved, while a multitude of magnetic orders exist, the transverse conical ordering allows both symmetries to be broken. It is therefore possible that identifying a RT transverse conical ordering is a key step in the search for RT multiferroic materials.
The W-type hexaferrite $SrCo_2Fe_{16}O_{27}$ has shown to be an interesting material with the Co based being the only W-type hexaferrite not to display uniaxial anisotropy. It has been predicted to display a longitudinal conical magnetic ordering which can be controlled through the application of an external field similar to other hexaferrite types [2, 3]. To study the material, a single crystal of $SrCo_2Fe_{16}O_{27}$ was studied on the I10 beamline at Diamond Light Source using the RASOR diffractometer. Resonant diffraction at the Co and Fe L3 edge was used on both structural and forbidden half order magnetic peaks. Using a variety of sample and field geometries, it has therefore been shown that the magnetic structure present in the material is transverse conical at room temperature and therefore a candidate for further study into the magnetoelectric properties of $SrCo_2Fe_{16}O_{27}$.

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Spin-wave implementation within the VAMPIRE software package

Ruta S, Hirst J, Ababei R, Ostler T, Evans R

Spin waves, also known as magnons, are collective excitations of the spins in a magnetic material. Magnons play an important role in the behaviour of magnetic materials, determining the system response in the GHz and THz regimes. The spin-wave dispersion relation, i.e. the spin wave frequencies as a function of the wavevector can be calculated theoretically using atomistic spin dynamics (ASD) and linear spin wave theory (LSWT). The LSWT is a first-order approximation for the spin-wave dispersion relation and can be computed using the SpinW [1] implementation.
The LSWT is limited by its linear approximation, which restricts it to small oscillations and long-wavelength excitations, and it cannot account for nonlinear effects or finite-temperature spin fluctuations. The ASD overcomes these limitations, simulating individual spins at the atomic level to capture nonlinear behaviour, thermal effects, and localized phenomena in complex magnetic systems. The temperature dependence of spin waves is important for understanding the dynamic properties of a wide range of magnetic materials. In spintronics, THz emission and the spin Seebeck effect are directly related to the SW and magnon-magnon [2] and magnon-phonon [3] interactions. In this work we will present the implementation of spin-wave calculations into the VAMPIRE software package [4,5]. The ASD model implemented in the current VAMPIRE software is able to describe a large range of temperature-dependent magnetic properties and the dynamics of complex magnetic systems. This allows simulation of spin waves for complex magnetic materials (ferromagnetic, ferrimagnetic, antiferromagnetic and frustrated spin configurations) and various geometries (core-shell particles, multilayers, systems with defects/impurities) and 2D materials. An example for a multilayer structure is illustrated in the figure.

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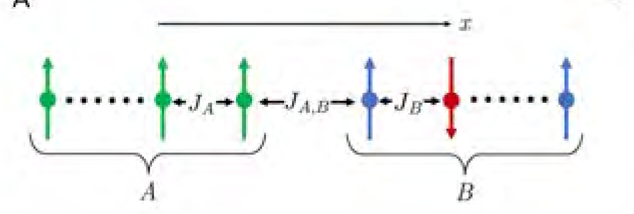
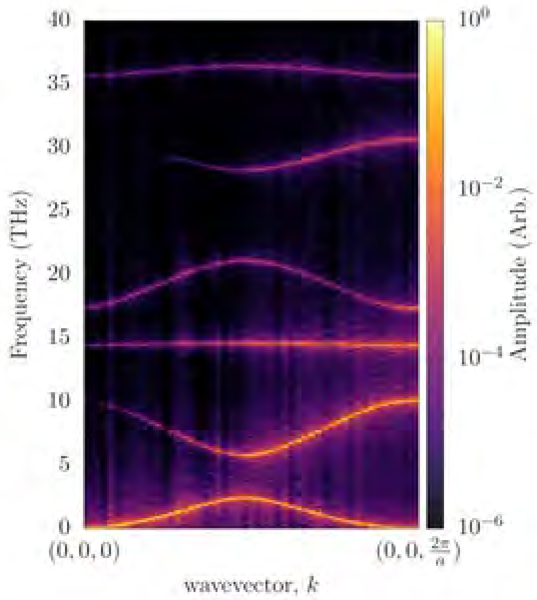


B

parameter/material	A	B	units
μ_s	2.22	1.72	μ_b
$J_{AA,BB}$	7.05×10^{-21}	-6.064×10^{-21}	J
J_{AB}	6.557×10^{-21}	6.557×10^{-21}	J
d_z	5.65×10^{-25}	6.69×10^{-25}	J

C



The search for spin-polarised edge states in InAs/GaSb quantum well devices

Saminathan A, Kelly M, Rosamond M, Li L, Sasaki S, Linfield E, Marrows C

The InAs/GaSb quantum well system with a well thickness (WT) greater than the critical WT has a broken gap band alignment resulting in the inversion of conduction and valence band states[1]. This causes the opening of a hybridisation gap which is predicted to host Quantum Spin Hall (QSH) states[2]. In this work, AlSb/InAs/GaSb/AlSb (50 nm/12.5 nm/8 nm/50 nm) heterostructure has been patterned into mesoscopic double-gated Hall bars as shown in the right inset in Fig. 1 (a). Magnetotransport measurements have been carried out within ±8 T magnetic field at 1.5 K, at a constant backgate of 0 V. The electron and hole carrier densities have been obtained by fitting the Hall resistance to the two-carrier model of transport. As seen in Fig. 1 (a), 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), which corresponds to the hybridisation gap, is expected to host the QSH states which are characterised by a pair of counter-propagating spin-polarised edge states along each edge. With the objective of detecting these spin-polarised edge states, ferromagnetic contacts of permalloy have been patterned on micron scale quantum well devices. The transmission line pattern shown in Fig. 1 (b) has been used to confirm the required high quality of contact between the ferromagnetic leads and the quantum well channel, enabling further studies for the detection of spin-polarised edge states in nano-scale devices using ferromagnetic contacts.

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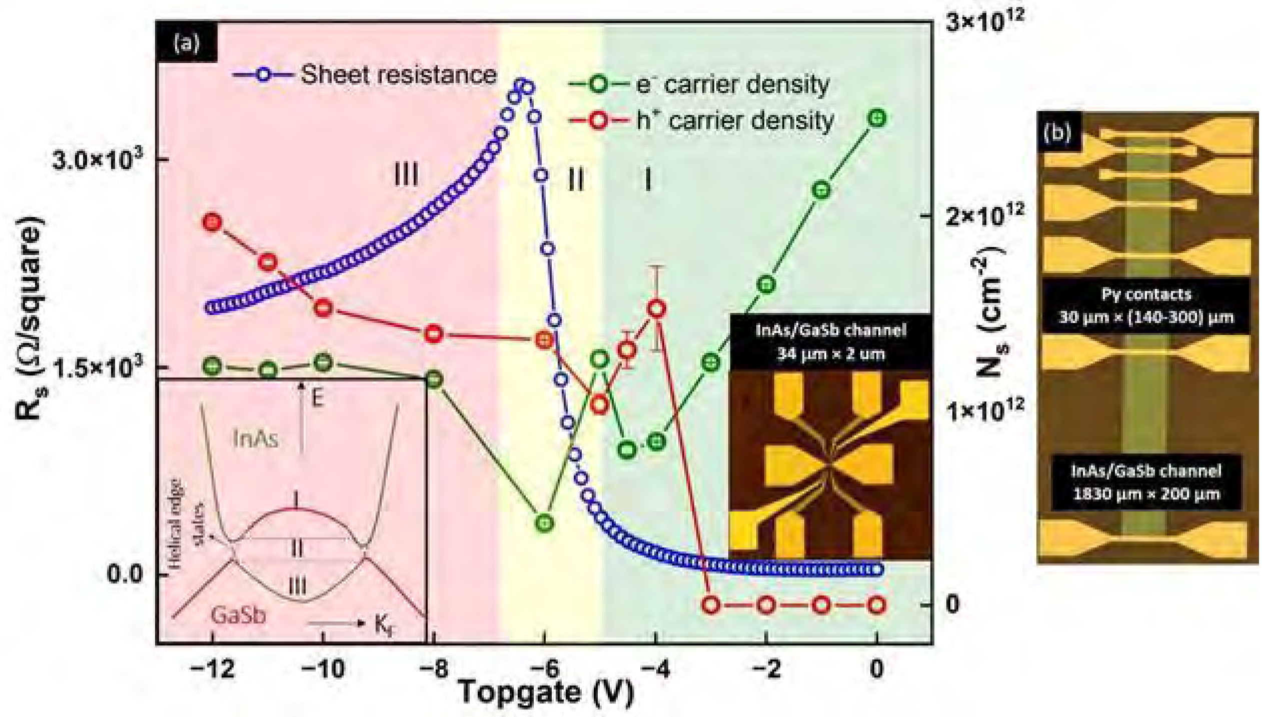

All-Electrical Magnetisation Switching of Connected Nanomagnets

Siddani R

Nanomagnets are increasingly utilized in data storage and neuromorphic computing[1], necessitating innovative methods for state manipulation beyond traditional approaches reliant on global magnetic fields. A promising alternative involves electrical switching effects like spin-orbit torque (SOT)[2]; however, existing SOT-based schemes require individual connections to each element, adding complexity. In nanomagnetic systems, the spectral response is highly sensitive to material, geometry and microstate [3] and previous neuromorphic schemes have leveraged this property as a readout mechanism[4]. In this work, we advance towards manipulating states using microwave (MW) signals and SOT. Through spin-torque ferromagnetic resonance (ST-FMR) measurements, we inject MW currents at varying powers and observe a frequency-dependent reduction in switching fields, where the frequency correlates with the bar geometry. Our magnetic system is comprised solely of Ni80Fe20 (Py) elements, with current passing through them, avoiding the need for high Spin Hall angle heavy metal layers such as W or Pt. We were able to verify these findings using micromagnetic simulation software such as Mumax3 and explore the switching process in more detail. This approach enables frequency-dependent currents to selectively write distinct subsets of magnetic elements via a single electrical connection, presenting significant implications for future neuromorphic designs.

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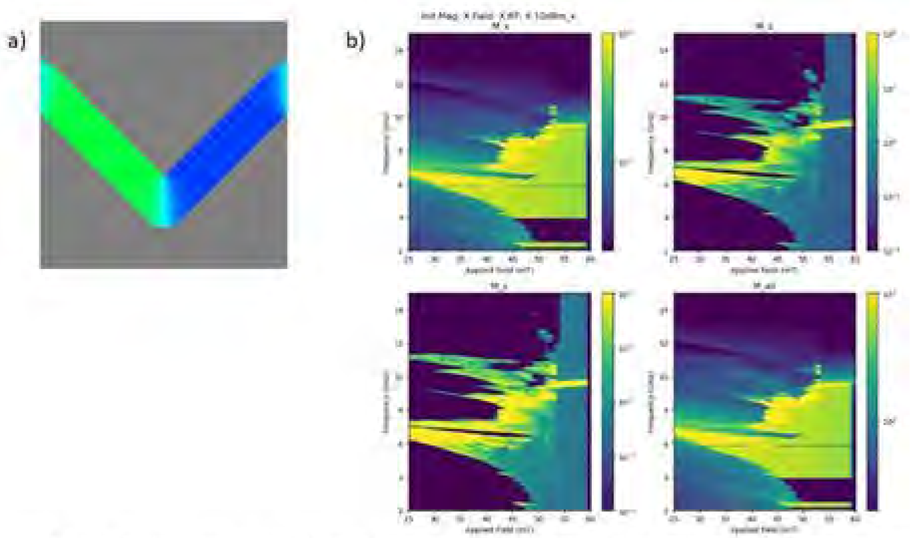

Fig. 1. (a) The initial magnetisation of one unit cell of connected nanomagnets. It is patterned into a chevron shape and, in reality, extends the gap in the signal line to complete the circuit and thus has current flowing through the element itself. b) Mumax3 simulations exciting the geometry in a) with linear RF excitation in the x-direction and static "Applied Field" in x. This graph shows the switching behaviour extending to lower fields at the resonant frequencies.

Correlation Between Local Structural Symmetry and Magnetic Anisotropy Energy: Insights into the Morin Transition in α-Fe_2O_3 Films

Song S, Lee H, Lee D, Ok J, Bell A, Moore T, Kang H, Park S

Recent advancements in spintronics have shifted focus from traditional ferromagnetic materials to antiferromagnetic materials, multiferroics, and their hybrid structures. These materials offer unique advantages such as faster switching speeds, higher stability, and reduced energy consumption, making them ideal for next-generation devices [1,2]. Extensive research efforts are being directed toward controlling the physical properties of these materials and understanding their interrelationships.
In this presentation, we report the correlation between local structural properties and magnetic anisotropy energy, focusing on their influence on the Morin transition of α-Fe2O3 films [3]. The structural properties were controlled by varying the thickness of the thin film grown by using puled laser deposition. As a result, the Morin transition varied as a function of thickness as shown in Figure 1. Through comprehensive structural analyses, it was confirmed that variations in the local symmetry of the FeO6 octahedron are more pronounced and influential than the macroscopic structure. Additionally, it was observed that these local structural changes induce alterations in electronic structure, which in turn affect the magnetic anisotropy energy of α-Fe2O3. Our results are expected to provide comprehensive insights into the correlation between magnetic anisotropy energy, particularly the Morin transition, and local structural symmetry.

Figure 1. (a) Schematic of the α-Fe2O3 crystal unit cell, illustrating the spin alignment at T < TM (left) and T > TM (right). (b) Evolution of Morin transition temperature (TM) as a function of thickness as a function of thickness. The inset shows the local structural distortion of the FeO6 octahedron.

Reference

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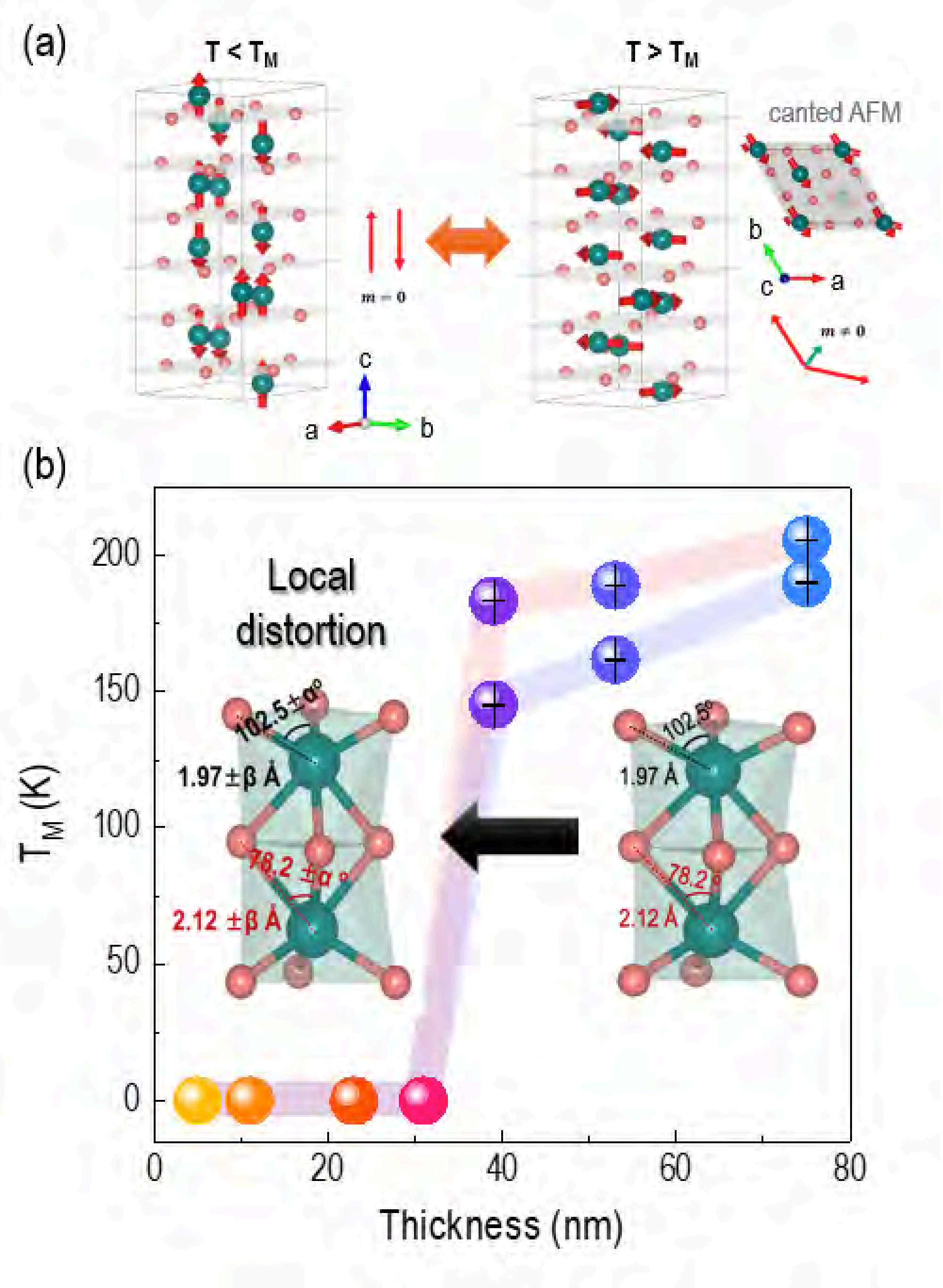
[2] V. Baltz et al., Antiferromagnetic spintronics, Rev. Mod. Phys. 90 015005 (2018)
[3] F. J. Morin et al., Magnetic Susceptibility of α-Fe2O3 and α-Fe2O3 with Added Titanium, Phys. Rev. 78, 819 (1950)


(a)
T < TM
T > TM
canted AFM
m = 0
m ≠ 0
c
a
b
(b)
Local
distortion
102.5±α°
1.97±β Å
78.2 ±α °
2.12 ±β Å
102.5°
1.97 Å
78.2 °
2.12 Å
TM (K)
Thickness (nm)
0
50
100
150
200
20
40
60
80

Beyond Room Temperature Magnetic Order in Low Dimensional van der Waal Crystals for use within Magnetic Tunnel Junctions

Stanfield H

Magnetoresistive random access memory (MRAM) addresses limitations of traditional computer memory architecture, such as cell size, reliability and energy efficiency. Most MRAM device configurations incorporate one or more magnetic tunnel junctions (MTJs), which contain a reconfigurable ferromagnetic layer. The lateral dimensions of MTJs in modern MRAM cells can be large, reducing their scalability, and the Curie temperature of the ferromagnetic layers must be above room temperature for commercial application. Recent advancements in spin-orbit torque MRAM (SOT-MRAM) cell technology have remotivated the search for magnetic materials that can provide both scalability and room-temperature magnetic order. To this end, we are investigating the layered magnetic van der Waals crystals $(Co_{0.5}Fe_{0.5})_5GeTe_2$ and Fe_3GaTe_2, two crystals which, literature shows, have ferromagnetic phases at room temperature. Fe_3GaTe_2 is shown to have perpendicular magnetic anisotropy, whereas $(Co_{0.5}Fe_{0.5})_5GeTe_2$ has simultaneous ferromagnetic and antiferromagnetic phases, contributing to a canted anisotropy that assists in facilitating field-free magnetic reversal via SOT [1,2]. Furthermore, we present magnetoresistance measurements taken on flakes of varying thicknesses, as well as heterostructures, which show quantised hysteresis loops via the anomalous Hall effect; analysis of the anomalous Hall signal demonstrates stable magnetic switching behaviour beyond 300 K within flakes of a few nm in thickness. MTJ structures we study are either those with tunnel barriers or, based on recent literature, those with twist angles, which may induce quantum tunnelling, which has been demonstrated in antiferromagnetic bilayers [3]; we study optical contrast as a function of flake thickness as a guide for fabrication with these materials. With efforts to reduce flake thickness, and implementation into MTJ structures with barriers within the 2-dimensional (2D) limit, we hope this work can lead to the development of fully 2D SOT-MRAM devices.

[1] B. Zhao et al. (2024) arXiv:2308.13408
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Large Bandgap Oxide Topological Insulators

Surtees N

Topological Insulators (TI) are a class of materials consisting of an insulating bulk and conducting surface states. This arises from a large spin orbit coupling creating a partial inversion of the valance and the electron bands. The spin degeneracy of the surface states is then lifted, allowing for currents at the surface to be 100% spin polarised. This has a wide range of applications for spintronic devices. Many existing experimentally verified TIs exhibit a semiconductor-like bandgap in the bulk rather than truly insulating behaviour. Jin et al. [1] theoretically predicted that perovskite Yttrium Bismuth Oxide (YBO) is a candidate for true bulk insulating TIs. This has advantages over existing TIs as the material is robust against environmental changes since it is already an oxide. Furthermore, the large bandgap predicted means that the surface state will dominate over the bulk when carrying a spin current. Work done by Bouwmeester et al. [2] showed the ability to grow YBO thin films on a Barium Bismuth Oxide buffer layer using a Pulse Laser Deposition system. However, they also noted that this growth in perovskite phase was difficult to achieve, and the films grown were of varying quality. This project has successfully optimised the growth conditions of YBO/BBO thin films and began to determine characteristics to prove the existence of topological surface states. Future work using Angle Resolved Photo Emission Spectroscopy (ARPES) will be done to see the characteristic Dirac cone from a surface state of a TI. Additionally, spin-ARPES can resolve spin information about the band structure, allowing the spin polarisation to be seen in the material. This will enable the creation of new spintronic devices.

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MnN As replacement for IrMn

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There is an urgent need to discover novel antiferromagnetic materials that can be used as an alternative to IrMn alloys for room temperature and above devices. This is due to the high cost and scarcity of Ir. MnN, a complex compound that exists in a wide range of phases and has a lower cost, might provide a viable alternative [1].

In this work, samples with composition Si/V(7 nm)/W(15 nm)/MnN (tMnN)/CoFe (2.5 nm)/Al (4 nm) were deposited under different growth conditions using a High target utilization sputtering (HiTUS) system. The thickness of the MnN layer, tMnN, was varied in the range 15 to 28 nm and was grown from a Mn target by reactive sputtering under different Ar:N2 gas mixtures ranging from 50:50 to 90:10. Prior to deposition of the W seed layer the substrate was heated to ~250°C for 20 minutes. The crystal structure of the samples was characterized using a Rigaku Smartlab X-ray diffractometer, while the magnetic properties were evaluated using a Microsense Model 10 vibrating sample magnetometer. Figure 1 shows θ/2 θ X-ray diffraction scans for four MnN films deposited in an Ar 75%:N2 25% atmosphere and a process pressure of 5 mTorr. The diffraction peaks of MnN observed at 2θ values of 36.53° and 42.40 correspond to the (111) and (002) reflections. In addition to the MnN peaks, significant diffraction peaks are observed at 2θ = 39.70° and 85.84°, corresponding to the (110) and (220) W reflections. Figure 2 shows examples of the hysteresis loops measured after annealing for 1 hour at different temperatures. Based on this data, the samples can withstand annealing temperatures in excess of 300°C. The full results and their interpretation will be presented in the full paper.

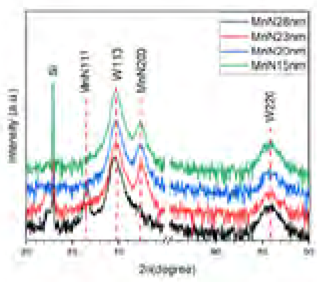

Figure 1. X-ray diffraction patterns for films of varying MnN thickness deposited in an Ar 75%: N_2 25% atmosphere at 5 mTorr.

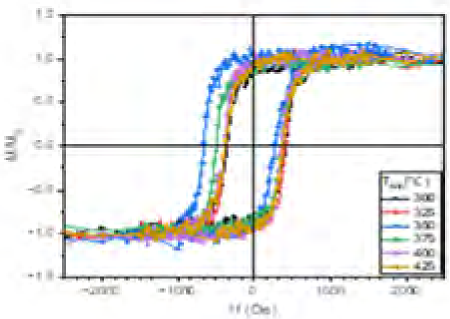

Figure 2. Hysteresis loops as a function of the annealing temperature.

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Ultrafast magnetization enhancement via the dynamic spin-filter effect of type-II Weyl nodes in Co3Sn2S2

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The magnetic type-II Weyl semimetal (MWSM) Co3Sn2S2 has recently been found to host a variety of remarkable phenomena including surface Fermi- arcs, giant anomalous Hall effect, and negative flat band magnetism. However, the dynamic magnetic properties remain relatively unexplored. Here, we investigate the ultrafast spin dynamics of Co3Sn2S2 crystal using time-resolved magneto-optical Kerr effect and reflectivity spectroscopies. We observe a transient magnetization behavior, consisting of spin-flipping dominated fast demagnetization, slow demagnetization due to overall half-metallic electronic structures, and an unexpected ultrafast magnetization enhancement lasting hundreds of picoseconds upon femtosecond laser excitation. By combining temperature-, pump fluence-, and pump polarization-dependent measure- ments, we unambiguously demonstrate the correlation between the ultrafast magnetization enhancement and the Weyl nodes. Our theoretical modelling suggests that the excited electrons are spin-polarized when relaxing, leading to the enhanced spin-up density of states near the Fermi level and the con- sequently unusual magnetization enhancement. Our results reveal the unique role of the Weyl properties of Co3Sn2S2 in femtosecond laser-induced spin dynamics. Reference: Nat Commun 15, 2410 (2024). https://doi.org/10.1038/s41467-024-46604-1