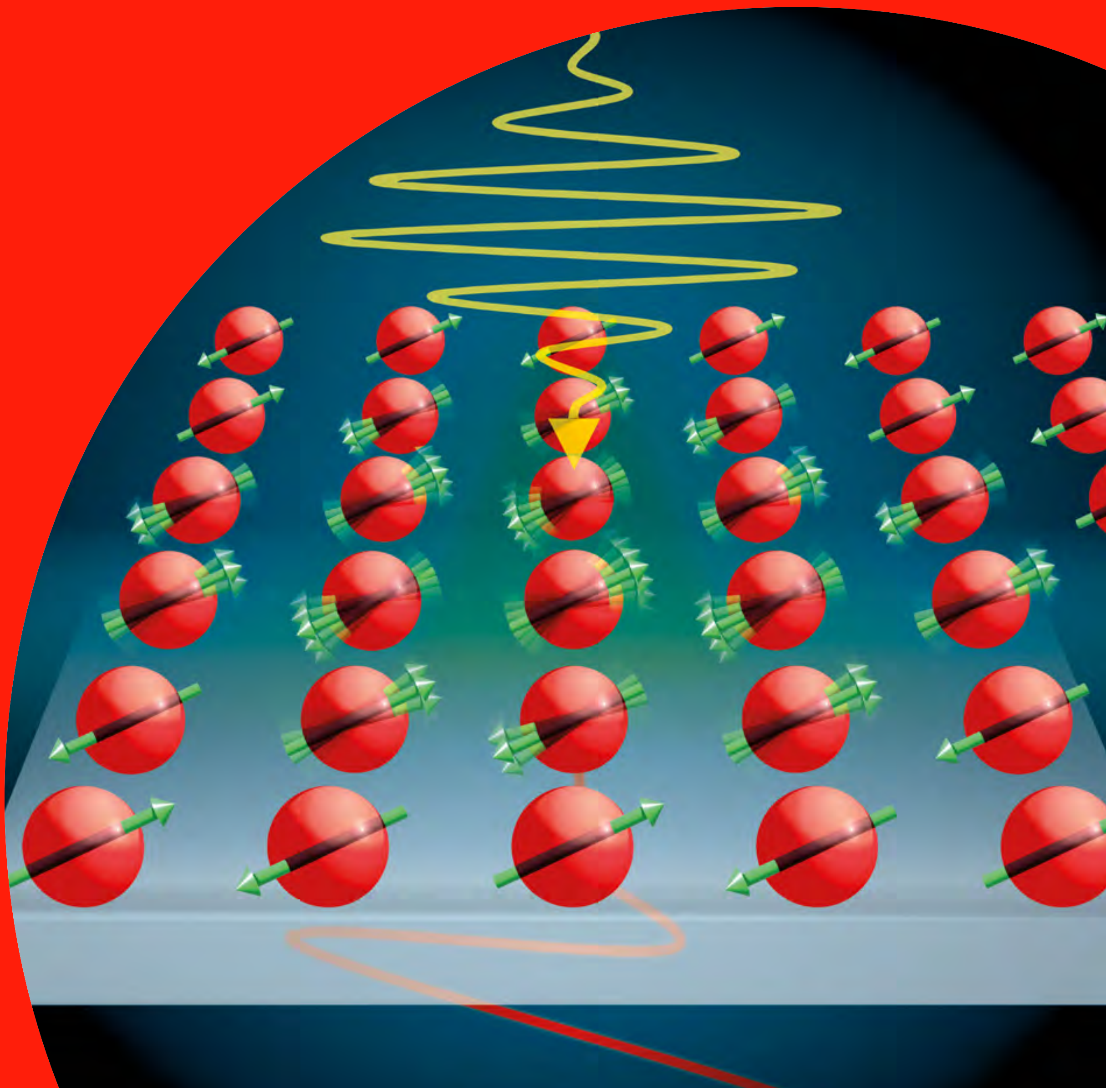
Magnetism 2024

25–26 March 2024
Holywell Park Conference Centre,
Loughborough University, UK



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Magnetism 2024

Monday 25 March 2024

	Room: Turing	Room: Stephenson
9:15am-10am	Registration and Arrival Refreshments	
10am-11:15am	Session 1: Correlated Systems **10am-10:30am: Invited Speaker Dr Ioannis Rusochatzakis.** Geometric frustration and Dzyaloshinskii-Moriya anisotropy in a layered spin-1/2 star lattice antiferromagnet **10:30am-10:45am: Paul Freeman.** Effect of the Commensurate to Incommensurate Crossover on the Magnetism in Charge-Stripe Ordered La2-xSrxNiO4 **10:45am-11am: Yuichi Saito.** Mid-infrared coherent excitation for room temperature phono-magnetism in antiferromagnetic FeBO3 **11am-11:15am: Joshua Bibby.** Synthesis of Atomically Flat Intrinsic Magnetic Topological Insulators using Magnetron Sputtering	Session 2: Thin Films I **10am-10:30am: Invited Speaker: Dr Oscar Lee.** Task-adaptive physical reservoir computing using magnetic skyrmions **10:30am-10:45am: Alex Vanstone.** Enhanced light absorption in nanomagnetic metamaterials **10:45am-11am: Debi Rianto.** Indirect Observation of Interlayer Coupling in Pt through Proximity-Induced Magnetization as a function of Pt Thickness in FM/Pt/FM Structure **11am-11:15am: Charles Swindells.** Spin Waves In Pt/NiFe Nanomagnetic Ring Arrays For Integrated Magnonic Reservoir Computing
11:15am-11:45am	Morning Break	
11:45am-1pm	Session 3: Spintronics **11:45am-12:15pm: Invited Speaker Dr Oto-obong Inyang.** Amorphous ferrimagnetic Rare-earth: Transitional metal (RE: TM) alloys for spintronic applications **12:15pm-12:30pm: Kevin Fripp.** Magnonic Fabry-Pérot resonators as programmable phase shifters and energy concentrators **12:30pm-12:45pm: Kelly Morrison.** Enhancement of spin Seebeck effect in Fe3O4/Pt thin films and bulk composites **12:45pm-1pm: Solveig Felton.** Large temperature hysteresis of a MnIII spin-crossover complex with spontaneous chiral resolution	Session 4: Thin Films II **11:45am-12pm: Emily Heppell.** Controlling the spin structure of antiferromagnetic NiO using a ferromagnetic layer **12pm-12:15pm: Lin Huang.** Temperature gradient-drive motion of magnetic domains in a chiral magnetic metal multilayer **12:15pm-12:30pm: Freya Johnson.** The Impact of Local Strain Fields in Non-Collinear Antiferromagnetic Films **12:30pm-12:45pm: Michał Grzybowski.** Wurtzite MnSe - epitaxy, optical, electronic and altermagnetic properties

1pm-2pm	Lunch, Poster Session 1 and Exhibition	
2pm-2:30pm	**IEEE UK and Ireland Magnetic Chapter AGM**	
2:30pm-3:30pm	**Plenary Speaker: Professor Stephen Blundell.** Probing singlet states in frustrated magnets with muons	
3:30pm-5:15pm	**Session 5: Computation and theory** **3:30pm-4pm: Invited Speaker Professor Samir Lounis.** Spinorbitronics in the nanoworld: a first-principles view on magnetic skyrmions **4pm-4:15pm: Ian Vidamour.** Device-Agnostic Dynamic Learning for Spintronic Platforms **4:15pm-4:30pm: Thomas Moore.** Precise transport of skyrmions by surface acoustic waves **4:30pm-4:45pm: Daan Arroo.** Monopole Density-Jump Transitions in Spin Ice **4:45pm-5pm: Riyajul Islam.** Electronic structure and magnetocrystalline anisotropy of W-type SrFe18O27 hexaferrite	**Session 6: High Frequency Spin Dynamics** **3:30pm-4:15pm: IEEE Distinguished Lecturer Satoru Emori.** Pumping Iron: Revealing Counterintuitive Mechanisms of Magnetization Dynamics **4:15pm-4:30pm: Nikolay Vovk.** THz-driven dynamics of spins and orbitals in TbFeO3 **4:30pm-4:45pm: Daniel Prestwood.** Low field spin wave resonance of Yttrium Iron Garnet stripe domains **4:45pm-5pm: Jack Bollard.** Stacking spinning tops: How to distinguish magnetic dynamics in chemically identical layers **5pm-5:15pm: Jack C. Gartside.** Ultrastrong Dipolar Magnon-Magnon Coupling and Magnon Frequency Combs in a Multilayered '3D' Artificial Spin Ice
5:15pm-6:30pm	Poster Session 2, Refreshments and Exhibition	
6:30pm-10pm	**Conference Dinner** National Space Centre, Exploration Drive, Leicester, LE4 5NS (buses are arranged to transport delegates to and from the venue)	

Tuesday 26 March 2024

	Room: Turing	Room: Stephenson
9am-10am	**Wohlfarth Lecture: Professor Dr Karin Everschor-Sitte.** Let's TWIST again. Topological Whirls In SpinTronics	
10am-10:30am	Morning Break	
10:30am-12:15pm	Session 7: Intelligent Computing **10:30am-11:15am: IEEE Distinguished Lecturer Kerem Çamsarı.** Probabilistic Computing with p-bits: Optimization, Machine Learning and Quantum Simulation **11:15am-11:30am: Guru Venkat.** Machine learning using a 3D artificial spin ice lattice **11:30am-11:45pm: Daniel Bromley.** High-Fidelity, Low-Power All-Optical Magnetic Switching in Dense Nanomagnetic Networks **11:45am-12pm: Alexander Welbourne.** Towards Racetrack Neural Networks	Session 8: Spintronics and 2D materials **10:30am-11am: Invited Speaker Dr Hariom Jani.** Designing topological antiferromagnetic solitons **11am-11:15am: Verena Brehm.** Topological magnon gap engineering in layered van der Waals ferromagnet CrI3 **11:15am-11:30am: Charlie Freeman.** Spin Dynamics and Ultrastrong Magnon-Magnon coupling in the vdW Antiferromagnet CrPS4 **11:30am-11:45am: Maciej Dąbrowski.** Time-resolved microscopy of magnetization dynamics in a 2D van der Waals magnet **11:45am-12pm: Amir Mehrnejat.** Direct measurement of spin signal in a two-dimensional device
12:15pm-1:20pm	Lunch, Poster Session 3 and Exhibition	
1:20pm-1:30pm	Poster Award Presentations	
1:30pm-2pm	EPSRC Talk by James Dennis	
2pm-2:30pm	Magnetism AGM	
2:30pm-3pm	Afternoon Break	

3pm-5pm	**Session 9: Low-dimensional Magnetism** **3pm-3:45pm: IEEE Distinguished Lecturer S.N. Piramanayagam**. Brain-Inspired Computing Using Magnetic Domain Wall Devices **3:45pm-4pm: Servet Ozdemir.** Kondo spin lattice signatures on interface of epilayer platinum/cobalt stacks and organic molecules **4pm-4:15pm: Hari Babu Vasili.** Large and Tunable Spin Hall Magnetoresistance at YIG/PtMn/C60 Interfaces **4:15-4:30pm: Yuting Liu.** Cryogenic in-memory computing using giant and tunable anomalous Hall effect in magnetic topological insulators **4:30pm-4:45pm: Daniel Roe.** Monitoring Ionic Diffusion from CoB in Molecular layers **4:45pm-5pm: Malcolm Connolly.** Nanomagnet-induced synthetic spin-orbit coupling in a hybrid superconductor-semiconductor nanowire island	**Session 10: Novel Techniques in Magnetism** **3pm-3:15pm: Daniel Roe.** Development of In-Situ FMR PNR Measurement Technique **3:15pm-3:30pm: Sara Villa.** Investigating the effect of Ga+ ion irradiation on a synthetic antiferromagnetic multilayer of [Pt/CoFeB/Ru/Pt/CoB/Ru] **3:30pm-3:45pm: Joseph Askey.** Direct visualization of domain wall pinning in sub-100nm 3D magnetic nanowires with cross-sectional curvature **3:45pm-4pm: Andrew Caruana.** Polarised neutron reflectivity to resolve interfacial spin canting in a ferromagnetic metal-semiconductor bilayer **4pm-4:15pm: Russell Ewings.** Symmetry lowering and magnetism in caesium superoxide **4:15pm-4:30pm: Holly Holder.** All-optical & surface-probe control of chiral spin textures in artificial spin ice **4:30pm-4:45pm: Aurys Silinga.** Advanced transmission electron microscopy of the three-dimensional magnetization distribution of a pinned domain wall in a Sm-Co-based permanent magnet **4:45pm-5pm: Aurys Silinga.** Focused Electron Beam Induced Deposition of 3D nanostructures for magnetic racetrack memory

Magnetism 2024
Poster Presentations

Poster Board No.	Name	Paper Title
1	Sahar Alimohammadi	Exploring magnetic domain wall movement and pinning in Permalloy nanowires by magnetic force microscopy
2	Mohammad Alneari	Current-induced resonance in finite length magnetic nanowires
3	Gregory Andrews	Stack design for skyrmion multilayer/B2-FeRh heterostructures
4	Mustafa Aziz	Electromagnetic wave induced resonance in cylindrical magnetic nanotubes
5	Ashna Babu	Flux jumps, cluster distribution model and vortex phase diagram of oxygenated Al-YBCO single crystal
6	Maha Badahdah	Coherent Phonon Stimulated Fast Inverse Spin Hall Effect in Pt:YIG
7	Callum Brennan-rich	Growth and Structure of Fe3Sn2 Intermetallic Alloy Thin Films
8	Ben Brereton	Topological insulator/magnetic multilayer heterostructures for skyrmion dynamics
9	Daniel Burrow	Ballistic spin injection via 1D nanomagnet/graphene interfaces
10	Andrew Caruana	Refl1d: Advanced Neutron and X-ray reflectivity modelling with Bayesian Uncertainty analysis
11	Ioannis Charalampidis	Multiscale investigation of a zero-field room temperature skyrmionic artificial synapse operation and design
12	Zhengfei Chen	Reproducible reservoir computing with thermally driven superparamagnets: controlling temperature sensitivity
13	Henry De Libero	Exploring spin-orbit torques on 50mm WS2/ferromagnet heterostructures
14	Manuel Dos Santos Dias	Complex magnetism and spin dynamics of Mn5Si3 and Mn5Ge3
15	Marios Georgiou	Multi-Q magnetic phases from frustration and chiral interactions
16	Amitava Ghosh	Anisotropy in magnetism and magnetocaloric effect in Gd2NiMnO6 double perovskite thin films
17	Shuvendu Ghosh	Magnetic and transport properties of GdFe2Si2 and Gd(Fe1-xMx)2Si2 (x=0.1)compounds (M= Co, Ni)
18	Emma Gilroy	Enhanced Non-Reciprocity of SAW-FMR in Magnetic Multilayer Films
19	Will Griggs	Analogue and digital circuit design for computing with skyrmionic artificial synapses
20	Will Griggs	Towards experimental realization of zero-field skyrmionic artificial synapses
21	Mohini Gupta	Single crystal growth and study of magnetic transitions in Sm(1-x)HoxFeO3
22	Dirk Honecker	Nanomagnetism seen with neutrons: Small-angle Neutron Scattering
23	Fumiyuki Ishii	First-Principles Calculation of Surface Anomalous Nernst Effect in Antiferromagnet
24	Mae Jankowski	Bismuth ferrite-lead titanate films for an investigation of the effects of the morphotropic phase transition on magnetic properties
25	Paul Keatley	Magneto-optical Kerr effect characterisation of static and dynamic processes in a Thulium Iron Garnet film
26	Megan Kelly	Magnetic contacts to probe helical edges states in InAs/GaSb coupled quantum wells
27	Christy Kinane	Structural and Magnetic depth profiling of Magnetic Thin Films with the POLREF reflectometer
29	Volodymyr Kruglyak	Magneto-acoustic metamaterials: From bulk to surface acoustic waves
30	Anna Kusmartseva	Pressure-induced, strain-tuned Kondo response in Pd2MnIn Heusler alloy
31	Anna Kusmartseva	Triple coil setup for studies of magnetic properties at high pressure
32	Naëmi Leo	Perspectives for Light-Controlled Nanomagnetic Computing via Magneto-Thermoplasmonics
33	Malena Martínez Cameros	Enhancing spin signals in pure spin currents
34	Rao Morusupalli	Revisiting Atomic Magnetism: A Monopolar Approach to Electron and Proton Spin
35	Noora Naushad	Developing novel magnetic L10 alloys for spintronics
36	Thomas Nussle	Quantum thermal expectation values from an effective atomistic spin dynamics model using path integrals.
37	John C. Osborne	Optimisation of magnetic multilayers for surface acoustic wave-driven skyrmion motion
38	Alisha P B	Stochastic Spintronics Device-Based Bayesian Networks for Efficient Uncertainty Modeling
39	Pooja Pooja	Evolution of ferrimagnetism against Griffiths singularity in Calcium Ruthenate

40	Dan Porter	Recent Developments on Materials & Magnetism Beamline, I16 at Diamond Light Source Ltd
41	Connor Sait	Testing the capacity of microcoil devices for pulsed magnetisation reset in pump-probe measurements
42	Abhirami Saminathan	Tuning into the Quantum Spin Hall Insulator state of InAs/GaSb quantum well
43	Alessandro Sola	Transverse thermoelectric materials obtained by powder metallurgy
44	Kilian Stenning	Overparameterisation in physical neural networks of nanomagnetic arrays
45	Charles Swindells	Multi-Output Heterogeneous Magnetic Nanoring Arrays for High-dimensional Reservoir Computing
46	Guru Venkat	Exploring physical and digital architectures in magnetic nanoring array reservoir computers
47	Zhengming Wu	Thermal scanning probe lithography for nanoscale magneticmdomain switching

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NEWS

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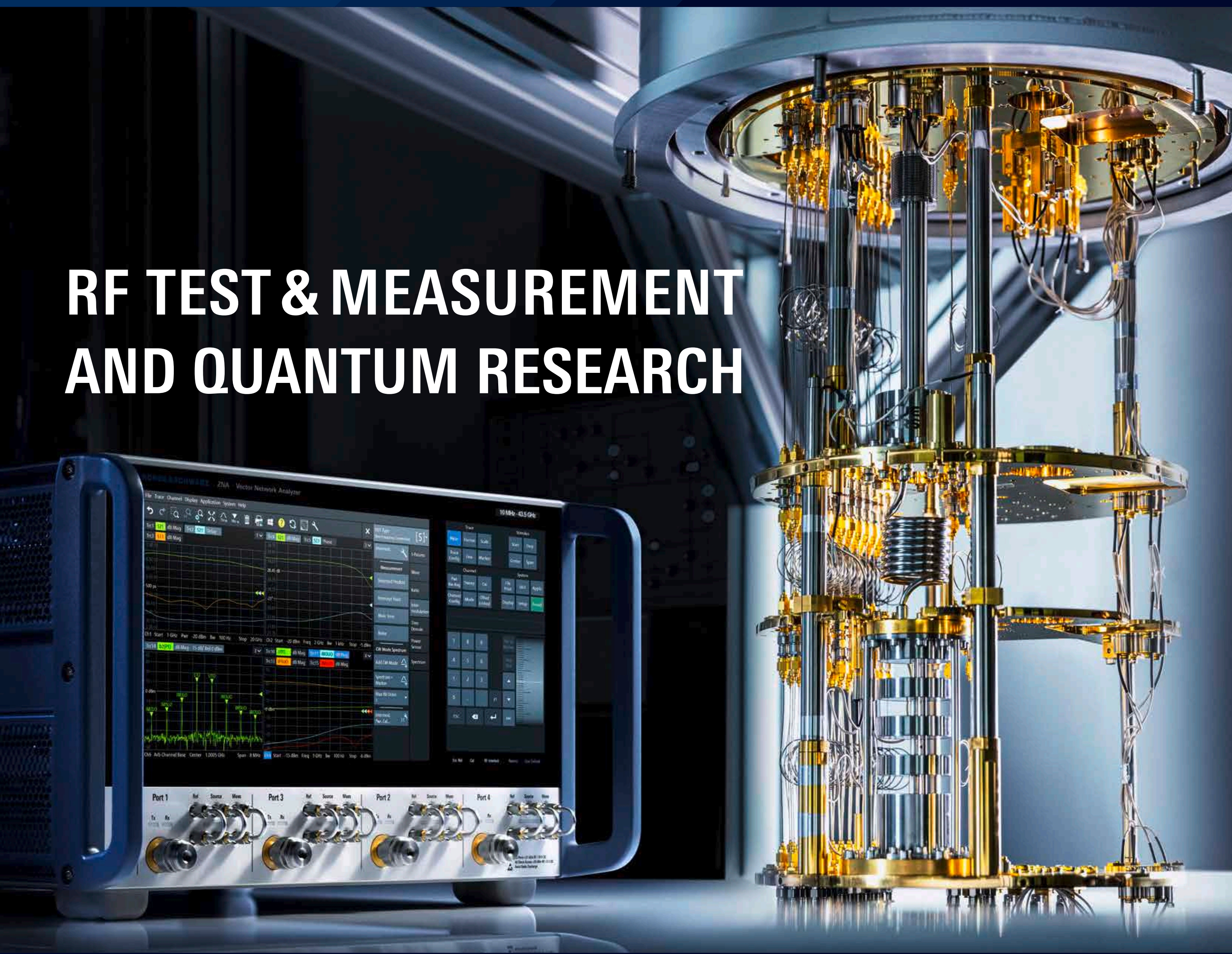

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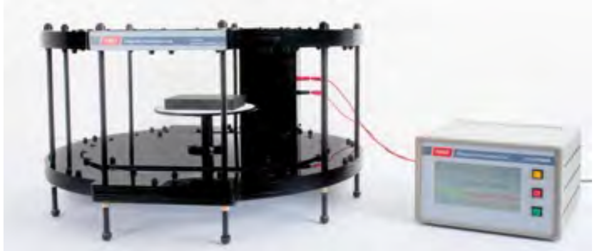



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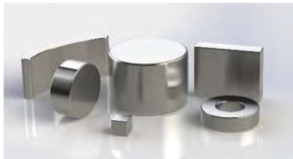
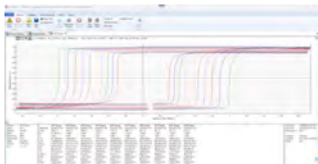


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PFM08-40 and PFM08-70

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Wohlfarth Lecture

Let’s TWIST again Topological Whirls In SpinTronics

Karin Everschor-sitte[1]
[1]*University of Duisburg-Essen, Germany*
Wohlfarth Lecture: Professor Dr Karin Everschor-Sitte, March 26, 2024, 09:00 - 10:00

Skyrmions are topologically stable whirls that are realized in different areas of physics and were initially discovered by Tony Skyrme in particle physics in the 1960's.

Skyrmions, which occur in magnetic systems, were first observed experimentally in 2009. Since then, the field of magnetic skyrmions has developed into a very active area of research, with the aim of exploiting the topological properties of the magnetic whirl-like particles for spintronics applications. For example, the peculiar twist of the magnetization in skyrmions leads to a very efficient coupling to electric currents and allows for “banana kicks” analogous to those in soccer. More recently, magnetic skyrmions have been of strong interest for unconventional computing schemes such as stochastic computing, quantum computing and reservoir computing.

Plenary Speaker

Probing singlet states in frustrated magnets with muons

Stephen Blundell[1]
[1]*University of Oxford, United Kingdom*
Plenary Speaker: Professor Stephen Blundell, March 25, 2024, 14:30 - 15:30

The technique of muon-spin rotation (μSR) has emerged as one of the most important spectroscopic techniques in condensed matter physics, used to study everything from superconductors to skyrmions. It is particularly useful in studying magnetism. As I will describe, it is now possible to understand the interaction between the muon and its neighbouring spins in quantitative detail to probe entanglement and decoherence [1] and to characterise the muon site in many different materials with high accuracy [2,3]. An outstanding problem is that many magnetically frustrated systems exhibit what is known as persistent spin dynamics (PSD) in μSR experiments, the origin of which has remained mysterious since their discovery in the 1990s. As the temperature is lowered, the muon-spin relaxation rate rises (as would be expected for the slowing-down of spin fluctuations) but this rate then saturates at low temperature. To explain this phenomenon, I will describe how muons can couple to singlet states [4] and how this can be extended to understand the way muons couple to a variety of systems exhibiting highly frustrated magnetism. μSR experiments are usually carried out without resonance, but I will describe a new project which aims to use insights from magnetic resonance and include them into μSR, thereby extending the reach of the technique.

References:
[1] J. M. Wilkinson and S. J. Blundell Phys. Rev. Lett., 125, 087201 (2020)
[2] S. J. Blundell and T. Lancaster Appl. Phys. Rev., 10 , 021316 (2023)
[3] P. Bonfà, I. J. Onuorah, F. Lang, I. Timrov, L. Monacelli, C. Wang, X. Sun, O. Petracic, G.Pizzi, N. Marzari, S. J. Blundell, and R. De Renzi, Phys. Rev. Lett. 132, 046701 (2024)
[4] S. J. Blundell J. Phys.: Conf. Ser., 2462, 012001 (2023)

IEEE Distinguished Lecturers

Probabilistic Computing with p-bits: Optimization, Machine Learning and Quantum Simulation

Dr. Kerem Camsari[1]
[1]*UCSB, United States*

Session 7: Intelligent Computing, March 26, 2024, 10:30 - 12:15

The slowing down of Moore's era has coincided with escalating computational demands from Machine Learning and Artificial Intelligence. An emerging trend in computing involves building physics-inspired computers that leverage the intrinsic properties of physical systems for specific domains of applications. Probabilistic computing with p-bits, or probabilistic bits, has emerged as a promising candidate in this area, offering an energy-efficient approach to probabilistic algorithms and applications [1-4].

Several implementations of p-bits, ranging from standard CMOS technology to nanodevices, have been demonstrated. Among these, the most promising p-bits appear to be based on stochastic magnetic tunnel junctions (sMTJ) [2]. sMTJs harness the natural randomness observed in low-barrier nanomagnets to create energy-efficient and fast fluctuations, up to GHz frequencies [4]. In this talk, we will discuss how magnetic p-bits can be combined with conventional CMOS to create hybrid probabilistic-classical computers for various applications. We will provide recent examples of how p-bits are naturally applicable to combinatorial optimization, such as solving the Boolean satisfiability problem [3], energy-based generative machine learning models like deep Boltzmann machines, and quantum simulation for investigating many-body quantum systems.

Through experimentally informed projections for scaled p-computers using sMTJs, we will demonstrate how physics-inspired probabilistic computing can lead to GPU-like success stories for a sustainable future in computing.

[1] S. Chowdhury, A. Grimaldi, N. A. Aadit, S. Niazi, M. Mohseni, S. Kanai, H. Ohno, S. Fukami, L. Theogarajan, G. Finocchio, S. Datta, K. Y. Camsari, A full-stack view of probabilistic computing with p-bits: devices, architectures and algorithms, IEEE Journal on Exploratory Solid-State Computational Devices and Circuits, (2023)
[2] W. A. Borders, A. Z. Pervaiz, S. Fukami, K. Y. Camsari, H. Ohno, S. Datta, Integer Factorization Using Stochastic Magnetic Tunnel Junctions, Nature, 573, 390-393 (2019)
[3] N. A. Aadit, A. Grimaldi, M. Carpentieri, L. Theogarajan, J. M. Martinis, G. Finocchio, K. Y. Camsari, Massively Parallel Probabilistic Computing with Sparse Ising Machines, Nature Electronics (2022)
[4] N. S. Singh, S. Niazi, S. Chowdhury, K. Selcuk, H. Kaneko, K. Kobayashi, S. Kanai, H. Ohno, S. Fukami and K. Y. Camsari, Hardware Demonstration of Feedforward Stochastic Neural Networks with Fast MTJ-based p-bits, IEDM (2023)

Pumping Iron: Revealing Counterintuitive Mechanisms of Magnetization Dynamics

Satoru Emori[1]
[1]*Virginia Polytechnic Institute and State University, United States*
Session 6: High Frequency Spin Dynamics, March 25, 2024, 15:30 - 17:15

In any magnetic material, rotating the magnetization involves “damping,” somewhat analogous to damped mechanical oscillations with friction. Minimizing magnetic damping is crucial for energy-efficient spintronic devices (e.g., nanoscale magnetic memories and oscillators). However, the mechanisms of damping in various materials – even in seemingly simple ones – have yet to be understood.

In this talk, I will present recent experimental insights into magnetic damping in simple model systems: thin films of elemental Fe. Our results reveal that – somewhat counterintuitively – cleaner epitaxial Fe films at low temperature exhibit higher damping [1]. This observation cannot be accounted for by the classical eddy current loss, but is instead well explained by the so-called breathing Fermi surface model due to “procrastinating” electrons. Moreover, I will demonstrate that Gilbert damping in polycrystalline Fe at room temperature is remarkably insensitive to the film microstructure, while there also exists a large non-Gilbert contribution that is influenced by disorder in a highly nontrivial way [2]. These findings constitute a path forward in understanding and engineering damping for energy-efficient device applications.

References: [1] B. Khodadadi et al. Phys. Rev. Lett. 124, 157201 (2020). [2] S. Wu et al. Phys. Rev. B 105, 174408 (2022).

Brain-Inspired Computing Using Magnetic Domain Wall Devices

Prof. Prem S.N. Piramanayagam[1]
[1]Nanyang Technological University, Singapore

Session 9: Low-dimensional Magnetism, March 26, 2024, 15:00 - 17:00

Neuromorphic computing or brain-inspired computing is considered as a potential solution to overcome the energy inefficiency of the von Neumann architecture for artificial intelligence applications [1-4]. To realize spin-based neuromorphic computing practically, it is essential to design and fabricate electronic analogues of neurons and synapses. An electronic analogue of a synaptic device should provide multiple resistance states. A neuron device should receive multiple inputs and should provide a pulse output when the summation of the multiple inputs exceeds a threshold.

Our group has been carrying out investigations on the design and development of various synaptic and neuron devices in our laboratory. Domain wall (DW) devices based on magnetic tunnel junctions (MTJs), where the DW can be moved by spin-orbit torque, are suitable candidates for the fabrication of synaptic and neuron devices [2]. Spin-orbit torque helps in achieving DW motion at low energies whereas the use of MTJs helps in translating DW position information into resistance levels (or voltage pulses) [3]. This talk will summarize various designs of synthetic neurons synaptic elements and materials [4]. The first half of the talk will be at an introductory level, aimed at first-year graduate students. The second half will provide details of the latest research.

[1] K Roy, A Jaiswal and P Panda, Naure 575 607-617 (2019)
[2] WLW Mah, JP Chan, KR Ganesh, VB Naik, SN Piramanayagam, Leakage function in magnetic domain wall based artificial neuron using stray field, Appl. Phys. Lett., 123 (9) 092401 (2023).
[3] D Kumar, HJ Chung, JP Chan, TL Jin, ST Lim, SSP Parkin, R Sbiaa and SN Piramanayagam, Ultralow Energy Domain Wall Device for Spin-Based Neuromorphic Computing ACS Nano 17(7) 6261-6274 (2023)
[4] R Maddu, D Kumar, S Bhatti and S.N. Piramanayagam, Spintronic Heterostructures for Artificial Intelligence: A Materials Perspective, Phys. Stat. Sol. RRL 17(6) 2200493 (2023).

Invited Speakers

Amorphous ferrimagnetic Rare-earth: Transitional metal (RE: TM) alloys for spintronic applications

Dr Oto-obong Inyang[1]
[1]Durham University, United Kingdom

Session 3: Spintronics, March 25, 2024, 11:45 - 13:00

Rare Earth: Transitional Metal (RE:TM) ferrimagnetic alloys have attracted wide interest in recent years, due to their potential for spintronics applications. They comprise two antiferromagnetically coupled sublattices with magnetisation and angular momentum that vary with temperature and composition giving rise to compensation points, where the net magnetisation or the angular momentum is zero. Variation of atomic distribution of these sublattices has implications on the electronic structure of the bulk system and the interfaces affecting phenomena such as Perpendicular magnetic anisotropy (PMA), proximity-induced magnetisation (PIM), the compensation points and spin transport. RE:TM systems are nominally believed to be uniform but recent studies reveal complex spatial variation in the elemental species, which may impact applications.

During this presentation, I will discuss research at Durham on ferrimagnetic RE: TM alloys. I will show how the amorphous phase develops with RE content [1], I will introduce PIM [2] and show the orientation of the PIM induced in HM layers neighbouring RE:TM alloys [3] and most critically show the spatial variations of the atomic species and magnetisation through the thickness of nominally uniform RE: TM alloys films [4], which has critical implications for spintronics.

References:
[1] Inyang, O., et al. "The role of low Gd concentrations on magnetisation behaviour in rare earth: transition metal alloy films." Sci. Rep. 10.1 (2020): 9767.
[2] Inyang, O., et al. "Threshold interface magnetization required to induce magnetic proximity effect." Phys. Rev. B 100.17 (2019): 174418.
[3] Swindells, C.,Nicholson, B., Inyang, O., et al. "Proximity-induced magnetism in Pt layered with rare-earth–transition-metal ferrimagnetic alloys." Phys. Rev. Res. 2.3 (2020): 033280.
[4] Inyang, O., et al. "Non-uniform Gd distribution and magnetization profiles within GdCoFe alloy thin films." Appl. Phys. Lett. 123.12 (2023).

Designing topological antiferromagnetic solitons

<u>Dr Hariom Jani</u>[1]

[1]University of Oxford, United Kingdom

Session 8: Spintronics and 2D materials, March 26, 2024, 10:30 - 12:15

Platforms hosting topological spin solitons, such as skyrmions, merons and bimerons, are promising for the design of novel computing paradigms. However, the practical implementation of ferromagnetic systems has been inhibited by susceptibility to stray fields, long-range dipole fields and slower dynamics. To alleviate these issues, there has been a surge of interest in antiferromagnetic (AFM) solitons, predicted to be robust, scalable and faster by 100-1000 times. However, experimental progress in this field has been hampered by spin compensation in antiferromagnets, making it difficult to design and harness AFM solitons.

I will discuss how we overcame these limitations by utilising the AFM analogue of the celebrated Kibble-Zurek mechanism originally proposed in cosmology. This allowed us to generate a wide family of nanoscale topological solitons, in the classic antiferromagnet hematite at room temperature.[1]We have also recreated this phenomenology in free-standing 3D nano-platforms enabling strain-driven spatial design of AFM solitons.[2]Promisingly, these solitons are coupled to multi-polar emergent magnetic charge distributions, facilitating classification and read-out of AFM vorticity.[3]AFM states in hematite can be tuned via magneto-crystalline interactions[4], fields[5]and spin currents, opening up unprecedented control over soliton dimension, chirality and dynamics.[6]Hence, hematite may emerge as a tunable platform to harness AFM solitons for efficient and ultra-fast AFM functionalities.[7]

[1] H Jani, J-C Lin, et al. Nature 590, 74 (2021).
[2] H Jani,* J Harrison,* et al. Nature Materials 23, In Press (2024).
[3] A Tan,* H Jani,* et al. Nature Materials 23, 205 (2024).
[4] H Jani, J Linghu et al. Nature Communications 12, 1668 (2021).
[5] J Harrison, H Jani et al. Optics Express 32, 5885 (2024).
[6] J Harrison, H Jani et al. Physical Review B 105, 224424 (2022).
[7] ZS Lim,* H Jani* et al. MRS Bulletin 46, 1053 (2021).

Team Acknowledgement: This talk is a culmination of research performed in the P.G. Radaelli group (Oxford), Ariando group and T. Venkatesan group (Singapore), M. Atatüre group (Cambridge), C.B. Eom group (Wisconsin-Madison). Team includes J.C. Lin, J. Harrison, J. Chen, C. Godfrey, S. Prakash, S. Hooda, G.J. Omar, J. Hu, P. Nandi, M. Lal, J. Schad, F. Maccherozzi, S. Finizio, J. Raabe, T.A. Butcher, A. Tan, M. Hogen, C. Castelnovo.

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Task-adaptive physical reservoir computing using magnetic skyrmions

Dr Oscar Lee[1], Tianyi Wei[1], Kilian D. Stenning[1], Jack C. Gartside[1], Dan Prestwood[1], Shinichiro Seki[2], Aisha Aqeel[3,4], Kosuke Karube[5], Naoya Kanazawa[2], Yasujiro Taguchi[5], Christian Back[3], Yoshinori Tokura[2,5], Will R. Branford[1], Hidekazu Kurebayashi[1,6]
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Session 2: Thin Films I, March 25, 2024, 10:00 - 11:15

Physical reservoir computing (PRC) is a specific neuromorphic architecture potentially offering energy-efficient solutions for processing machine learning (ML) tasks requiring heavy computation. However, establishing a methodology for on-demand control of reservoir properties remains challenging. This is due to the rigidity of configuring the crucial hyperparameters required to maximise computational performance. Hence, physical reservoirs are typically constrained to well-execute a pre-defined set of ML tasks. In this talk, we experimentally demonstrate a flexible task-adaptive PRC using the spectrum space of a single magnetic system with distinctive phase properties. The reservoir is constructed with data-mapped collective spinwave excitations of skyrmion and conical modes. We scrutinise the task-adaptive nature via trivial magnetic phase control in a chiral magnetic insulator Cu2OSeO3 as a model system and bridge the key reservoir properties with various magnetic phases. Our results highlight that skyrmions excel in forecasting chaotic signals, unlike the conical modes that are optimal for nonlinear transformation tasks. Room-temperature demonstrations on FeGe and Co8.5Zn8.5Mn8.5 confirm that our task-adaptive approach to PRC via magnetic phase control is transferable to other phase-rich systems, taking a step closer to energy-efficient computing.

Spinorbitronics in the nanoworld: a first-principles view on magnetic skyrmions

Samir Lounis[1]
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Session 5: Computation and theory, March 25, 2024, 15:30 - 17:15

Spin-orbitronics is an emergent and fast-growing subject, encompassing both fundamental new physics as well as prospective technological developments hinging on the discovery of novel concepts for magnetic bits, their stability, manipulation and efficient detection. In this context, magnetic skyrmions, which are spin-swirling textures of topological nature, emerged as particles with highly potential to store, transport and read information. This is however hindered by various challenges, encompassing the unavoidable inhomogeneities ubiquitous to any device, which affect their detection, nucleation, motion and velocity.

In this talk, I will present an overview of how first-principles simulations enable to make progress in this field. I will discuss ab-initio inspired protocols for efficiently detecting non-collinear spin-textures and their chiral nature with all-electrical [1,2] or optical means owing to the presence of topological orbital moments [3]. I will address progress in finding combination of materials that can host intrinsic (non-synthetic) topological AFM solitons, which can have intriguing properties. In contrast to ferromagnetic skyrmions, they are expected to be immune to the skyrmion Hall effect, might offer terahertz dynamics while being insensitive to magnetic fields and dipolar interactions. They emerge as single and strikingly interpenetrating chains with non-trivial dynamics in a row-wise AFM Cr film deposited on PdFe bilayer/Ir(111) [4]. If time permits, I will present our mapping of the energy-landscape of single magnetic nanoskyrmions interacting with 3d and 4d transition single-atom impurities, establishing a universal shape as function of the defect's electron filling [5]. These findings open exciting avenues for engineering and detecting chiral entities for spintronics applications.

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Geometric frustration and Dzyaloshinskii-Moriya anisotropy in a layered spin-1/2 star lattice antiferromagnet

Ioannis Rousochatzakis[1]
[1]Loughborough University, UK

Session 1: Correlated Systems, March 25, 2024, 10:00 - 11:15

I will discuss a joint experimental and theoretical study [1] of a layered spin-1/2 copper compound which is a close realization of the star lattice antiferromagnet, one of the playgrounds of geometric frustration and resonating valence bond physics in two spatial dimensions. This compound shows no long-range magnetic ordering down to at least 0.1 K, and a characteristic field-induced entropic shift which points to the emergence of compound spin-1/2 degrees of freedom at low energy scales. The system shows, in addition, a peculiar magnetization response, with a Curie-like susceptibility as well as a 1/3 magnetization plateau for one direction of the field, and a completely different response for other directions. Using first-principles calculations, exact diagonalizations and an effective strong-coupling description, we show that these experimental puzzles are signatures of the strong geometric frustration of the star lattice, the presence of sizable Dzyaloshinskii-Moriya interactions, as well as the emergence of a continuous U(1) symmetry.

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Oral Presentations

Monopole Density-Jump Transitions in Spin Ice

Omar Abbas[1,2], Professor Steven Bramwell[1,2], Dr Daan Arroo[3,2]
[1]University College London, United Kingdom, [2]London Centre for Nanotechnology, United Kingdom, [3]Imperial College London, United Kingdom

Session 5: Computation and theory, March 25, 2024, 15:30 - 17:15

Our work [1] addresses an old puzzle in the description of magnetic monopoles in spin ice using Debye-Hückel theory, originally developed as a model of dilute electrolytes. Debye-Hückel theory has proved extraordinarily successful for describing both pyrochlore and artificial spin ice systems [2,3] but it has long been noted [4] that this model predicts a phase transition at low temperatures in which the monopole density abruptly “jumps” by several orders of magnitude. Such jumps would have clear experimental signatures but to date these have not been observed.

Here we show that while density-jump transitions are a robust prediction of Debye-Hückel theory, certain assumptions made in early applications of the model to spin ice led to the transition temperature being overestimated. By dispensing with these assumptions, we link density-jump transitions to charge-ordering transitions predicted by other models of spin ice [5,6] and make suggestions for how such transitions might be observed experimentally.

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Direct visualization of domain wall pinning in sub-100nm 3D magnetic nanowires with cross-sectional curvature

Dr. Joseph Askey[1], Dr. Matthew Hunt[2], Dr. Lukas Payne[1], Dr. Ioannis Pitsios[3], Dr. Arjen van den Berg[1], Alaa Hejazi[1], Prof. Wolfgang Langbein[1], Dr. Sam Ladak[1]
[1]Cardiff University, United Kingdom, [2]Huntleigh Healthcare, United Kingdom, [3]VitreaLab GmbH, Austria

Session 10: Novel Techniques in Magnetism, March 26, 2024, 15:00 - 17:00

Three-dimensional (3D) magnetic nanostructures exhibit rich phenomena from topological spin texture stabilisation through nanoscale curvature [1], to novel ground states driven by 3D frustrated interactions [2]. However, the rapid fabrication of 3D magnetic systems with feature sizes on the order of tens of nanometres poses a significant challenge. In this work, we present sub-100 nm 3D ferromagnetic nanowires with both cross-sectional and longitudinal curvature (Figure 1a), fabricated via two-photon direct laser writing using a 405 nm wavelength laser and conventional thermal evaporation. Physical characterisation reveals lateral feature sizes down to 80 nm can be obtained (Figure 1b-e), whilst micromagnetic simulations elucidate a range of novel domain wall configurations induced by the cross-sectional curvature of the system. Magnetic force microscopy characterisation in externally applied magnetic fields is used to directly visualise the injection and pinning of domain walls in these 3D magnetic nanowires. Using a simple model which considers only the local magnetostatic energy landscape, the domain wall pinning is shown to arise due to subtle variations in thickness and roughness across the nanowire.

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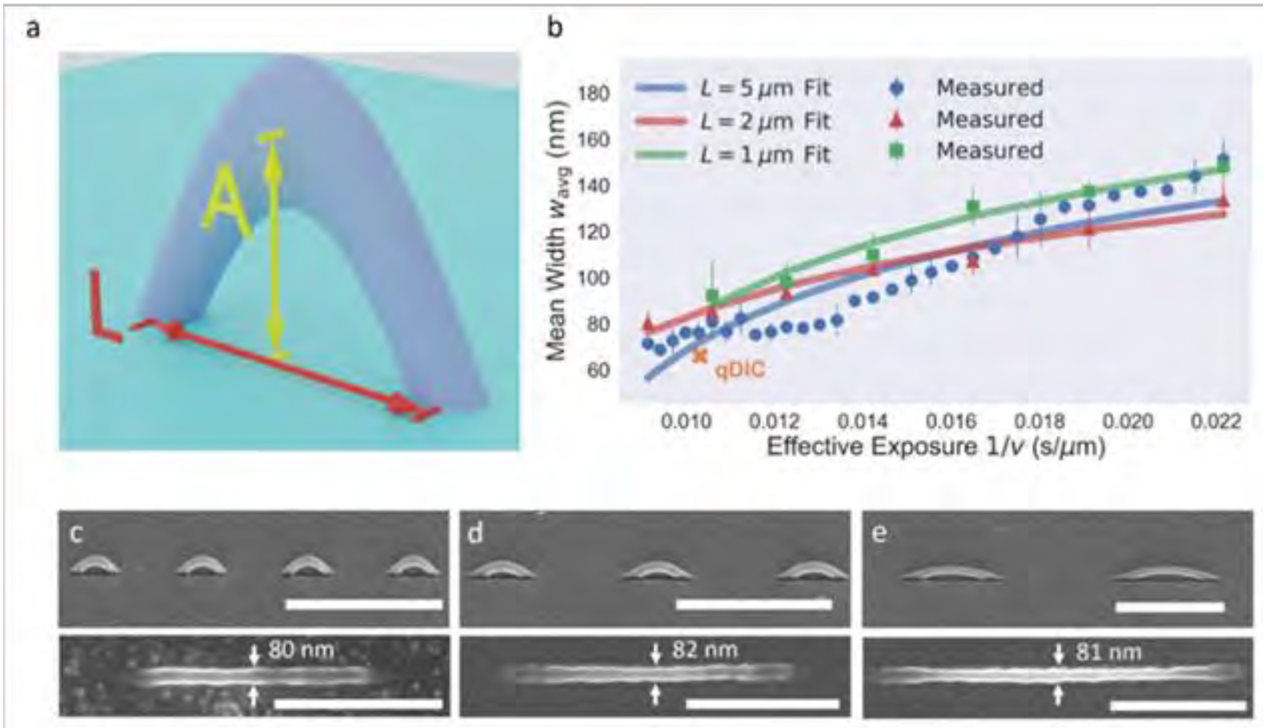

Synthesis of Atomically Flat Intrinsic Magnetic Topological Insulators using Magnetron Sputtering

Mr Joshua Bibby[1], Peng Chen[2], Prof. Thorsten Hesjedal[1], Prof. Gerrit van der Laan[3]
[1]University of Oxford, United Kingdom, [2]ShanghaiTech University, China, [3]Diamond Light Source, United Kingdom

Session 1: Correlated Systems, March 25, 2024, 10:00 - 11:15

Magnetic topological insulators (MTIs) have long showed promise as materials for the observation of quantum phenomena such as the quantum anomalous Hall effect (QAHE). However, introducing the magnetic order required for their observation into TIs has proven to be a significant challenge [1]. A recent breakthrough has been a new class of material referred to as intrinsic MTIs, in which magnetic order is intrinsic to the material. The prototypical intrinsic MTI MnBi2Te4 derives it's magnetic ordering from antiferromagnetically coupled MnTe bilayers interspersed with Bi2Te3 quintuple layers, resulting in a septuple layer system [Fig. 1(a, b)] [2].

However, the nature of the coupling between the bilayers introduces its own challenges as the state of the material is dependant on the number of septuple layers, with either a QAHE or axion insulator state selected with odd or even numbers of septuple layers, respectively. Therefore, both island-dominated molecular beam epitaxy growth and exfoliation of bulk samples struggle to produce samples with controlled thickness and adequate lateral size for devices. Sputter deposition and annealing has shown that it is possible to produce atomically flat MnBi2Te4 [3]. We have recently demonstrated growth of the intrinsic MTI MnBi2Te4 using this deposition method, enabling the direct study of the magnetic order in this using element-selective x-ray magnetic circular dichroism (XMCD).

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Figure 1

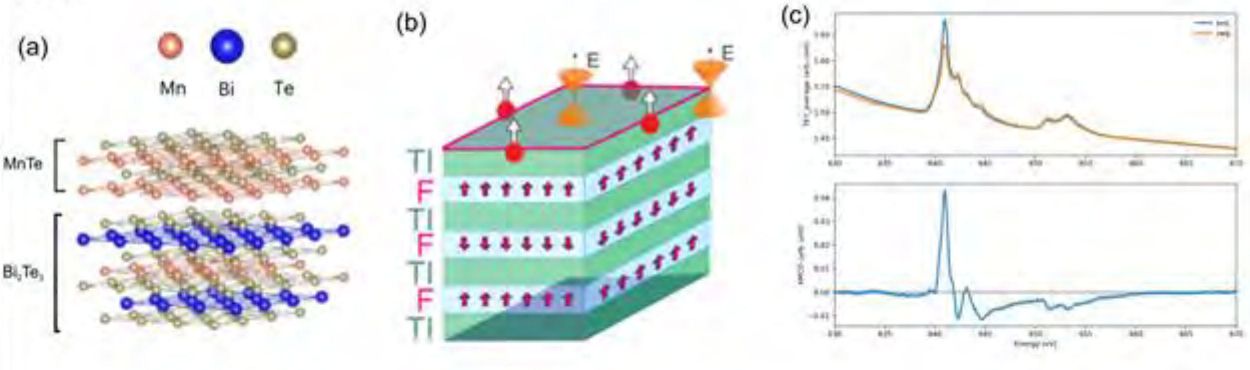
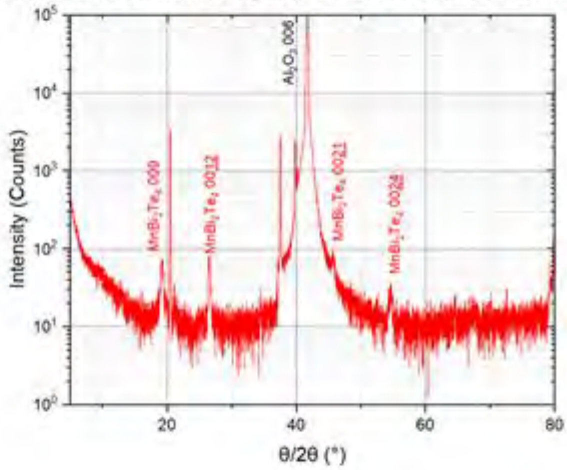


Figure 2: XRD Spectra of $MnBi_2Te_4$ Synthesised via Magnetron Sputtering



Stacking spinning tops: How to distinguish magnetic dynamics in chemically identical layers

Mr. Jack Bollard[1,2]
[1]Diamond Light Source, Didcot, United Kingdom, [2]University of Oxford, United Kingdom

Session 6: High Frequency Spin Dynamics, March 25, 2024, 15:30 - 17:15

Magnetic multilayers offer immense opportunities for the development of ultrafast functional devices. In a recent series of experiments at Diamond Light Source, we have combined x-ray detected ferromagnetic resonance with x-ray resonant reflectivity, revealing the depth-dependent profile of the magnetisation dynamics [1]. In 2020, using this reflectivity ferromagnetic resonance (RFMR) technique, we uncovered a phase lag between adjacent ferromagnetic layers undergoing magnetic resonance in the chiral heterostructure [MgO/CoFeB/Ta]4 [2]. Since then, we have focused on understanding complex heterostructures, e.g., RKKY-coupled perpendicular magnetic anisotropy synthetic antiferromagnets and spin valve systems. Here, we will provide a brief overview of recent developments, with a particular focus on the dependence of the dynamics in a chiral heterostructure on the ferromagnetic layer thickness (0.50-1.75 nm). We observed that complex interfacial effects can disrupt the uniform precession, and produce depth-dependent variations in the precessional amplitude and phase. The [CoFeB/MgO/Ta]4 multilayers host a variety of rich magnetic textures, with a transition from in-plane to out-of-plane magnetisation when the thickness of CoFeB is reduced to below 1.5 nm. By comparing the depth-dependence of the RFMR signal, we found that at this transition point adjacent layers in these heterostructures show strong decoupling of their precession, while samples hosting only one ferromagnetic mode (in-plane or out-of-plane) showed strong coupling between layers. With RFMR, we are able to measure GHz magnetisation dynamics within the different layers with the same chemical composition in a multilayered nanostructure, hidden deep below the surface.

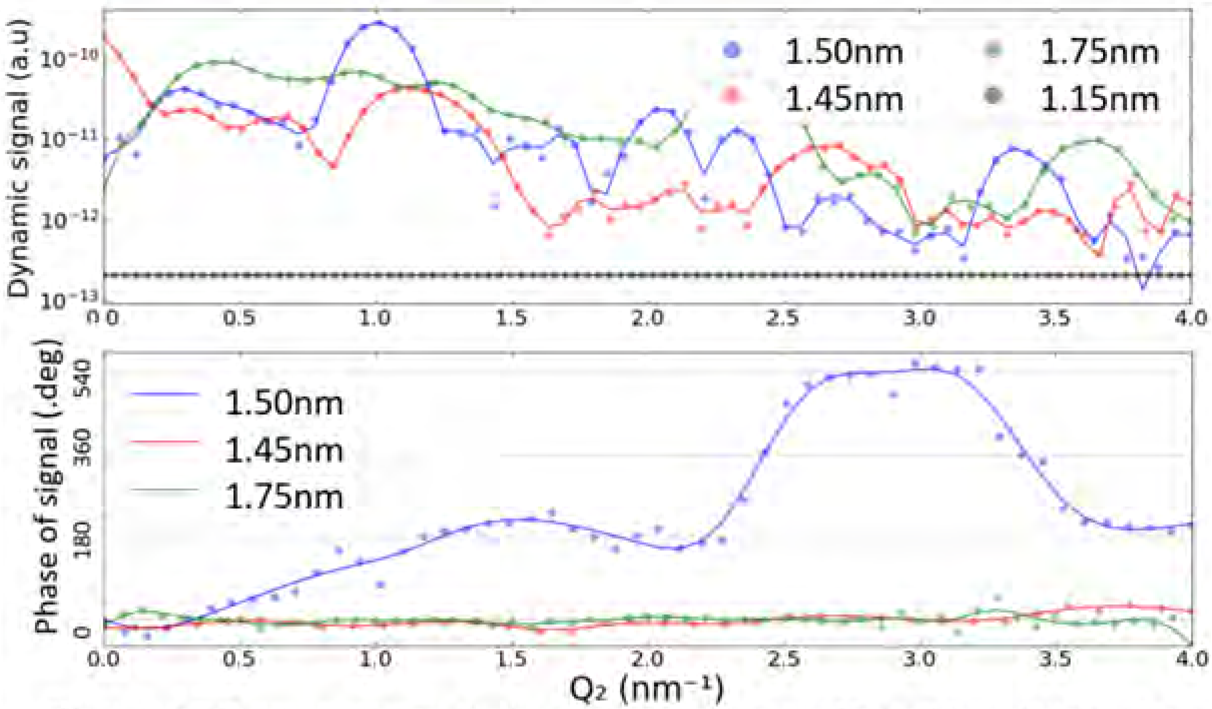


Figure 1: ***RFMR measurements*.** Varying the delay time between RF signal (pump) and incident x-ray pulses (probe) allows for mapping of the precessional cone at given Qz, resulting in a sinusoidal curve at the frequency of the RF excitation. These delay scans are repeated for a range of incident x-ray angles in a $\theta - 2\theta$ geometry, resulting in an XRR curve measurement of the dynamic contribution. Plot of the delay scan amplitudes (above) and phases (below), obtained from sinusoidal fits. The RFMR signal is proportional to the dichroism in reflectivity. Note that the sample with a 1.15 nm thick CoFeB layer showed no observable dynamics. VNA-FMR and VSM measurements showed that the sample series exhibits an in-plane to out-of-plane anisotropy transition when the CoFeB thickness is reduced to below 1.5 nm.

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Topological magnon gap engineering in layered van der Waals ferromagnet CrI3

Verena Brehm[1], Pawel Sobieszczyk[2], Jostein Kløgetvedt[1], Richard F. L. Evans[3], Elton J. G. Santos[4], Alireza Qaiumzadeh[1]

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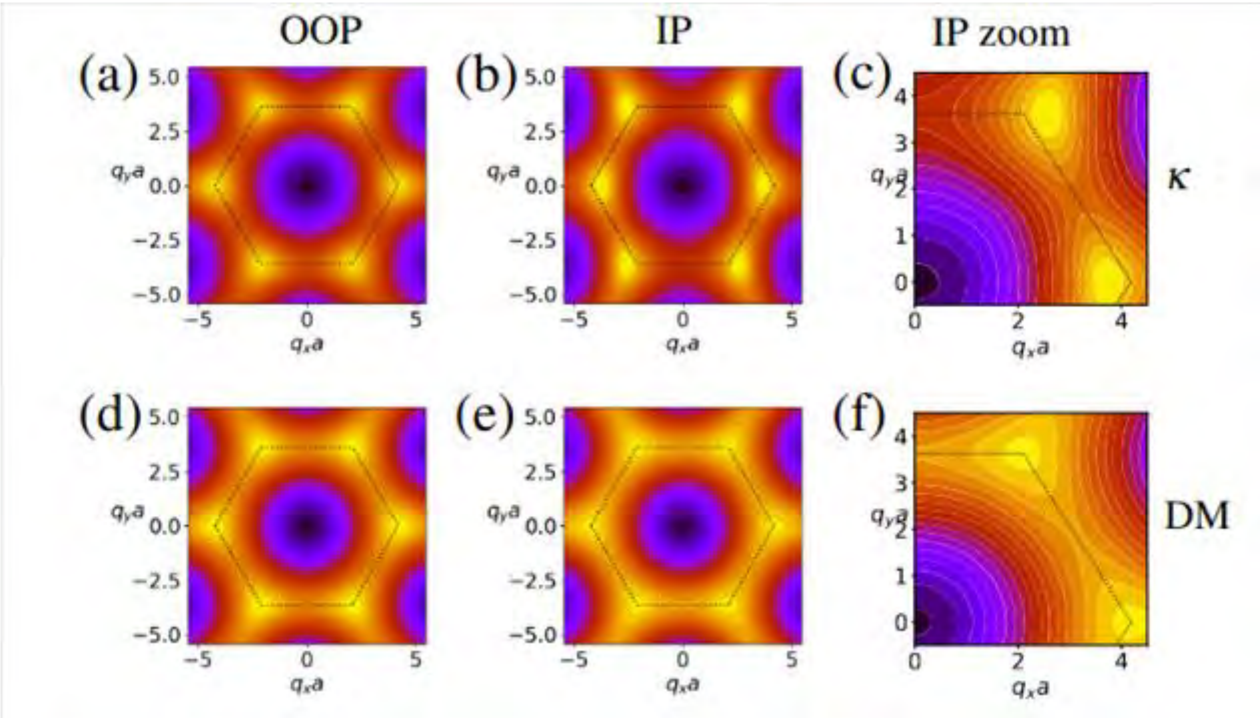
Session 8: Spintronics and 2D materials, March 26, 2024, 10:30 - 12:15

Since its discovery in 2018, the origin of the band gap in the magnon dispersion relation of the ferromagnetic van der Waals material CrI3 has been controversial. We investigate the angular magnetic field dependence of the magnon dispersion gap of a single layer CrI3 at the K-points by comparing two gap-opening scenarios; the Dzyaloshinskii-Moriya (DM) and Kitaev interactions. We implement stochastic atomistic spin dynamics simulations and linear spin wave theory and observe three distinct magnetic field dependencies between these two topological magnon gap opening mechanisms. First, we demonstrate that the Kitaev-induced magnon gap is influenced by both the direction and amplitude of the applied magnetic field, while the DM-induced gap is solely affected by the magnetic field direction. Second, our findings reveal that the position of the Dirac cones within the Kitaev-induced magnon gap shifts in response to changes in the magnetic field direction, whereas they remain unaffected by the magnetic field direction in the DM-induced gap scenario. Third, we find a direct-indirect magnon band-gap transition in the Kitaev model by varying the applied magnetic field. These differences may distinguish the origin of topological magnon gaps in CrI3 and other van der Waals magnetic layers.
Our findings pave the way for exploration and engineering topological magnets in novel magnetic van der Waals materials.



High-Fidelity, Low-Power All-Optical Magnetic Switching in Dense Nanomagnetic Networks

Dr Daniel Bromley[1], Dr Kilian D Stenning[1], Dr Alex Vanstone[1], Dr Xiaofei Xiao[1], Holly H Holder[1], Dr Jack C Gartside[1], Prof Rupert F Oulton[1], Prof Will R Branford[1]
[1]*Imperial College London, United Kingdom*

Session 7: Intelligent Computing, March 26, 2024, 10:30 - 12:15

Artificial spin systems, comprising strongly-interacting nanomagnet networks, hold significant promise for advancing information processing technologies. The realisation of efficient optical control in nanomagnets, 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 power-intensive femtosecond-pulsed lasers[2] and complex magnetic materials[3] underscore the need for a rapid and localised microstate control method across extensive nanomagnetic networks.

Building upon our prior breakthrough in nanomagnetic writing within dense square artificial spin ice (ASI) arrays[4], we present a robust, high-fidelity technique. A noteworthy observation highlights the critical role of NiFe quality in fidelity determination, even among samples with nearly identical coercive fields. Our method excels in writing different-energy magnetic states in ASI arrays with varying dimensions, laser parameters, and polarisation angles. Moreover, our approach enables reproducible intricate microstate engineering through long-chain writes. Crucially, this easily integrable technique paves the way for cost-effective, low-power, optically controlled devices, offering transformative potential in data storage, neuromorphic computation, and reconfigurable magnonic technologies.

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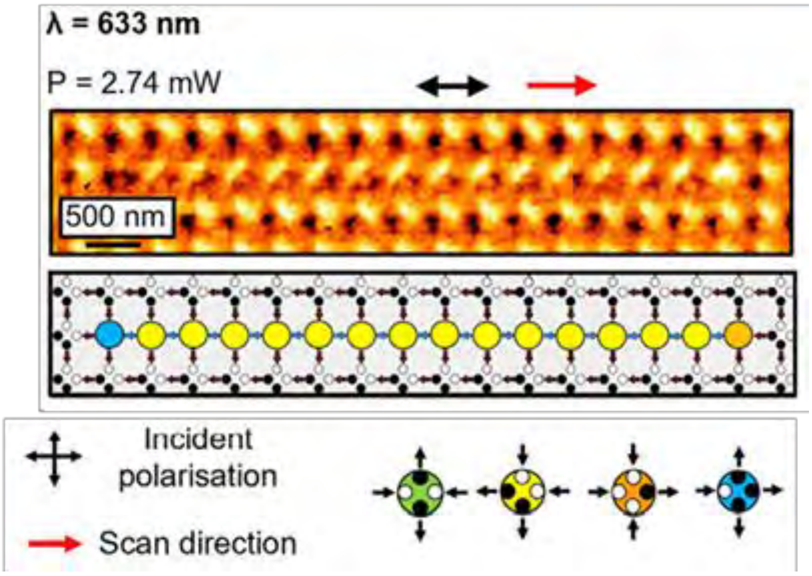

Ultrastrong Dipolar Magnon-Magnon Coupling and Magnon Frequency Combs in a Multilayered '3D' Artificial Spin Ice

Dr Jack C. Gartside[1], Dr Troy Dion, Dr Kilian D. Stenning, Dr Alex Vanstone, Ms Holly H. Holder, Ms Rawnak Sultana, Mr Ghanem Alatteili, Ms Victoria Martinez, Dr Mojtaba Taghipour Kaffash, Prof Takashi Kimura, Prof Hidekazu Kurebayashi, Prof Will R. Branford, Prof Ezio Iacocca, Prof Benjamin Jungfleisch

[1]*Imperial College London, United Kingdom*

Session 6: High Frequency Spin Dynamics, March 25, 2024, 15:30 - 17:15

Strongly-interacting nanomagnetic arrays are ideal systems for exploring the frontiers of magnonic control. They provide functional reconfigurable platforms and attractive technological solutions across storage, GHz communications and neuromorphic computing. Typically, these systems are primarily constrained by their range of accessible states and the strength of magnon coupling phenomena.

Increasingly, magnetic nanostructures have explored the benefits of expanding into three dimensions.
This has broadened the horizons of magnetic microstate spaces and functional behaviours, but precise control of 3D states and dynamics remains challenging.

Here, we introduce a 3D magnonic metamaterial(1) compatible with widely-available fabrication and characterisation techniques. By combining independently-programmable artificial spin-systems strongly coupled in the z-plane, we create a system with a rich 16^N microstate space and intense static and dynamic dipolar magnetic coupling.
The system exhibits a broad range of emergent phenomena including ultrastrong magnon-magnon coupling with normalised coupling rates of $\Delta\omega/\gamma=0.57$, GHz mode shifts in zero applied field and reconfigurable generation of magnon frequency combs.

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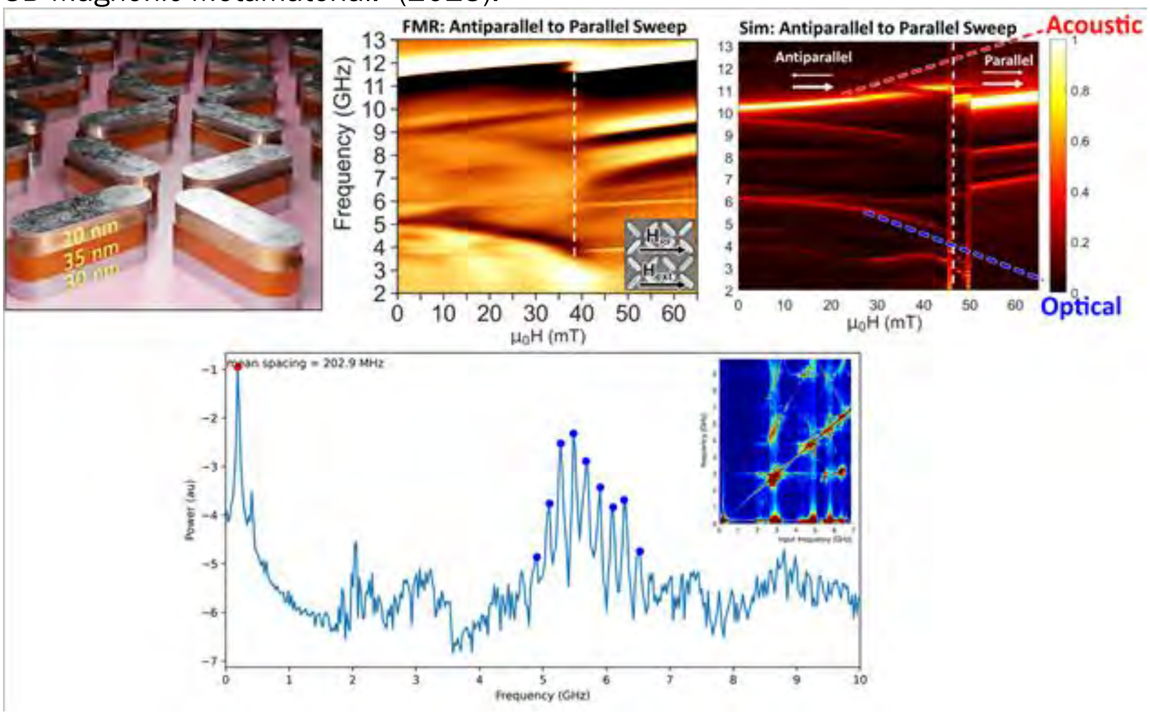


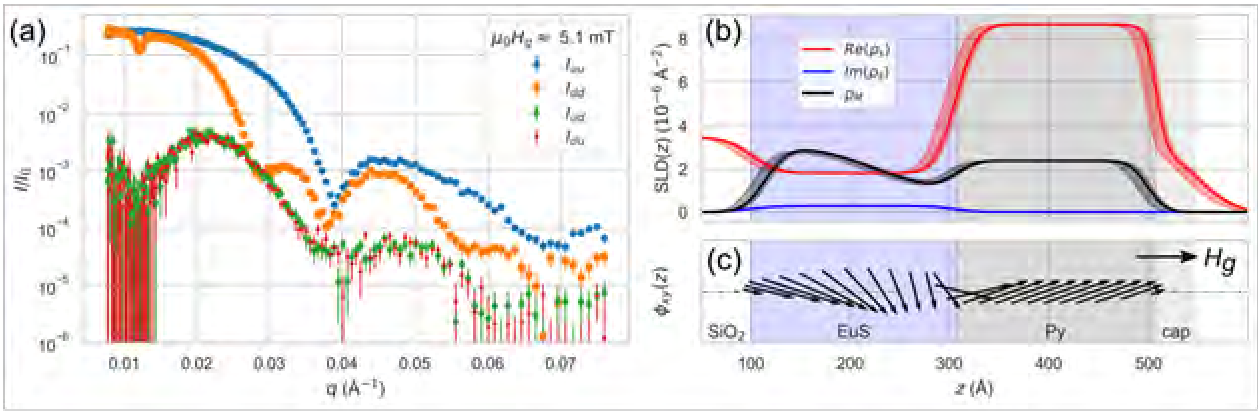
Polarised neutron reflectivity to resolve interfacial spin canting in a ferromagnetic metal-semiconductor bilayer

Dr Andrew Caruana[1], Dr Prasanta Muduli[2], Dr Hironari Isshiki[3], Dr Jorge Puebla[4], Dr Christy Kinane[1], Professor YoshiChika Otani[3], Dr Naëmi Leo[5]

[1]ISIS Neutron and Muon Source (STFC, UKRI), United Kingdom, [2]Indian Institute of Technology Madras, India, [3]University of Tokyo, Japan, [4]Center for Emergent Matter Science, RIKEN, Japan, [5]TU Wien , Austria

Session 10: Novel Techniques in Magnetism, March 26, 2024, 15:00 - 17:00

Ferromagnetic semiconductors and insulators have gained interest due to their potential to increase the efficiency of spintronic devices. This improvement arises from the fact that in insulators, such as europium sulphide EuS, spin currents and spin orbit torques do not involve dissipative charge currents, and thus avoid unnecessary losses due to Joule heating. Furthermore, crucial to developing more power-efficient nanoscale devices for practical applications based on phenomena such as magnetoresistive response, dynamic behaviour, and spin-transfer torque switching is the understanding the structural and magnetic coupling typically localised at the thin-film interface between materials e.g., between ferromagnetic insulator/ferromagnetic metal bilayers.
Inspired by interesting features found in the magnetoresistance of EuS|Py bi-layers indicating non-collinear interfacial magnetic coupling, here we present results from Polarised Neutron Reflectometry with Polarisation Analysis, taken at the POLREF beamline to investigate the in-plane canting at the EuS|Py interface as a function of depth. We found a significant neutron spin flip signal, indicating sizable spin canting in the bilayer system. From model fits to determine the depth-dependent magnetisation profile, we find that this spin canting is strongest at the EuS|Py interface and decays further away from the Py, aligning back to the applied guide field direction. At low temperatures, this canting persists for applied magnetic fields up to 75 mT, and disappears above the EuS ferromagnetic transition temperature at 16 K. The strong spin canting localised at the interface between ferromagnetic metals and insulators could therefore be interesting for spintronic applications, such as spin-transfer torque switching.



(a) Non-spin-flip and spin-flip neutron reflectometry data. (b,c) Fit results for the shown data, including depth-dependent structural and magnetic scattering length densities $\rho_s(z)$ and $\rho_M(z)$ as well as the depth-dependent in-plane spin canting $\phi_{xy}(z)$.

Nanomagnet-induced synthetic spin-orbit coupling in a hybrid superconductor-semiconductor nanowire island

Dr Malcolm Connolly[1]
[1]*Imperial College London, United Kingdom*

Session 9: Low-dimensional Magnetism, March 26, 2024, 15:00 - 17:00

Inhomogeneous magnetic fields generated by nanomagnet arrays are predicted to induce a synthetic spin-orbit interaction (SOI) in hybrid superconductor-semiconductor nanowires commonly used in the search for Majorana bound states [1]. By obviating the need for intrinsic SOI, nanomagnets could thus widen the range of materials available for realising topological superconductivity, for instance to include lower-disorder materials such as carbon nanotubes or silicon nanowires. We present conductance measurements of a proximitised Indium Arsenide nanowire fabricated adjacent to an array of nanomagnets. In the Coulomb-blockade regime we observe tunnelling resonances at low source-drain bias consistent with the presence of sub-gap Andreev bound states [2]. Using a sequence of externally applied switching fields, we verify the expected shift in bound state energy between the anti-aligned and aligned nanomagnet configuration. Our results are consistent with quantum transport simulations and demonstrate the viability of using local magnetic textures to modify SOI in hybrid superconductor-semiconductor devices.

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Time-resolved microscopy of magnetization dynamics in a 2D van der Waals magnet

Dr Maciej Dąbrowski[1], Dr Sumit Haldar[2], Dr Safe Khan[3], Dr Dimitrios Sagkovits[3], Zekun Xue[3], Charlie Freeman[3], Paul Keatley[1], Dr Ivan Verzhbitskiy[4], Prof Goki Eda[4], Prof Hidekazu Kurebayashi[3], Prof Elton Santos[2], Prof Rob Hicken[1]

[1]University Of Exeter, United Kingdom, [2]The University of Edinburgh, United Kingdom, [3]University College London, United Kingdom, [4]National University of Singapore, Singapore

Session 8: Spintronics and 2D materials, March 26, 2024, 10:30 - 12:15

Since the first observation of ultrafast demagnetization, significant progress has been made in understanding its underlying microscopic origin. In contrast, considerably less attention has been paid to remagnetization, i.e., the recovery of magnetization after exposure to an ultrafast laser pulse. Heat conduction is the primary process governing remagnetization and remains a key engineering challenge in modern electronics and spintronics. Van der Waals materials possess unique thermal properties due to the highly anisotropic nature of the bonding, and provide new opportunities for thermal control of nanoscale devices. Here we demonstrate how the temperature change induced by an ultrafast laser pulse may be controlled within the 2D magnet CGT. The response of different microscale flakes is explored by means of a time-resolved beam-scanning magneto-optical Kerr effect microscopy technique. In particular, we show that by reducing the thickness of the 2D magnet, enhanced heat dissipation into the adjacent substrate allows the timescale for the remagnetization to be decreased from several nanoseconds down to a few hundred picoseconds. Finally, we demonstrate how the low out-of-plane thermal conductivity may be exploited in retrieving the original domain structure, even after a full demagnetization. This makes thick CGT a robust magnetic domain memory under the influence of intense laser pulses, a behaviour that has so far been unachievable in other materials.

Symmetry lowering and magnetism in caesium superoxide

Russell Ewings[1], Pascal Manuel, Dmitry Khalyavin, Fabio Orlandi, Alex Gibbs, Martin Jansen
[1]*ISIS Pulsed Neutron And Muon Source, United Kingdom*

Session 10: Novel Techniques in Magnetism, March 26, 2024, 15:00 - 17:00

CsO_2 belongs to the family of alkali superoxides (AO_2, where A = Na, K, Rb, and Cs). These compounds exhibit magnetic behaviour due to open p-shell electrons on O_2- molecules. Using neutron diffraction, we elucidated the crystal and magnetic structures of CsO_2. Our observations reveal a complex series of structural changes as temperature decreases from room temperature to 1.6 K.

These include an incommensurate modulation in the crystal structure, followed by a lock-in transition that doubles the unit cell compared to the previously assumed orthorhombic unit cell. In both cases, our structural analysis indicates a staggering of caesium ion positions along the b-axis, distinct from other alkali superoxides where staggered tilts of the O_2- dimers are observed.

Below 10 K, we detected magnetic Bragg peaks and refined an antiferromagnetic structure with magnetic moments predominantly aligned along the b-axis, with a minor component along the a-axis, suggesting possible anisotropic exchange coupling.

Our recent inelastic neutron scattering measurements reveal a rich spectrum that can be explained by a strong exchange coupling along one of the body diagonals of the parent tetragonal structure. This implies that CsO_2 can be regarded as a staggered 1-dimensional spin chain, although the chain axis is perpendicular to that assumed in analysis of previous NMR and bulk susceptibility measurements.

These results point to CsO_2 being an interesting example of a structure-properties relationship, and may indicate a future avenue for engineering the anisotropic exchange needed for effects such as multiferroicity or Kitaev spin liquid physics.

Large temperature hysteresis of a MnIII spin-crossover complex with spontaneous chiral resolution

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Session 3: Spintronics, March 25, 2024, 11:45 - 13:00

Molecular materials provide an interesting playground for designing materials with different types of interactions. In the magnetic sphere, this can be used to create single molecule magnets [1], antiferromagnetic molecular films [2], and spin-crossover compounds [3]. The latter exhibit a transition between high and low spin states in response to stimuli such as temperature, light, or electric field. Possible applications include as temperature sensors, in displays and for storage of information.

Here we report on an MnIII containing spin-crossover complex with the chelating R-sal2323 ligand and an EtOH anion [4]. The complex shows a large temperature hysteresis in the S=2 to S=1 transition temperature, see Figure 1, near room temperature. Thermal hysteresis is rare in MnIII containing spin-crossover complex. Here, the hysteresis is combined with a spontaneous chiral resolution despite the lack of chirality in the anion.

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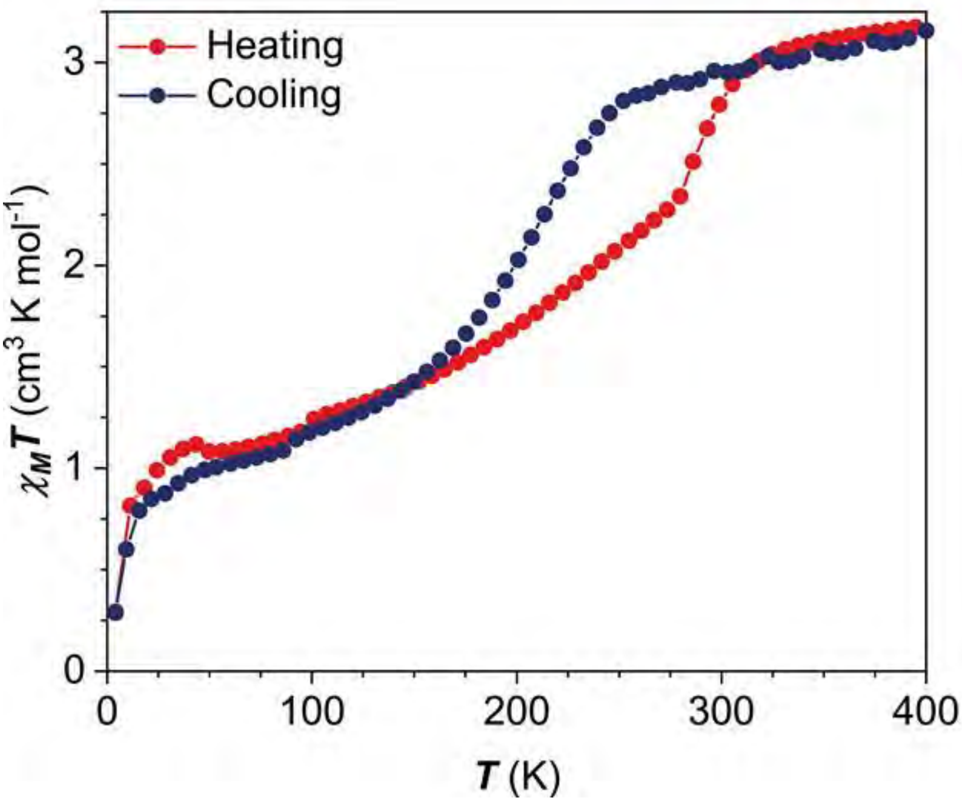

Spin Dynamics and Ultrastrong Magnon-Magnon coupling in the vdW Antiferromagnet CrPS4

Charlie Freeman[1,2], Zekun Xue[1], Goki Eda[3], Dimitrios Sagkovits[1,2], Safe Khan[1], Adam Budniak[3], Hidekazu Kurebayashi[2], Murat Cubukcu[1,2]
[1]University College London, United Kingdom, [2]National Physical Laboratory , United Kingdom, [3]National University of Singapore (NUS), Singapore

Session 8: Spintronics and 2D materials, March 26, 2024, 10:30 - 12:15

The ability to generate, transport and manipulate spin currents in 2D materials suggests that they could provide a suitable platform to build beyond-CMOS spintronic devices [1, 2]. Antiferromagnets have attracted attention in recent years due to their absence of stray fields, high intrinsic precession frequency (~THz) and high stability under magnetic fields [3].

We present a spin dynamics study of the 2D van der Waals antiferromagnet chromium thiophosphate (CrPS4), a material with layer dependent magnetic properties [4].The evolution of the FMR measurements across temperatures below the Neel transition of 38K is reported and discussed. An opening of a zero-field gap in the easy axis orientation (c-axis) is observed and its origin from orthorhombic anisotropy is shown. This orthorhombic anisotropy leads to intrinsic symmetry breaking which allows for ultrastrong magnon-magon coupling in the canted regime between the optical and acoustic resonance modes. We report the full temperature dependence of this phenomena along with determination of the magnetic parameters. Finally, we confirm that the coupling depends solely on anisotropy and saturation, offering the potential for precise control of the coupling parameter."

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Effect of the Commensurate to Incommensurate Crossover on the Magnetism in Charge-Stripe Ordered La2-xSrxNiO4

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Session 1: Correlated Systems, March 25, 2024, 10:00 - 11:15

In La-based high-temperature superconducting cuprates, superconductivity results in only a partial gapping of the magnetic excitation spectrum[1,2]. With magnetic excitations extending to lower energies in La-based cuprates, their low energy excitations bares a close similarity to those of charge-stripe ordered materials such as insulating La2-xSrxNiO4+delta, that the two materials are often compared and contrasted[3].

Our understanding of the magnetism of charge-stripe ordered La2-xSrxNiO4+delta is limited to detailed studies of the magnetic order[4-6], complemented by a limited number of studies on a limited number of doping levels of the magnetic excitations primarily at base temperatures, see for example: [7-9]. We have undertook combined neutron diffraction and inelastic scattering studies of doping levels around the commensurate third doping level. We will show how our combined systematic high resolution cold neutron scattering, and thermal neutron scattering mapping of the magnetic excitations to temperatures beyond the magnetic ordering, illuminates new understanding of the magnetic interactions of charge-stripe ordered La2-xSrxNiO4+delta. We will discuss the role of magnetism in the ordering process, beyond the role played by charge interactions [10]. Furthermore, we will discuss the role of the crossover between commensurate charge-stripe order and incommensurate charge-stripe order on the magnetic interactions of La2-xSrxNiO4+delta, with competing models proposed [11,12].

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Magnonic Fabry-Pérot resonators as programmable phase shifters and energy concentrators

Anton Lutsenko[1], Dr Kevin Fripp[2], Andrei Shytov[2], Volodymyr Kruglyak[2], Sebastiaan van Dijken[1]
[1]Aalto University, Finland, [2]University of Exeter, United Kingdom

Session 3: Spintronics, March 25, 2024, 11:45 - 13:00

Efficient control of the amplitude of spin waves propagating in YIG magnonic media is achieved using Fabry-Pérot resonances [1].The latter are formed due to spin-wave reflection from magnonic dispersion mismatches at interfaces between YIG regions with and without a metallic ferromagnet overlayer [2]. We demonstrate that such structures ('magnonic Fabry-Pérot resonators') can also serve as reprogrammable spin-wave phase-shifters. Figure 1 shows the frequency dependence of the spin-wave transmission coefficient for a Fabry-Pérot resonator (CoFeB stripe) overlaid onto a YIG film. A programmable phase shift of ~π is achieved for spin waves at ~1.25 GHz frequency controlled by the orientation of the stripe's magnetisation. Our experimental results are in a good agreement with micromagnetic simulations. The latter reveals concentration of spin-wave energy in YIG under the stripe, contrasting with spin-wave energy "trapping" in the stripe itself for chiral magnonic resonators [3]. Such a device may act as a building block in future magnonic circuitry, while the spin-wave energy concentration may be used in construction of magnonic neurons [4].

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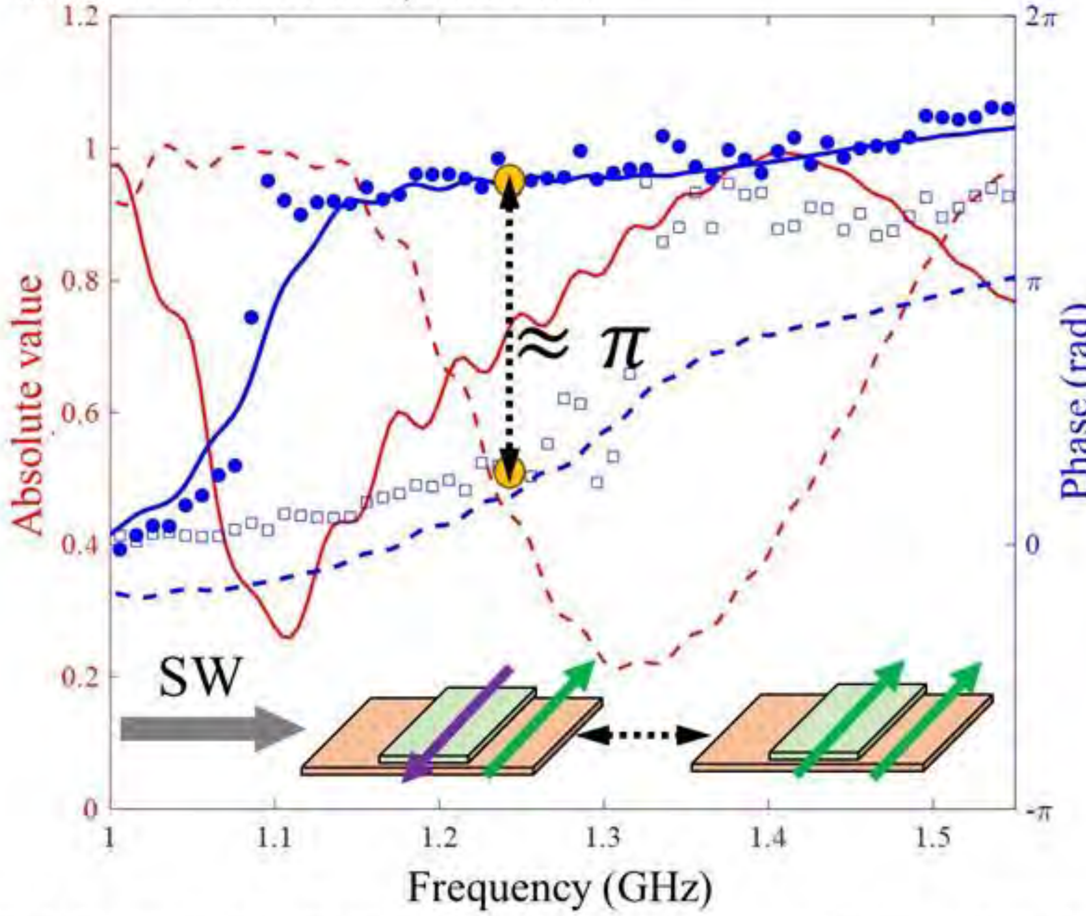

Fig. 1. The amplitude (red) and phase (blue) of the transmission coefficient are shown for a magnonic Fabry-Perot resonator in different magnetic configurations. The solid / dashed lines and filled / empty symbols correspond to the antiparallel / parallel alignments of the magnetisations in the CoFeB overlayer and YIG medium (see the insets). The lines and symbols are used for simulated and measured results, respectively.

Wurtzite MnSe - epitaxy, optical, electronic and altermagnetic properties

Dr Michał Grzybowski[1], Dr hab. Carmine Autieri[2], Dr Jaroslaw Domagala[3], Mr Cezary Krasucki[1,3], Dr Anna Kaleta[3], Dr hab. Sławomir Kret[3], Dr Katarzyna Gas[3,4], Prof. Maciej Sawicki[3], 1 Rafał Bożek[1], Dr hab. Jan Suffczyński[1], Dr hab. Wojciech Pacuski[1]

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Session 4: Thin Films II, March 25, 2024, 11:45 - 13:00

In this work we present a new candidate of recently discovered family of altermagnets, which are materials exhibiting both collinear compensated magnetic order and simultaneous spin-splitting of the bands. Uncommon, wurtzite MnSe is shown with ab initio calculations to posses altermagnetic spin-splitting of the bands. The critical temperature well above room temperature is predicted. It is the first material from such space group identified to have altermagnetic properties. Moreover, we demonstrate experimentally that it is possible to obtain thin films of the intriguing wurtzite phase of MnSe on GaAs substrates with molecular beam epitaxy. It is the proper choice of buffer layers, which play a crucial role in stabilizing the desired resulting phase. We provide a basic characterization of its structural and optical properties.

M. J. Grzybowski et al., arXiv:2309.06422.

Controlling the spin structure of antiferromagnetic NiO using a ferromagnetic layer

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[1]University of Oxford, United Kingdom, [2]Diamond Light Source, United Kingdom, [3]ISIS Neutron and Muon Source, STFC Rutherford Appleton Laboratory, United Kingdom

Session 4: Thin Films II, March 25, 2024, 11:45 - 13:00

Antiferromagnets have long lived in the shadow of ferromagnets for spintronics applications despite their advantages: They are robust against perturbations, lack magnetic stray fields, offer faster switching speeds, and have long spin diffusion distances [1]. With the discovery of spin-orbit torques and magnetoresistance effects in antiferromagnets, a path towards antiferromagnetic spintronics is now evident [2-3].

Effective control of antiferromagnetic states is essential for developing antiferromagnetic spintronic devices. In conventional spintronics, antiferromagnets are often passive elements used to “pin” a ferromagnetic layer through exchange bias [4-5]. However, we can reverse this convention to allow for control of the antiferromagnet through the ferromagnet [6].

Manipulating an antiferromagnet requires impractically large magnetic fields due to the absence of a net magnetic moment. Using x-ray absorption spectroscopy and magnetic linear dichroism, we directly probe the antiferromagnetic spin structure. We demonstrate antiferromagnetic domain switching in sputtered NiO(001) using only small magnetic fields by coupling to an adjacent ferromagnetic Co layer. We exploit the low switching fields of Co and strong exchange coupling with the NiO at the interface and find that the spin orientation of Co can imprint onto the antiferromagnet. Replacing Co with a magnetically softer material reveals a clear correlation between antiferromagnetic control and its inverse effect, i.e. exchange bias. Our work shows a clear path towards tailoring the controllability of an antiferromagnet without losing its magnetic stability.

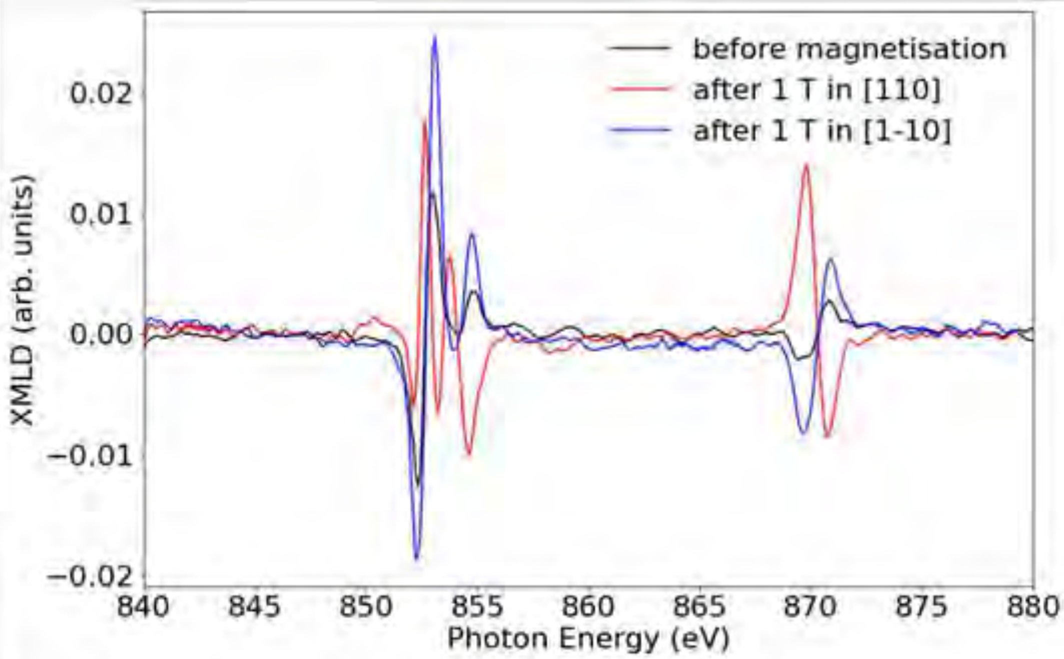

Figure 1: X-ray magnetic linear dichroism (XMLD) spectra at the Ni-$L_{3,2}$ edges of our MgO(001)/NiO (22.8 nm)/Co (2.7 nm)/Pt (1.5 nm) sample before magnetisation (black) and after application of a 1 T magnetic field in the two easy anisotropy directions of the antiferromagnet (red/blue). The sample normal was oriented parallel to the beam direction, with the linear horizontal and vertical x-ray polarisations aligned with the two easy anisotropy directions. The total electron yield signal is shown.

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All-optical & surface-probe control of chiral spin textures in artificial spin ice

Miss Holly Holder[1], Dr. Jack C Gartside[1,2], Dr. Alex Vanstone[1], Dr. Kilian Stenning[1,3], Dr. Xiaofei Xiao[1], Professor Rupert Oulton[1], Professor Will Branford[1,2]
[1]Blackett Laboratory, Imperial College London, United Kingdom, [2]London Centre for Nanotechnology, Imperial College London, United Kingdom, [3]London Centre for Nanotechnology, University College London, United Kingdom
Session 10: Novel Techniques in Magnetism, March 26, 2024, 15:00 - 17:00

Artificial spin-vortex ice (‘ASVI’) is a reconfigurable metamaterial tailored to support both Ising macrospin and vortex textures, providing an excellent platform for the realisation of neuromorphic computation[1]. Here we demonstrate two techniques for precise ASVI vortex seeding and control, and then use these techniques to reconfigurably customise ASVI, tailoring systems to have multi-level local switching fields.

We present all-optical seeding of double vortices via tightly-focussed illumination from a linearly-polarised λ=633nm laser spot at powers ≤5mW. Bar subsets can be selectively activated via laser polarisation, with bars preferentially turning into double vortices when the linear polarisation of the laser aligns with the short axis (in contrast to all-optical macrospin switching[2]). We present statistical results from investigations exploring the effect of laser polarisation on selectivity, and discuss the effect of initial saturation direction on double vortex chirality. We also utilise the moving magnetic tip procedure, using it to ‘write’ chains of vortices into our ASVI system, with control over vortex chirality provided by the location of the tip with respect to the bar centre, affirming the results of previous micromagnetic studies[3].

Finally, we tailor and explore the customisable energy landscape of the system, with the different switching fields for macrospins, single vortices, and double vortices allowing for rich, emergent textural dynamics in this highly customisable multi-level system.

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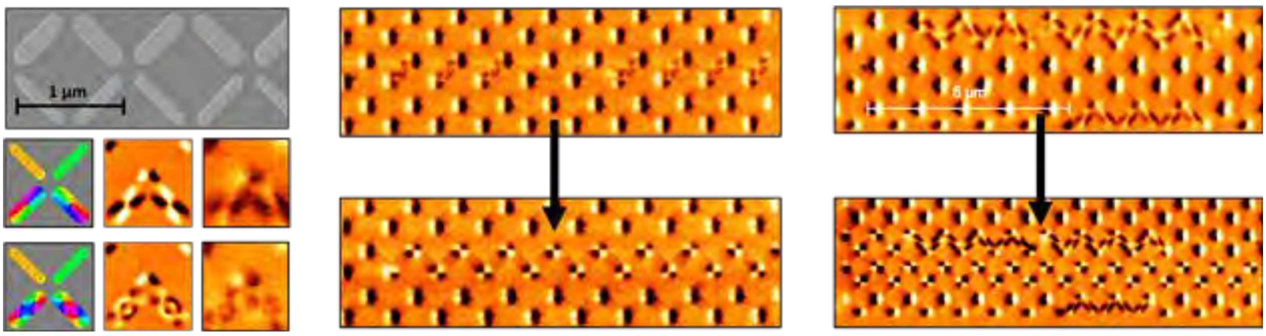

Temperature gradient-drive motion of magnetic domains in a chiral magnetic metal multilayer

Lin Huang[1], Nathan Satchell[1], Philippa M. Shepley[1], Lekshmi Kailas[1], Golam Hafiz[1], Simon D. Cornell[1], Gavin Burnell[1], Christopher H. Marrows[1]
[1]*University of Leeds, United Kingdom*

Session 4: Thin Films II, March 25, 2024, 11:45 - 13:00

Magnetic textures can be set in motion by spin-transfer torques arising from spin currents, which usually arise from spin-polarised electrical currents [1,2]. Nevertheless, a magnonic spin current will also flow down a temperature gradient from hot to cold owing to the spin Seebeck effect. Whilst thermal skyrmion motion has previously been observed in metals [3,4], the motion of a domain wall has only ever been reported in the magnetic insulator, YIG [5].
We studied the displacement of magnetic domains under temperature gradients in Ta/[Pt/Co68B32/Ir]10/Pt multilayer tracks with microfabricated Pt heaters/thermometers. The locations and sizes of the domains were measured by magnetic force microscopy (MFM). As shown in Fig. 1, when the temperature difference between the heater and the room temperature is larger than 65 °C (30 mA heater current), the domains start moving forward to the hot region. The direction of domain motion is the same for -30 mA heater current, although the motion is slower.
The different domain velocity can be explained by an Oersted field contribution from the heater current that enhances or opposes thermally driven motion. Subtracting out the effects of the Oersted field reveals the pure temperature gradient-driven motion, as shown in Fig. 2. The larger the thermal gradient along the track (owing to proximity to the heater or larger heater currents), the larger observed displacements of the domains. Our results show that temperature gradient-driven domain motion is possible in metals as well as insulators, and may prove useful for scavenging waste heat in spintronic devices.

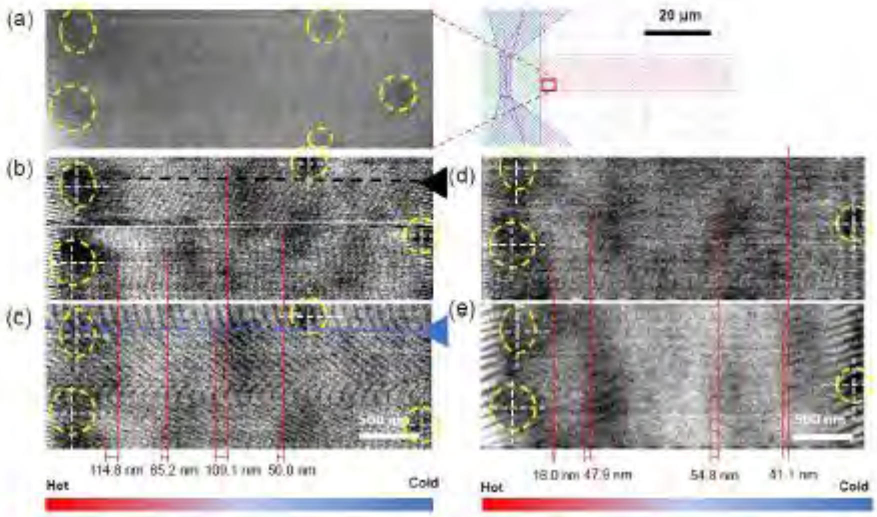

Fig. 1 (a) The MFM image when the track is fully saturated with 700 Oe and the dark regions in the dash yellow circles are the defects on the track surface. The right-hand side is a schematic showing the magnetic track (red), heater (blue) and insulating oxide between them (green). The region imaged by MFM is indicated by the red box. (b)-(c) are the MFM images in 30 Oe before and after +30 mA current applied to the heater for two minutes, respectively. (d)-(e) MFM image in 30 Oe before and after -30 mA current applied to the heater for two minutes, respectively.

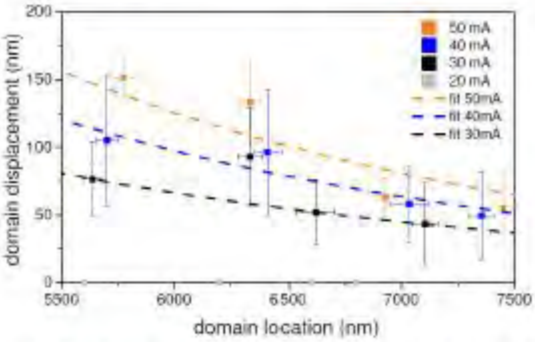

Fig 2. The average domain displacement driven by varying positive and negative heater currents at different distances from the heater, with exponential fits.

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Electronic structure and magnetocrystalline anisotropy of W-type SrFe18O27 hexaferrite

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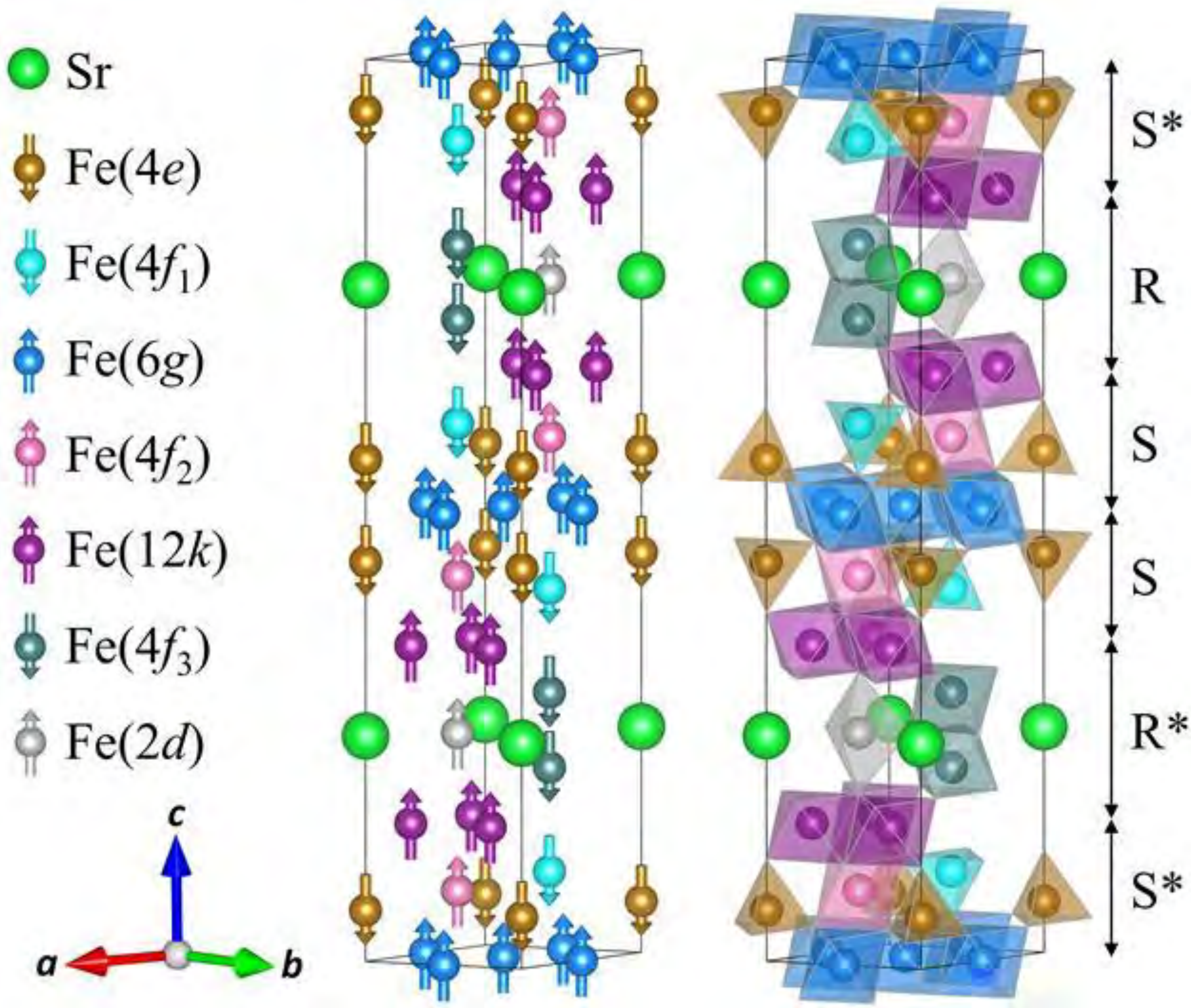
[1]*Aarhus University, Denmark*

Session 5: Computation and theory, March 25, 2024, 15:30 - 17:15

Extending the range of superior permanent magnets will ease supply strain on the present rare-earth-based permanent magnets. The hard-magnetic properties of rare-earth magnets are unrivaled, however, the search for alternatives is still of the utmost importance, especially for those that contain little to no rare-earth elements. W-type SrFe18O27 hexaferrite has received a lot of attention as a prospective "gap" magnet due to its high magnetization and unique magnetic properties, with appreciable magnetocrystalline anisotropy energy (MAE) derived from the seven magnetic sublattices of Fe cations. Here, we report first-principles density functional theory calculations of the electronic structure and intrinsic magnetic properties of SrFe18O27 (SrW), SrNi2Fe16O27 (SrNW), SrZn2Fe16O27 (SrZW) and SrNiZnFe16O27 (SrNZW) hexaferrite compounds. The MAE constant Ku of the SrW, SrNW, SrZW and SrNZW hexaferrites are computed, and examined based on the electronic structure and evaluated individual contribution of different Fe sublattices. The calculated Ku values indicate that the compounds are uniaxial with easy axis along the (001) direction. Detailed analysis of the electronic structure reveals that MAE is significantly influenced by orbital distortion. The results highlight the challenge of simultaneously enhancing Ku and magnetization Ms in W-type hexaferrite compounds. However, SrZW compounds show intriguing properties with moderate Ku and high Ms values, which may outperform the conventional M-type ferrite magnets in some applications. This work is supported by the Independent Research Fund Denmark – Green Transitions COMPASS project (1127-00235B) and Computational resources are provided by DeiC National HPC (g.a. DeiC-AU-N2-2023011 and DeiC-AU-L5-0010).



Sr
Fe(4e)
Fe(4f1)
Fe(6g)
Fe(4f2)
Fe(12k)
Fe(4f3)
Fe(2d)
c
a
b
S*
R
S
S
R*
S*

The Impact of Local Strain Fields in Non-Collinear Antiferromagnetic Films

Dr Freya Johnson[1], Frederic Rendell-Bhatti[2], Bryan Esser[3], Aisling Hussey[4], David W. McComb[5], Jan Zemen[6], David Boldrin[2], Lesley Cohen[7]
[1]University of Cambridge, United Kingdom, [2]University of Glasgow, United Kingdom, [3]Monash University, Australia, [4]Trinity College Dublin, Ireland, [5]The Ohio State University, USA, [6]Czech Technical University in Prague, Czech Republic, [7]Imperial College London, United Kingdon

Session 4: Thin Films II, March 25, 2024, 11:45 - 13:00

Antiferromagnets hosting structural or magnetic order that breaks time reversal symmetry are of increasing interest for ‘beyond von Neumann computing’ applications because the topology of their band structure allows for intrinsic physical properties, exploitable in integrated memory and logic function. One such group are the non-collinear antiferromagnets, which we have shown demonstrate an enhanced optical and electronic response due to non-zero Berry curvature. [1,2] In order to experimentally realise these effects, the existence of small net moments found routinely when the material is synthesised in thin film form have been considered to be essential, as they allow for domain manipulation in applied magnetic field. These net moments have been attributed to symmetry-breaking caused by spin canting, either from the Dzyaloshinskii–Moriya interaction or from strain. However, although the spin arrangement of these materials makes them highly sensitive to strain, [3,4] there is little understanding about the influence of local strain fields caused by lattice defects on global properties, such as magnetisation and anomalous Hall effect.

In this talk I will investigate this premise, by examining non-collinear films that are either highly lattice mismatched or closely matched to their substrate. In either case, edge dislocation networks are generated and for the former case these extend throughout the entire film thickness, creating large local strain fields. These strain fields allow for finite intrinsic magnetisation in seemly structurally relaxed films and influence the antiferromagnetic domain state and the intrinsic anomalous Hall effect.

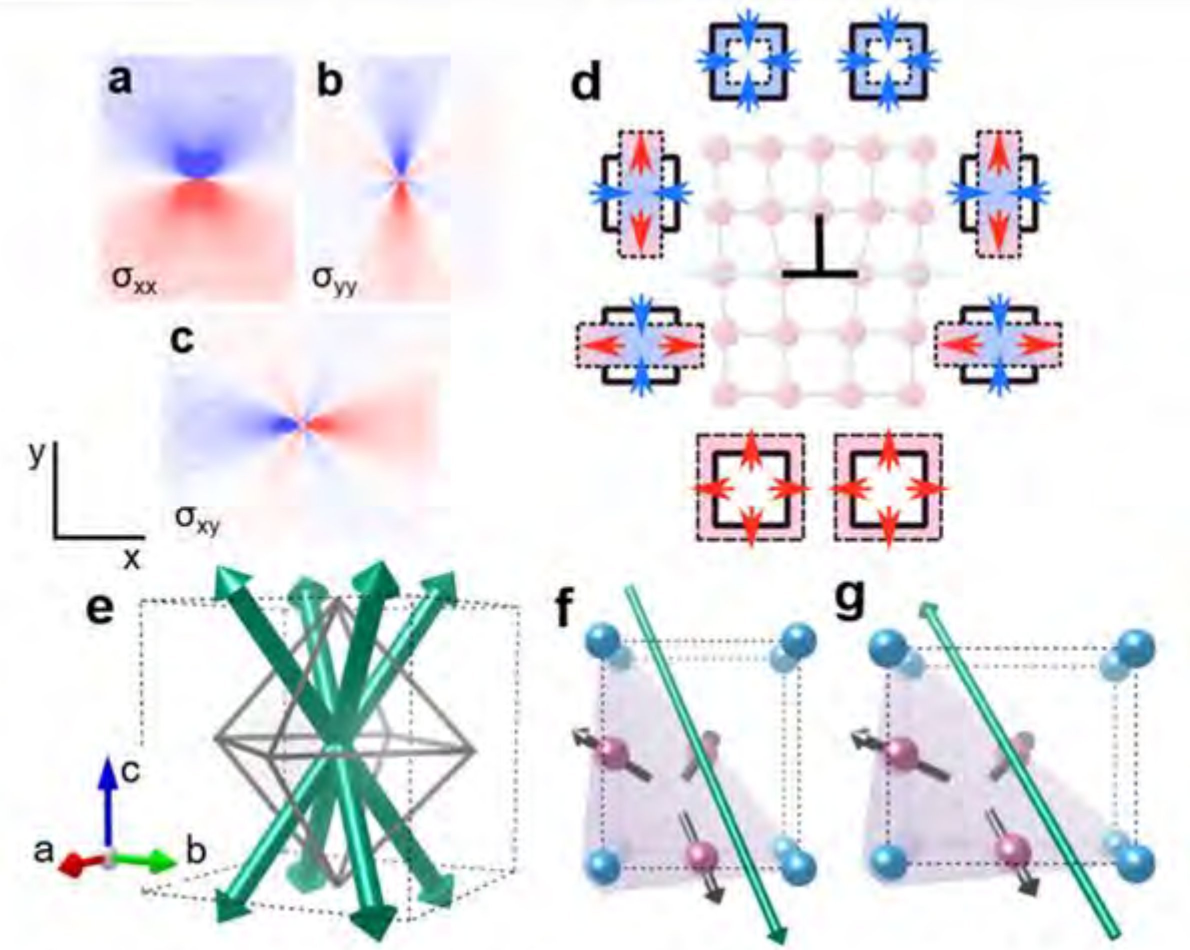


Figure 1. a,b,c) Components of the stress tensor surrounding an edge dislocation. d) Schematic of tetragonal distortions created from the stress field of an edge dislocation. e) Illustration of the possible piezomagnetic moments produced from tetragonal strain. f,g) The piezomagnetic moment for a fixed antiferromagnetic domain state may be reversed by reversing the tetragonality i.e. going from $c/a > 1$ to $c/a < 1$.

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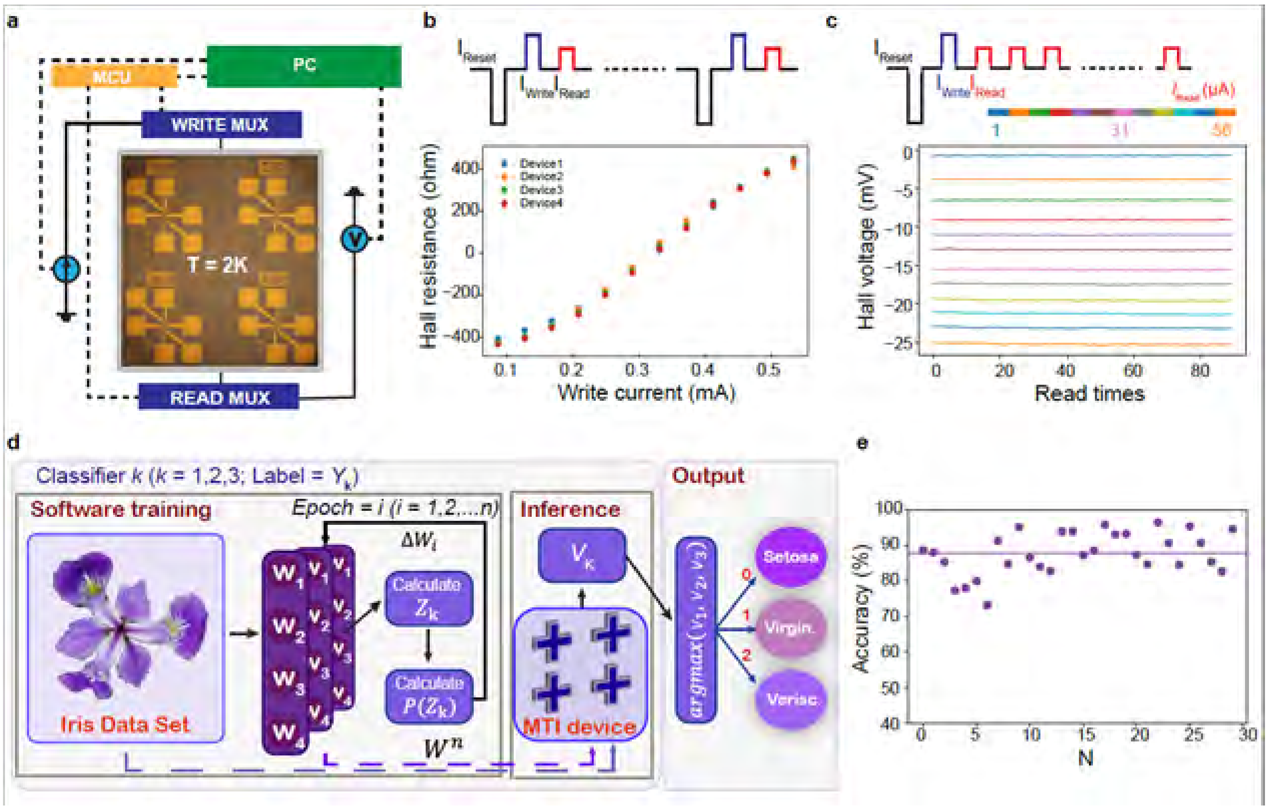
Cryogenic in-memory computing using giant and tunable anomalous Hall effect in magnetic topological insulators

Yuting Liu[1], Albert Lee[3], Kun Qian[2], Peng Zhang[3], Zhihua Xiao[2], Haoran He[3], Zheyu Ren[2], Shun Kong Cheung[2], Ruizi Liu[2], Yaoyin Li[1], Xu Zhang[2], Zichao Ma[2], Jianyuan Zhao[1], Weiwei Zhao[1], Guoqiang Yu[4], Xin Wang[5], Junwei Liu[2], Zhongrui Wang[6], Kang L. Wang[3], Qiming Shao[2]

[1]Harbin institute of Technology, China, [2]The Hong Kong University of Science and Technology, China, [3]Univeristy of California, USA, [4]University of Chinese Academy of Sciences, China, [5]The City University of Hong Kong, China, [6]The University of Hong Kong, China

Session 9: Low-dimensional Magnetism, March 26, 2024, 15:00 - 17:00

Cryogenic in-memory computing holds the promise of energy-efficient hardware implementation for machine learning algorithms, particularly for crucial quantum computation tasks like quantum error correction[1] and quantum control[2]. However, achieving this requires the development of energy-efficient memristors that can operate at deep cryogenic temperatures, specifically at or below the temperature of liquid helium (4.2 K), a challenge that has yet to be overcome. Magnetic topological insulators are promising candidates due to their tunable magnetic order by electrical currents with high energy efficiency[3,4]. Here, we build magnetic topological memristors and introduce a cryogenic in-memory computing scheme based on the coexistence of the chiral edge state and the topological surface state. We achieve high accuracy in a proof-of-concept classification task using four magnetic topological memristors. Furthermore, our algorithm-level and circuit-level simulations of large-scale neural networks based on magnetic topological memristors demonstrate a software-level accuracy and lower energy consumption for image recognition and quantum state preparation compared with existing magnetic memristor and CMOS technologies. Our results not only showcase a new application of chiral edge states besides their applications in topological quantum computing, resistance standards, and dissipationless interconnects, but also may inspire further topological quantum physics-based novel computing schemes.



Direct measurement of spin signal in a two-dimensional device

Amir Mehrnejat[1], Dr Mark C Rosamond[2], Dr Fasil Dejene[1]
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Session 8: Spintronics and 2D materials, March 26, 2024, 10:30 - 12:15

Utilizing two-dimensional (2D) materials in spintronic applications has been a focus of extensive studies.[1] The versatility and the great number of members in the 2D materials family have led to the realization of devices that are enhancing effective manipulation of the spin information and exploring properties like spin diffusion length and spin lifetime. In all such spintronic devices, the methodology employed for injection and detection of the spin is of paramount importance with the nonlocal spin valve configuration being the standard method.[2] In 2D materials with strong spin-orbit coupling (SOC), the direct injection and detection of spin current is of significant challenge due to the short spin diffusion length in these materials. Here, we report on directly measuring the charge current induced spin signal in the topological candidate Weyl semimetal WTe2 and provide an alternative way of characterising the spin-orbitronic properties. We present the efficacy of the measurements in various temperatures. Such observations are promising for quantifying the spin-driven applications as in next-generation memory devices.

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Precise transport of skyrmions by surface acoustic waves

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Session 5: Computation and theory, March 25, 2024, 15:30 - 17:15

Magnetic skyrmions are topologically protected spin structures that are promising candidates for magnetic memory and logic devices. Skyrmions present undesired Hall-like motion, complicating the device design. Therefore, developing ways to transport skyrmions in a straight line is of significant interest [1,2]. Here we investigate the transport of skyrmions by surface acoustic waves (SAWs) via several modalities in a field/current-free fashion using micromagnetic simulations. The schematic diagram of the proposed device is shown in Fig. 1. A Co/Pt thin film with perpendicular magnetic anisotropy (dimensions $1024 \times 256 \times 1$ nm^3 employing repeated boundary conditions) is coupled to a lithium niobate substrate surrounded by two pairs of interdigitated transducers (IDT), which can generate SAWs with wavelengths of 512 nm and 64 nm, respectively. SAWs with different propagation modes can be achieved by applying RF signals to one or more IDTs. We demonstrate skyrmion pinning sites created at anti-nodes [2][3] of standing SAWs (Fig. 2a) and skyrmion Hall-like motion without pinning driven by travelling SAWs (Fig. 2b). We also show how orthogonal SAWs formed by combining a longitudinal travelling SAW and a transverse standing SAW can be used for the precise 2D positioning of skyrmions due to the balance of the SAW-induced forces acting on the skyrmion. Our results suggest SAWs offer a viable approach for the precise transport of multiple skyrmions along a multichannel racetrack.

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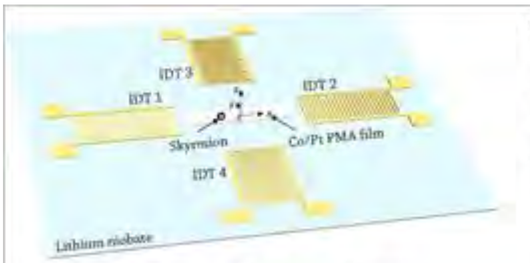

Figure 1. Diagram of the proposed device.

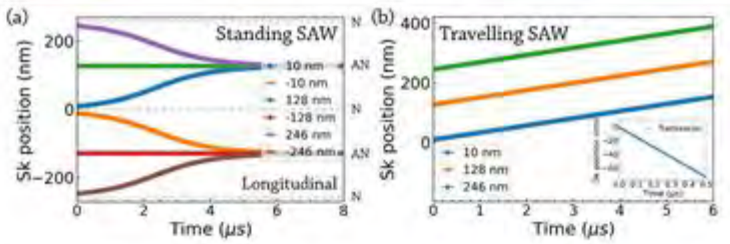

Figure 2. (a) Translation of skyrmion in the longitudinal direction in the presence of the standing SAW. (b) Translation of skyrmion in the longitudinal direction and transverse direction (insert graph) in the presence of the travelling SAW.

Enhancement of spin Seebeck effect in Fe3O4/Pt thin films and bulk composites

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Session 3: Spintronics, March 25, 2024, 11:45 - 13:00

The spin Seebeck effect (SSE)[1] is defined as the generation of spin accumulation in a magnetic material (such as Co2MnSi, YIG, or Fe3O4) in response to a temperature gradient. It is often characterised by measuring the voltage generated in an adjacent, non magnetic (NM) layer such as Pt, where the inverse spin Hall effect (ISHE) results in a measurable voltage proportional to the spin current injected into the NM layer[2].
From a fundamental standpoint, there are challenges in separating the voltage generated due to spin Seebeck effect from other effects such as the anomalous Nernst and proximity induced anomalous Nernst effects. In addition, where the spin Seebeck coefficient is determined in this way it will be impacted by any small changes at the interface of the ferromagnet (FM)/PM bilayer that impact on the efficiency of spin injection.
With regards to application as a potential thermoelectric, routes to maximise the power generated are desirable. This can include modifying the FM/PM interface, or creating multilayer[3] or composite[4] devices that scale up the voltage generation further.
We will discuss results of a series of SSE measurements of Fe3O4/Pt where: (1) we determine the optimum lengthscale of the FM layer by SSE and inelastic neutron scattering[5]; (2) we observe a 64% increase in the spin Seebeck coefficient with inclusion of Fe nanodroplets at the FM/PM interface (Figure 1)[6]; and (3) we observe an order of magnitude increase in the power factor generated by bulk composite pellets compared to thin film (Figure 2).

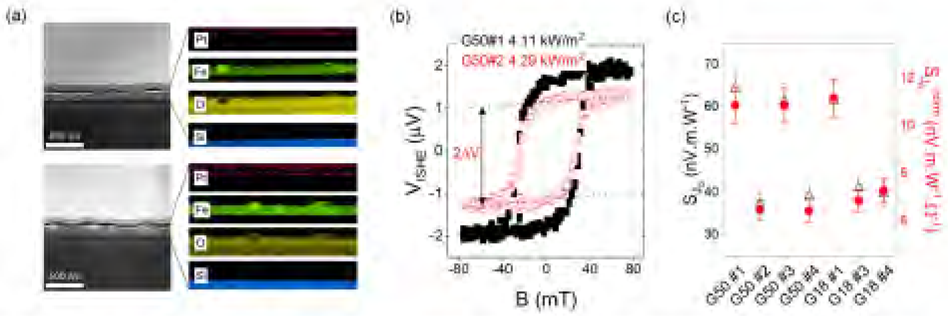

Figure 1 - Summary of the effect of Fe nanodroplets at the interface of Fe_3O_4/Pt thin films, on the measured spin Seebeck effect. (a) Representative darkfield TEM for low density (G50#2, top) and high density (G50#1, bottom) nanodroplets. (b) Raw spin Seebeck measurements for samples shown in (a). (c) Spin Seebeck coefficient of G50 and G18 series, demonstrating enhancement of voltage generated per unit Watt for samples with increased Fe nanodroplets.

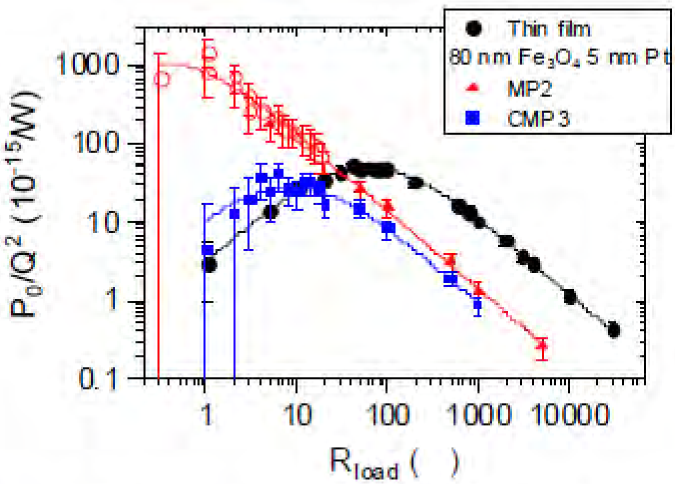

Figure 2 - Power factor measurements of thin film and bulk composite Fe_3O_4/Pt, where MP2 was a bulk pellet prepared from co-precipitated Fe_3O_4 and Pt nanoparticles and CMP3 was a bulk pellet prepared from 50-100 nm Fe_3O_4 nanoparticles and Pt powder purchased from Sigma Aldrich.

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Kondo spin lattice signatures on interface of epilayer platinum/cobalt stacks and organic molecules

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Session 9: Low-dimensional Magnetism, March 26, 2024, 15:00 - 17:00

A lattice like ordering of molecules has been observed in both metal-C60 and metal-phthalocyanine interfaces, with a band dispersion imaged for the former, through ARPES experiments[1], and a significant enhancement of well-known single ion Kondo effect reported in the latter, through scanning tunnelling spectroscopy experiments[2]. Despite the above observations, recent magnetometry or transport experiments on metal-organic molecule interface report physical effects predominantly due to a spin-polarised charge transfer[3], or due to a single-ion Kondo effect[4]. We show that, the interface effects due to molecules for the case of epilayer platinum/cobalt films grown, possessing perpendicular magnetic anisotropy, are strong enough to flip magnetisation into planar orientation once the temperature is lowered. Further understanding gained by XMCD/XAS and transport experiments hint at a temperature dependent phase transition at the cobalt-molecule interface, suggesting a physical mechanism that goes beyond spin polarised charge transfer, with spatially ordered molecules on the metal surface interacting collectively to form a lattice of polarised spins that tilts the perpendicular magnetic anisotropy into a planar orientation at lower temperatures.

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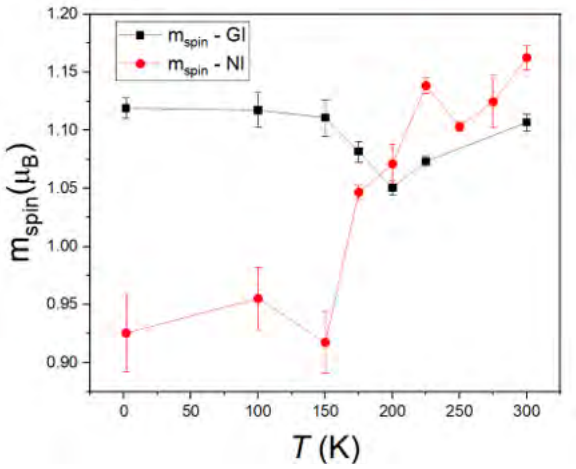

Low field spin wave resonance of Yttrium Iron Garnet stripe domains

Daniel Prestwood[1,2], Kilian Stenning[2], Tianyi Wei[1], Jack Gartside[2], Oscar Lee[1], Takashi Kikkawa[5], Eiji Saitoh[3,4,5,6], Troy Dion[7], Yves Henry[8], Daniel Stoeffler[8], Matthieu Bailleul[8], Will Branford[2], Hidekazu Kurebayashi[2,4,9]

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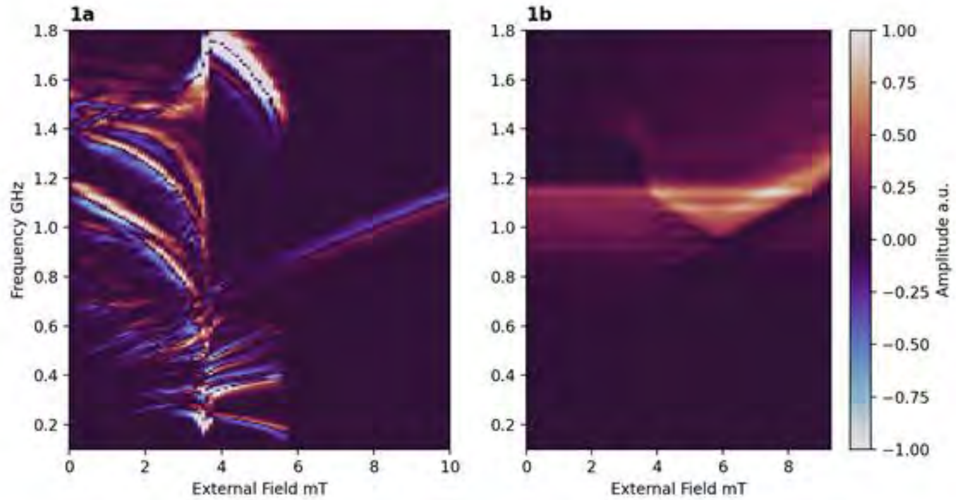
Session 6: High Frequency Spin Dynamics, March 25, 2024, 15:30 - 17:15

Yttrium Iron Garnet (YIG), an insulating ferrimagnet, has historically been a material of great interest for research into magnetisation dynamics. YIG's extremely low intrinsic damping (10^-3 – 10^-5) allows for a particularly long spin wave propagation length. This property opens opportunities for low power signal transmission ,circumventing Joule heating, in addition to novel forms of signal processing through magnon-magnon and magnon-photon coupling. While many applications require large magnetic fields to saturate the magnetic state, applying small fields (<10mT) allows for reduced energy consumption and may also lead to dynamic behaviour that proves more beneficial for a variety of applications.

Here, we show the complex low field (<10mT) spin wave resonances (Figure 1a-b) of a 5μm thin film of YIG and demonstrate their origin to be the magnetic stripe domain structure that forms below ~5mT. We also show how the striped reorient under the application of a small external field as shown by magnetic force microscopy measurements (Figure 2a-e). Additionally, we demonstrate how the spin wave resonant modes are altered depending of the angle between stripe domains and the radio frequency excitation field, allowing for a highly tuneable set of resonant modes. This may prove useful for neuromorphic computation as the domains have a memory, by their orientation, of the previous field applied.

We use Mumax3 simulations to, in part, confirm the attribution of the complex resonances to stripe domain structure (Figure 3a-d) although some aspects of the resonant spectrum remain unexplained by the simplified model.


1a
1b
Frequency GHz
External Field mT
Amplitude a.u.
1.00
0.75
0.50
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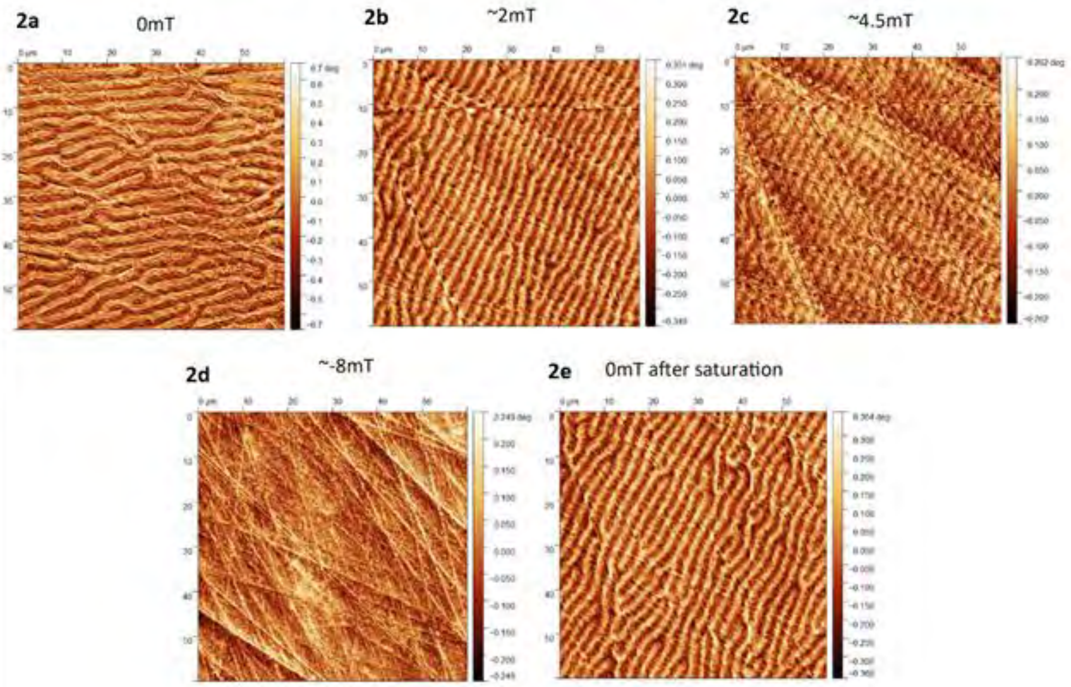
2a
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2c
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2d
~-8mT
2e
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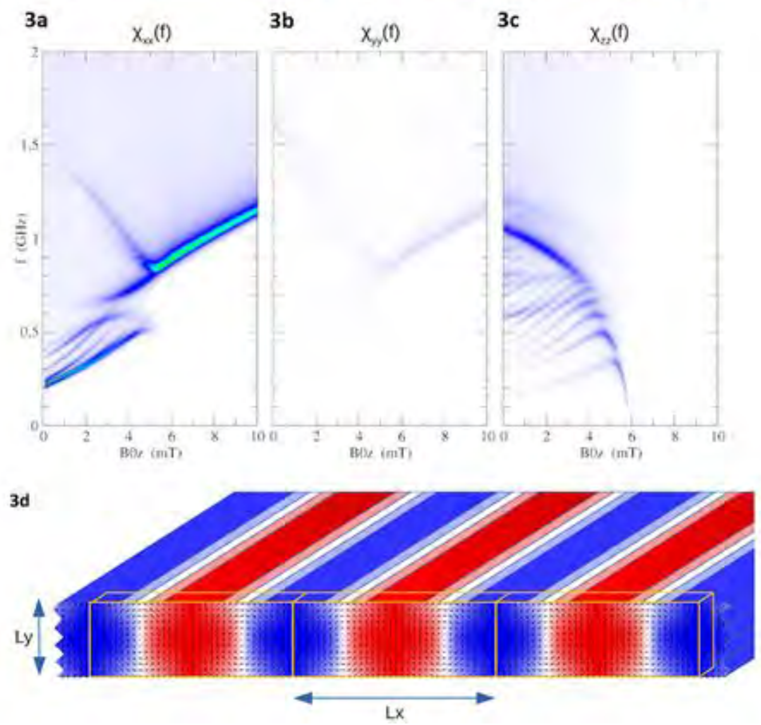
3a
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3c
f (GHz)
B0z (mT)
3d
Ly
Lx

Indirect Observation of Interlayer Coupling in Pt through Proximity-Induced Magnetization as a function of Pt Thickness in FM/Pt/FM Structure

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[1]Durham University, United Kingdom, [2]Advanced Photon Source, Argonne National Laboratory, USA, [3]University of Warwick, United Kingdom, [4]Institute of Molecular Physics, Polish Academy of Sciences, Poland

Session 2: Thin Films I, March 25, 2024, 10:00 - 11:15

Proximity-induced magnetization (PIM) plays a crucial factor in promoting interlayer coupling in Ferromagnet (FM)/Heavy Metal (HM)/Ferromagnet (FM) systems, where the HM materials approaching the Stoner Criterion, such as Pt and Pd [1-4]. PIM typically arises from d-d orbital hybridization in alloys or at the FM/HM interface, inducing spin polarization in HM. Although Pt PIM has been presumed short-range [4], recent discoveries [5] suggest that polarized Pt moments can interact, enabling long-range coupling [6], particularly when PIM occurs at both interfaces in FM/Pt/FM structures. As the strength of PIM is proportional to exchange coupling [4], investigating PIM strength serves as an indicator of the interlayer coupling.
We explored the interlayer coupling by examining the PIM profile in a CoFe/Pt/Co/Pt system using X-Ray Magnetic Circular Dichroism (XMCD) and X-ray Resonant Magnetic Reflectivity (XRMR) techniques measured at the Pt L3-edge. Figure 1(a) depicts sample structures grown using magnetron sputtering, featuring a wedge-shaped Pt1 of thickness from 2 to 10 nm. Figure 1(b) shows the captured XMCD data, revealing the total Pt PIM increases as the separation of two FM interfaces decreases. XRMR analysis, as shown in Figure 2, further shows an enhancement Pt PIM at the FM1/Pt1 interface for separation. Significantly, the interaction between the two interfaces persists up to 7 nm, which contrast with previous studies below 2.2 nm [3] and 5.3 nm [7] of the Pt layer. This observation is critical considering the crucial role of interlayer coupling in spintronic devices, such as in controlling domain wall mobility [7-9].

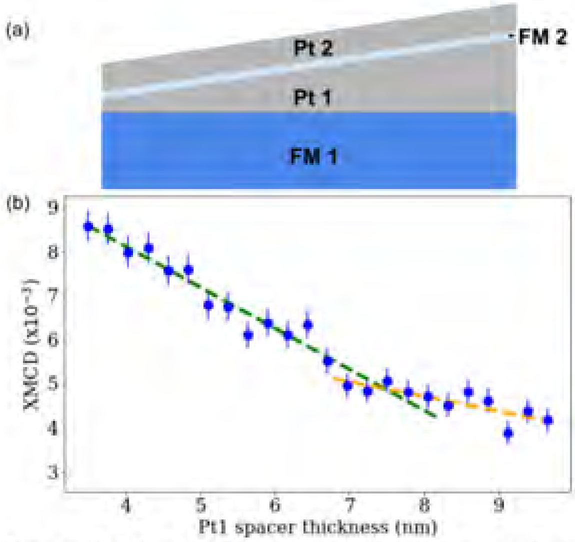

Figure 1.(a) sample structure with a wedge-shaped Pt thickness and an inserted FM2 layer. (b) XMCD signals at Pt L_3-edge plotted against Pt1 thickness, providing a comprehensive view of the relationship between Pt thickness and XMCD signals.

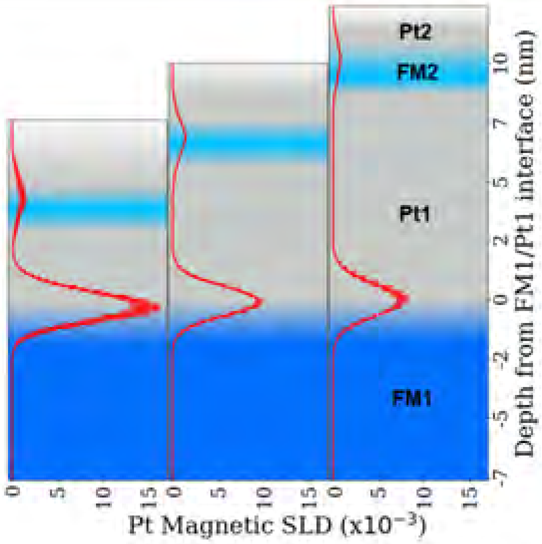

Figure 2. XRMR derived Pt magnetic Scattering Length Density (mSLD) profiles (red) for three different Pt1 thickness between FM1 and FM2 layers.

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Monitoring Ionic Diffusion from CoB in Molecular layers

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Session 9: Low-dimensional Magnetism, March 26, 2024, 15:00 - 17:00

Molecular layers have been used to manipulate magnetic properties of thin films [1]. We explore the possibility of using molecular thin films as a host for ionic diffusion and consequently as a way to control the magnetic properties of a ferromagnetic alloy. Molecular materials offer an alternative to ionic liquids for electrical control magnetism with the advantages of ultra-high vacuum deposition and greater functional temperature ranges [2]. We investigate this by annealing trilayers of C60/CoB/C60 in which we anticipate Boron ions to diffuse into the C60 molecular layer. Using Polarised Neutron Reflectivity (PNR), we can observe the changes in the nuclear and magnetic structure of the sample due to the annealing process. PNR measurements were performed at ISIS Neutron and Muon source using the POLREF beamline with an in-situ vacuum anneal capability [3]. After annealing the Boron composition of the CoB layer is reduced and the magnetisation increases. In the C60 layers, we observe Boron rich regions close to the top and bottom interfaces. SQUID measurements show further evidence of Boron migration as the magnetic moment increases significantly during annealing. These results are a promising basis for the use of C60 in thin film ionic molecular batteries and as a means to control magnetic properties through ionic diffusion. We have also investigated the potential reversibility of this affect by the application of voltages.
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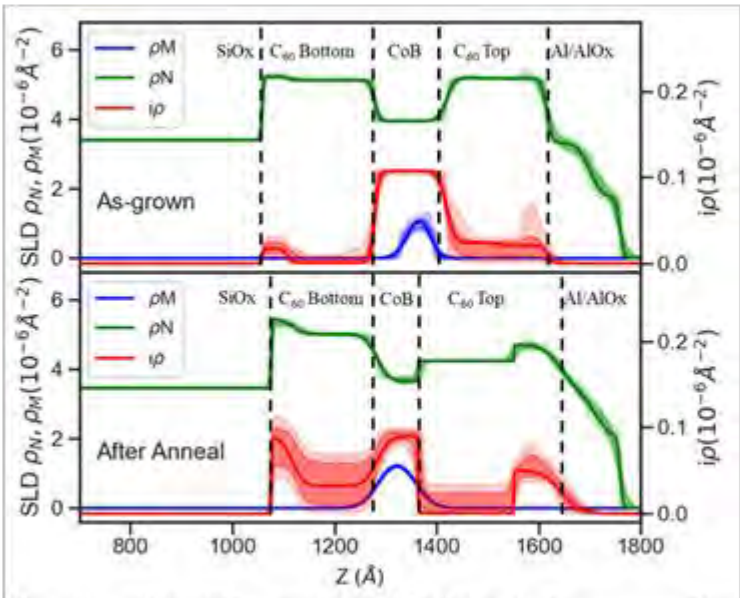

Figure 1. SLD profiles obtained from the fitting of PNR data for the as-grown (top) and after anneal (bottom) data respectively. The blue, green and red lines represent the best fits of the magnetic, nuclear and absorption profiles respectively. The shaded bands represent the σ and 2σ ranges for each profile. As Boron is the only element in the sample with a significant absorption, the absorption profile (red) shows the boron distribution throughout the sample.

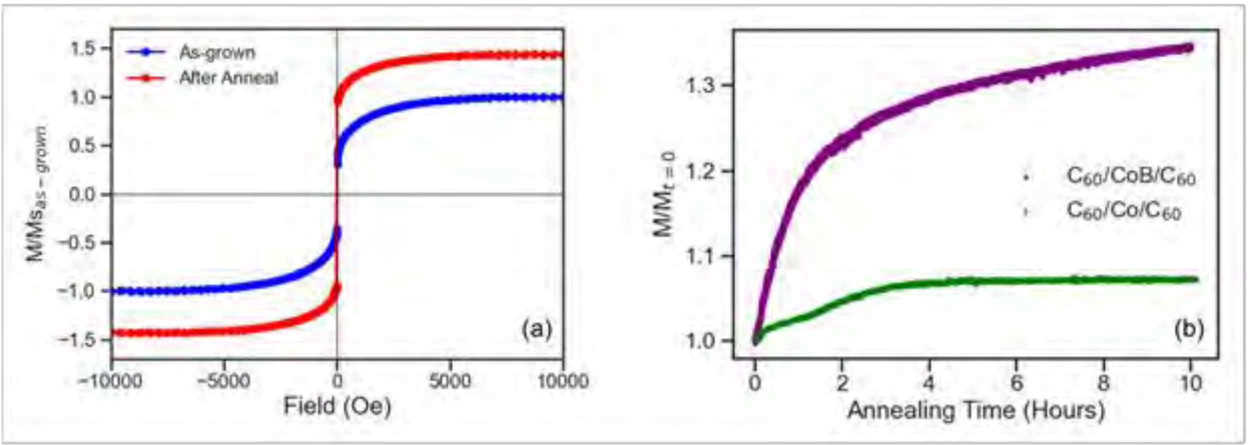

Figure 2. (a) Magnetic hysteresis loops of a sample of Si/SiOx(100)/C_{60}(20)/CoB(15)/C_{60}(20)/Al(5) (thickness in brackets in nm) as grown (blue) and after annealing at 300°C for 10 hours (red). (b) Magnetic moment measured during annealing at 300°C for 10 hours for trilayers of C_{60}/CoB/C_{60} (purple) and C_{60}/Co/C_{60} (green). The CoB sample the moment dramatically increases during annealing as Boron migrates into the adjacent C_{60} layers leaving a Co rich region with a greater moment.

Development of In-Situ FMR PNR Measurement Technique

Daniel Roe[1,2], Poppy McPeake[2], Matthew Rogers[1], Mannan Ali[1], Christy Kinane[2], Gavin Stenning[2], Andrew Caruana[2], Sean Langridge[2], Oscar Cespedes[1]
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Session 10: Novel Techniques in Magnetism, March 26, 2024, 15:00 - 17:00

In this work, we attempt to measure the precession of the magnetisation of a sample due to ferromagnetic resonance (FMR) using polarised neutron reflectometry (PNR). FMR is a technique that can give information about the magnetisation dynamics of a sample/material. However, conventional FMR measurements can only inform us of the bulk properties of the sample - there is no spatial resolution. PNR is a measurement technique that is used to measure the magnetisation profile through the depth of a sample and is specifically sensitive to interfacial magnetism. By performing these two techniques in tandem, we aim to combine the benefits of both to determine depth dependent magnetisation dynamics. Simulations show that by rotating the sample magnetisation away from the Neutron polarisation axis the changes in PNR can be maximised. To achieve this experimentally we use a FM/AF multilayer of [Co/FeMn]x10 to give strong anisotropy via exchange bias and to maximise the magnetic signal with a large number of multilayer repeats. Comparing between PNR measurements with the FMR on and off suggest there may be small changes in the magnetism, however these may be too small to give differences outside of the range of error bars when we analyse the fitting results. The fitting results show that a cone angle of more than 0.5° would be large enough to resolve changes between on and off resonance states. We aim to achieve this by updating the experimental set up to allow for greater microwave input power.

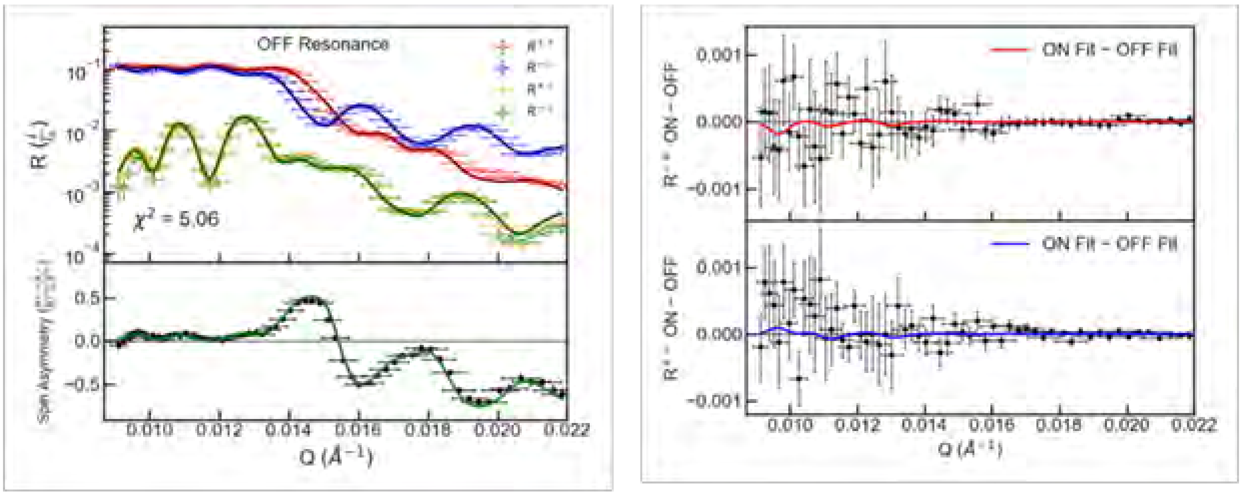

Figure 1. (left) Example PNR data for the Si/SiOx/Ta(6)/[Co(5.5)/FeMn(12)]x10/Ta(6) (thickness in nm) sample in the off resonance state. The solid lines show the fitting results. (right) Difference in between the on and off states for the spin flip reflectivities (R^{+-} and R^{-+}). Here the solid lines show the difference between the fits for on and off resonance

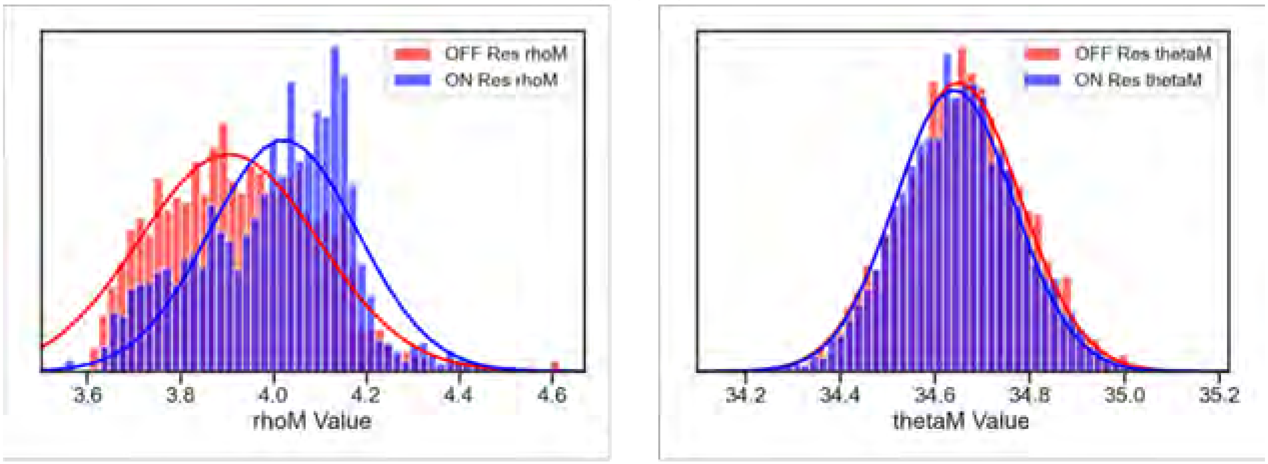

Figure 2. Comparison of the magnetic fitting parameter probability histograms for off (red) and on (blue) states. RhoM denotes the magnetic scattering magnitude and is proportional to the sample magnetisation. ThetaM is the magnetisation angle relative to the neutron polarisation axis.

Mid-infrared coherent excitation for room temperature phono-magnetism in antiferromagnetic FeBO3

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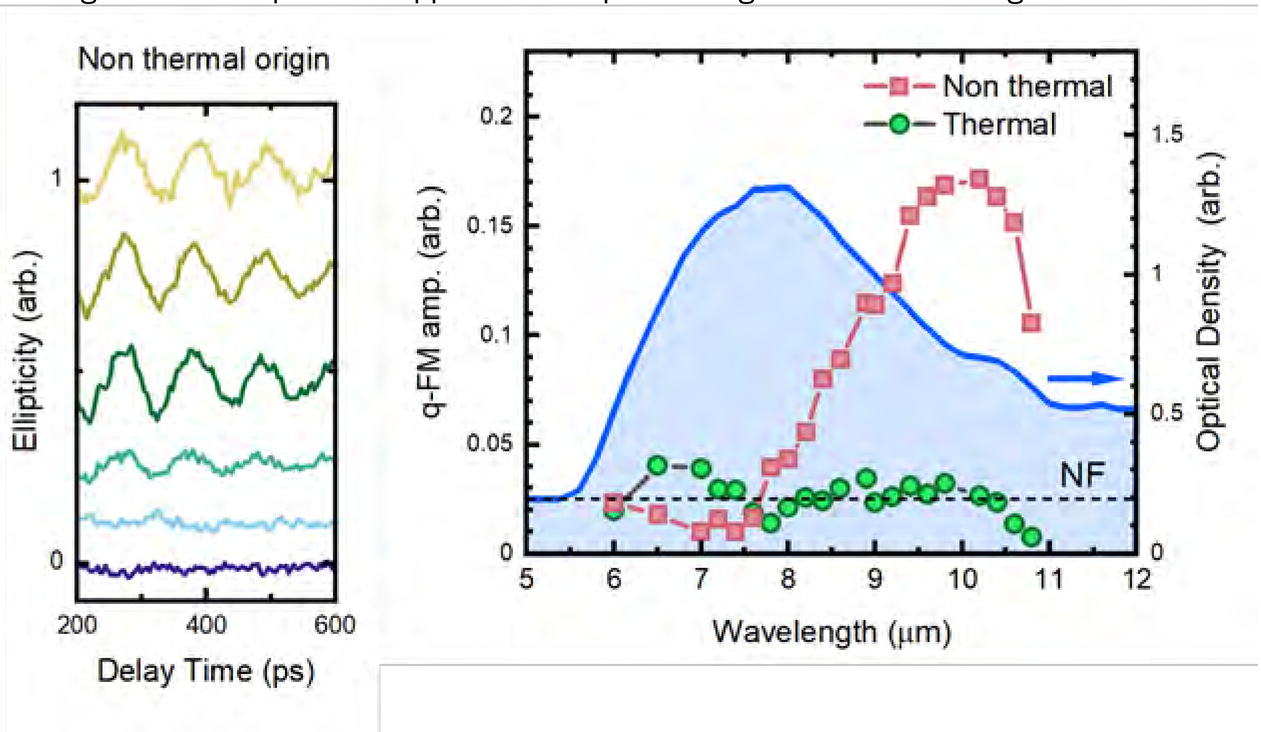
Session 1: Correlated Systems, March 25, 2024, 10:00 - 11:15

Ultrafast magnetism opened the door to control the spin system with the unexpected speed in a sub-picosecond. For a few decades, to drive spin dynamics, laser sources operating in the almost visible region were used for electronic excitation. However, mid- and far-infrared spectral range, in resonance with elementary lattice vibration modes, can be used instead of conventional electronic excitations, and we can suppress the occurrence of hot electrons whose energy incoherently dissipates into other quasi-particles, i.e., phonons. The impulsive stimulation of atomic bonding through a mid-infrared femtosecond pulse coherently induces spin excitation via phonon-magnon coupling. Here, we demonstrate a new fundamental feature of the phono-magnetic process – its maximal efficiency is red-shifted with respect to the phonon absorption line centre in a canted antiferromagnetic oxide FeBO3, which has an isolated phonon peak. We interpret this shift as an intrinsic property of coherent phono-magnetism. Our finding informs phono-magnonic engineering and provides invaluable insights into tuning wavelength to achieve maximal efficiency. Besides this fundamental aspect, coherent spin dynamics driven by an ionic vibration were hitherto reported only in one type of materials – rare earth orthoferrites – only at cryogenic temperature, and the practical utilization of this phenomenon was limited. In FeBO3 we achieved coherent phonon-assisted excitation of magnons at room temperature and above, making the case for practical applications of phono-magnetism much stronger.



Advanced transmission electron microscopy of the three-dimensional magnetization distribution of a pinned domain wall in a Sm-Co-based permanent magnet

Mr Aurys Silinga[1], Trevor Almeida[1], András Kovács[2], Ziyuan Rao[3], Tatiana Smoliarova[4], Konstantin Skokov[5], Baptiste Gault[3], Oliver Gutfleisch[5], Michael Farle[4], Rafal Dunin-Borkowski[2]

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Session 10: Novel Techniques in Magnetism, March 26, 2024, 15:00 - 17:00

Sm(CoFeCuZr)7 permanent magnets have a high energy product and are commonly used in applications at elevated temperatures. Their high coercivity results in part from the pinning of magnetic domain walls at Sm2Co17 and SmCo5 phase boundaries [1]. Here, we use the advanced transmission electron microscopy (TEM) technique of electron holographic tomography, in combination with model-based reconstruction [2], to measure the three-dimensional magnetisation distribution at a pinned domain wall in a needle-shaped sample of the permanent magnet Sm(CoFeCuZr)7. The results are discussed by considering both the shape and the magnetocrystalline anisotropy of the sample, as well as local variations of its microstructure and chemical composition.

Multiple 4 μm long needles with average diameter of 0.1 μm were milled from a Sm-Co-based permanent magnet sample as shown in Figure (a). Dark field TEM imaging (Fig. b) revealed that multiple Sm-Co crystal phases were found in the needle, for which its long axis is perpendicular to the magnetocrystalline c-axis. Electron holography (Fig. c) shows that the phase boundaries act as pinning sites for magnetic domain walls, therefore we imaged two tilt-series and reconstructed the needle magnetisation in three dimensions (Fig. d). Comparison of two needles showed that their magnetic and structural properties are consistent. To summarise, the magnetocrystalline anisotropy is strong enough to stabilise multiple magnetic domains at phase boundaries despite large magnetostatic contribution due to the shape anisotropy of the needle.

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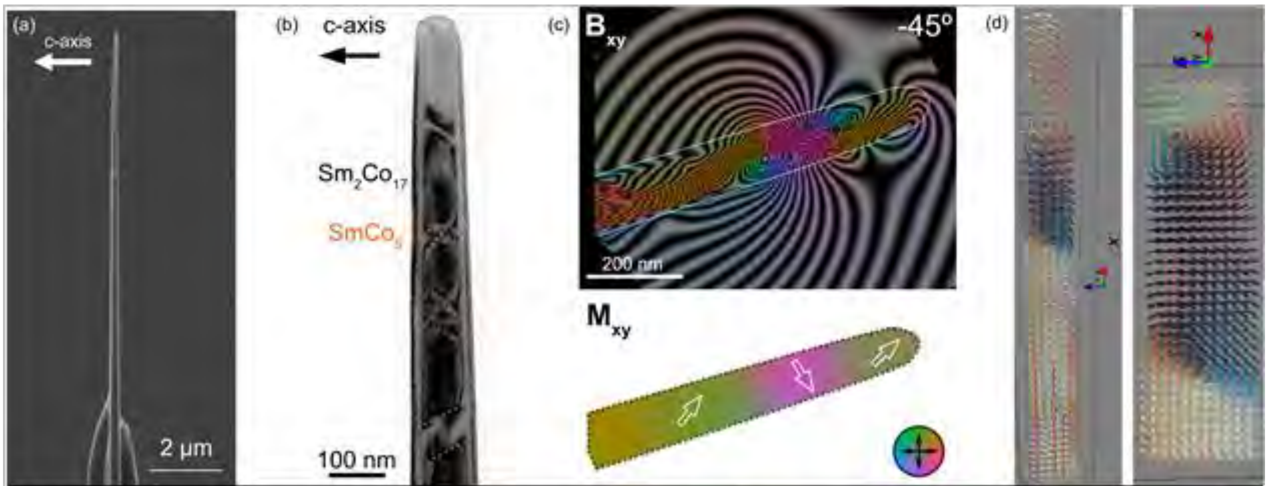

(a) SEM image of the needle and its base. (b) TEM image showing boundaries of different Sm-Co crystal phases. (c) Magnetic contour and diagram showing magnetic domain directions when needle is imaged at -45 degree tilt. (d) Tomographic reconstruction showing the direction of magnetic moments in 3-D (right image shows full resolution).

Focused Electron Beam Induced Deposition of 3D nanostructures for magnetic racetrack memory

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Session 10: Novel Techniques in Magnetism, March 26, 2024, 15:00 - 17:00

Magnetic-racetrack-memory [1] is a non-volatile spintronic data storage technology with higher energy efficiency than conventional DRAM at similar operational speeds [2]. To fabricate prototypes, a scanning electron microscope (SEM) was calibrated for the automated deposition of CAD modelled 3D nanostructures using focused electron beam induced deposition (FEBID). FEBID is an SEM technique based on the injection of precursor gases and the localised electron-beam-induced deposition of nanostructures. The automated growth of cobalt nanowires was performed using a Langmuir FEBID model under equilibrium conditions, with a thermal correction derived by modelling conduction in the deposited structure [3]. Several cobalt nanowires were fabricated, and their elemental composition was mapped in the TEM using electron energy loss spectroscopy to determine the optimal growth conditions, resulting in nanowire diameter of 130 nm and cobalt purity of 85 %. Furthermore, complex nanowires with geometric pinning sites were fabricated (Fig. a), and magnetic domain walls were imaged at multiple angles using the TEM technique of off-axis electron holography (Fig. b). The measured magnetic fields revealed that nanowire purity is directly proportional to the saturation magnetisation, and domain walls formed at the same sites after reversing the magnetisation direction with the saturating field of the TEM objective lens. A tomographic reconstruction (Fig. c) was performed to measure the 3D magnetisation distribution at the domain walls.

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[2] S. S. P. Parkin et al. Science, 320, 190-194. (2008).
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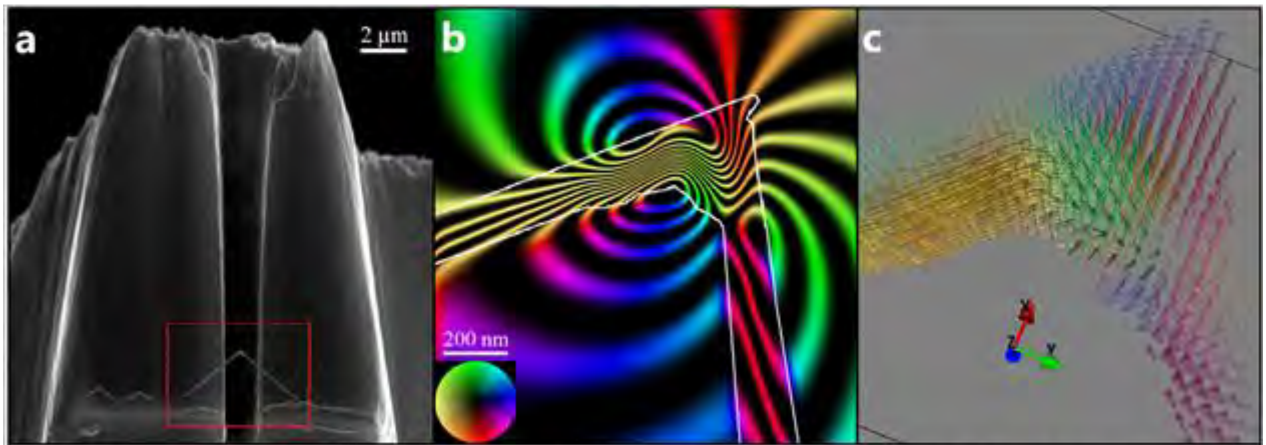

(a) SEM image showing a freestanding 'nanobridge' fabricated with FEBID. (b) Magnetic induction map showing the geometric outline and field contours at the tip of the nanobridge. (c) – Tomographic reconstruction of the magnetisation.

Spin Waves In Pt/NiFe Nanomagnetic Ring Arrays For Integrated Magnonic Reservoir Computing

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Session 2: Thin Films I, March 25, 2024, 10:00 - 11:15

With the rise in machine learning usage, the energy requirements of modern computing has substantially increased. A large portion of this consumption is used to transfer data between processing and memory units. Recently, there has been growing interest in exploiting inherent complex dynamics and memory in material systems to perform tasks at lower energy costs than their software counterparts. However, this approach requires efficient methods of interfacing with materials, to provide rich information regarding the state of the system.

Spin waves have long been proposed as an efficient alternative information carrier in next generation devices, and have recently been demonstrated as capable platforms for reservoir computing in systems including artificial spin ice arrays [1] and magnonic crystals [2]. We have recently shown the emergent dynamics within an ensemble of nanoring arrays provides a platform for reservoir computing [3-5]. In these proto-devices, the system state was probed using magnetoresistance, however this low dimensional readout restricts the representation of the nanorings complex state space to a scalar value, sacrificing potentially useful information. The spin wave spectra should provide more information about the number, orientation and type of states in the array, but in conventional ferromagnetic resonance measurements, a large ensemble is required to produce a measurable signal. Here we show the feasibility of creating device-compatible implementations of this approach by integrating a microscale-array onto a Pt waveguide and reading out magnonic spectra via the inverse spin Hall effect, thus offering a route towards miniaturisation.

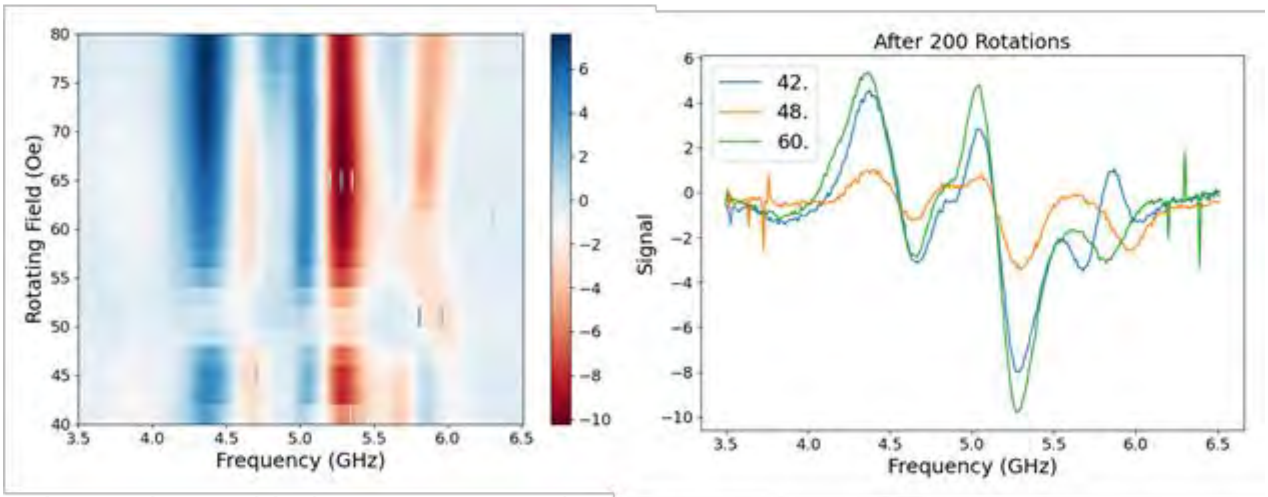

Figure: Colormap of the frequency response of a ensemble of 400nm and 500nm nanorings following 200 cycles of a rotating field (left). Linescans around the emergent response, when domain walls annihilate and form vortex states within the sensemble (right).

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Machine learning using a 3D artificial spin ice lattice

Dr Guru Venkat[1], Dr Arjen van den Berg[2], Mr Ian Vidamour[1,3], Dr Alex Welbourne[1], Dr Charles Swindells[1], Dr Joseph Askey[2], Dr Sam Ladak[2], Prof Tom Hayward[1]
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Session 7: Intelligent Computing, March 26, 2024, 10:30 - 12:15

Physical systems showing emergent behaviour under applied stimuli are promising for unconventional computing [1]. Artificial spin ices (ASIs) have attracted interest as they have large numbers of accessible states and rich magnetisation dynamics. Consequently, the inter-island interactions in 2D ASIs have previously been harnessed for reservoir computation (RC) [1,2]. Recent advances in 3D nanostructuring have provided routes to realise 3D ASIs, which exhibit complex, many body interactions in 3-dimensions making them even more exciting as reservoir substrates [3,4].

Here, a 3DASI lattice was fabricated using two-photon lithography in a diamond-bond geometry, upon which 50 nm of Ni81Fe19 was evaporated. This formed magnetic nanowires in the lattice shown in Fig. 1(a). Fig. 1(b) shows an atomic force microscopy image of the lattice with sublattice directions annotated.

To explore the feasibility of RC with these devices we encoded data within the amplitude of rotating magnetic fields applied in the plane of the underlying substrate and read out the resulting transient dynamics of the array using Magneto-optic Kerr effect magnetometry. We tested the performance of the reservoir by using it to perform periodic wave transformations (e.g. sine to sine-squared), shown in Fig 1(c) and prediction of the future behaviour of the pseudo-random Mackey-Glass (MG) time series. Fig. 1(d) shows how the accuracy of the MG prediction changes with temporal delay, while Figs. 1(e) & (f) show example reconstructions of the MG series at different delays. Our work shows initial proof-of-principle of harnessing 3D nanomagnetic systems for neuromorphic computation.

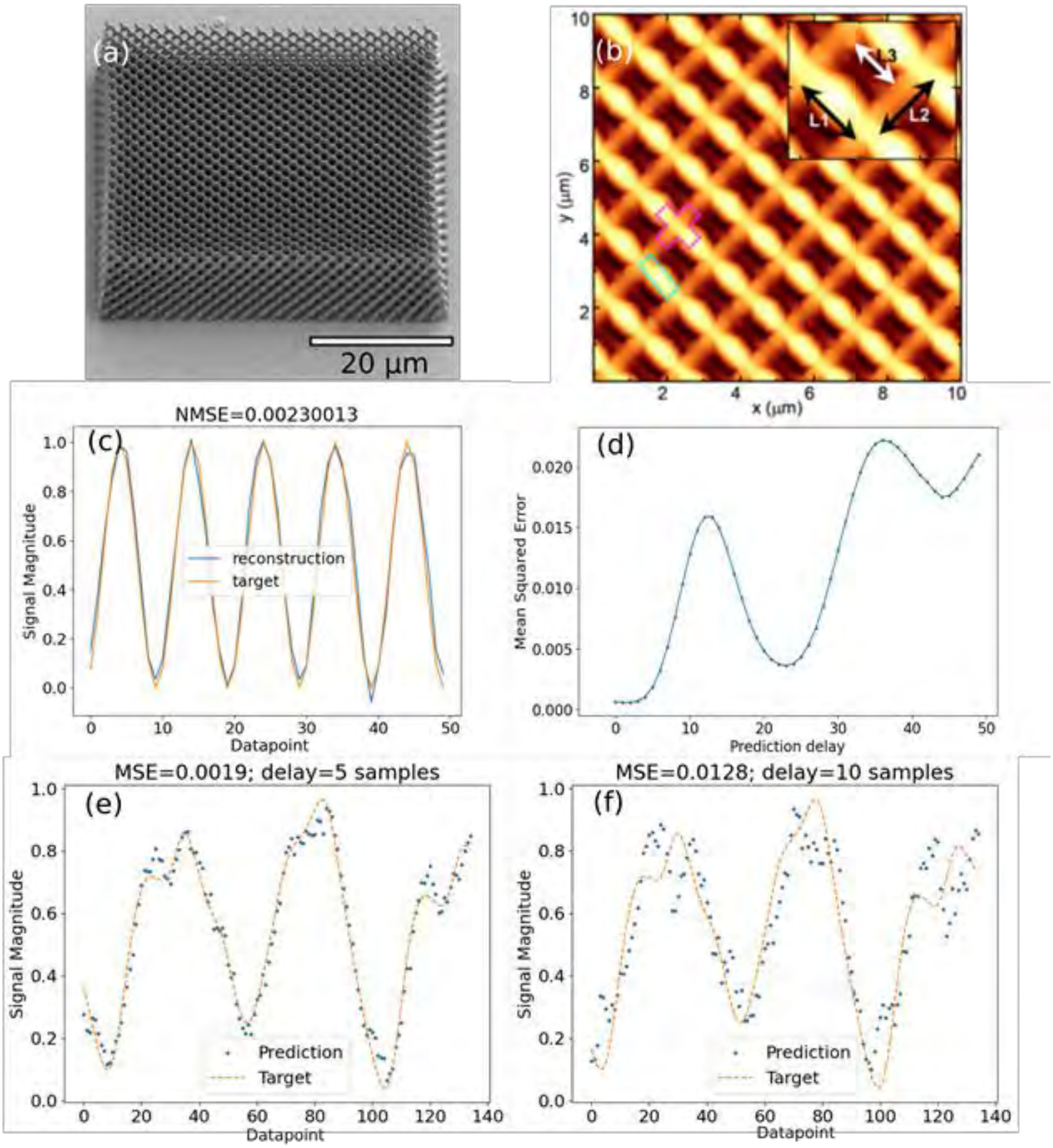

Figure 1: (a) SEM micrograph of the 3D nanowire lattice (b) AFM image of the lattice showing sublattice directions L1, L2 and L3. The image also has green and pink boxes indicating the coordination two and four vertices. (c) Signal transformation from a sinusoid input to a sine-squared waveform and (d) mean squared error of prediction delay of the Mackey-Glass time series and (e) and (f) show reconstruction attempts at two different prediction delays.

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Enhanced light absorption in nanomagnetic metamaterials

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Session 2: Thin Films I, March 25, 2024, 10:00 - 11:15

The recent discovery that a low-power continuous wave diode laser can switch NiFe nanomagnets in zero applied field was both intriguing and confusing [1]. The idea that optimising useful light absorption in the nanomagnets was crucial to this and has motivated further work on controlling light absorption in ferromagnetic metals. We present a study on the enhanced light absorption in an array of nanomagnets across a broad spectrum (500-1200 nm). By using an interference effect between the reflection from a mirror-like substrate (Al/SiO2) and the incoming light, we achieve remarkable absorption in the nanoarray. The spacing and size of the nanomagnetic arrays are carefully engineered to optimize this effect, as verified through Fourier Transform Infra-red (FTIR) spectrometry and absorption simulations. In addition, the research also aims to enhance the sensitivity of the Magneto-Optic Kerr Effect (MOKE) [2]. By improving the interaction of light with the nanomagnets, the sensitivity of MOKE can be significantly increased, potentially leading to more accurate and sensitive magnetic measurements. This research provides valuable insights into the light absorption mechanisms in nanomagnets and opens up possibilities for applications in optoelectronic devices and magnetic sensing.

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Large and Tunable Spin Hall Magnetoresistance at YIG/PtMn/C60 Interfaces

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Session 9: Low-dimensional Magnetism, March 26, 2024, 15:00 - 17:00

Antiferromagnets (AFs) have attracted attention in spintronics due to high frequency (~THz) applications, strong inverse spin Hall effect (SHE) and the absence of stray magnetic fields [1,2]. Using the metallic AFs (e.g. PtMn, IrMn), transporting the spin (only) angular momentum can be achieved in a ferrimagnetic insulator [$Y_3Fe_5O_{12}$(YIG)]/AF bilayer with the large spin-orbit coupling (SOC). The SOC can be further enhanced using the molecular overlayers such as C_{60} [3,4]. Here, we report the spin transport of YIG/PtMn(t)/C_{60}(15 nm), aiming at enhanced and tunable SHE, and other emergent properties.

The spin Hall magnetoresistance (SHMR) of YIG/PtMn at 290 K was significantly larger when interfaced with C_{60}, resulting in an enhanced spin Hall angle (~Js/Jc) from ~0.02 in PtMn to ~0.04 in PtMn/C_{60} (Figures 1(a,b)). X-ray Absorption Spectroscopy (XAS) and X-ray Magnetic Circular Dichroism (XMCD) reveal a charge transfer from Mn to C (Figure 1(d)). The C_{60} interface resulted in uncompensated Mn spins while the bare PtMn remains same. The PtMn -being AF- introduces an exchange bias with YIG at low temperatures (Figure 1(e)). This is correlated to the SHMR sign change below a blocking temperature (~50 K, Figure 1(c)) because of changing the Neel vector direction during the spin flop [5]. We note that the SHMR magnitude is asymmetric with the temperature -see Figure 1 (c)- attributed to the presence of unidirectional exchange anisotropy (UEA) at the YIG/PtMn interface in the out-of-plane direction. We disentangle the spin transfer torque for the UEA (~cosθ) which is different from the conventional SHMR (~$\cos^2\theta$).

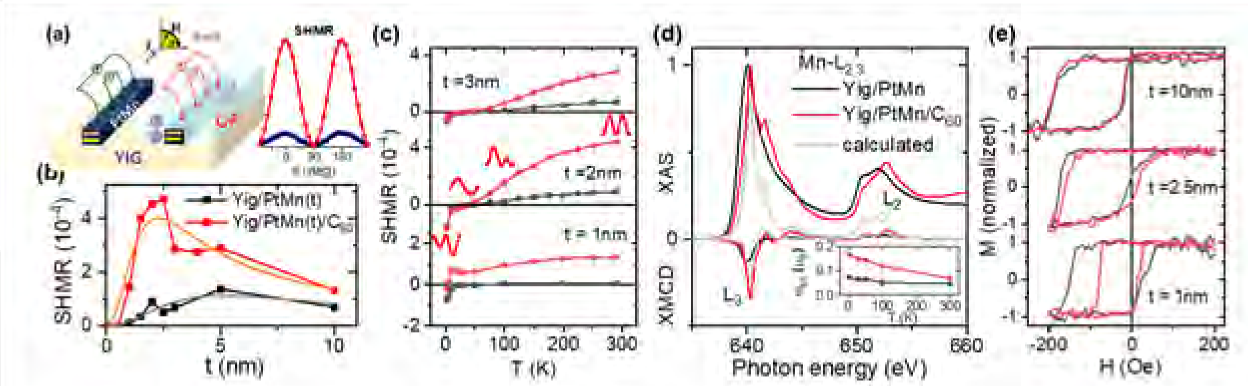

Figure 1: (a) Sketch of SHMR on Yig/PtMn(t)(/C_{60}). The SHMR data at **(b)** 290 K and **(c)** low temperatures. **(d)** Mn-$L_{2,3}$ XAS and XMCD. Inset show the temperature variation of m_{tot}. **(e)** Magnetization of Yig/PtMn(t) at 2K.

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Device-Agnostic Dynamic Learning for Spintronic Platforms

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Session 5: Computation and theory, March 25, 2024, 15:30 - 17:15

Spintronic devices have been presented as a possible solution to the growing energy concerns of modern machine learning platforms [1]. However, a lack of analytical mathematical descriptions of device dynamics means standard machine learning approaches are often inaccessible to spintronic systems. Consequently, recent demonstrations of computing with spintronic platforms are limited to either implementations under the reservoir computing (RC) paradigm [2], or as static networks [3]. Both of these methodologies sacrifice computational power for simpler training of networks: reservoir computing approaches scale poorly to harder tasks due to the limitations of random connectivity, while static networks fail to exploit the natural memory provided by the dynamic properties of the underlying systems. In order to harness the full potential of spintronics for computing, methods for optimising networks which exploit the dynamic properties of a given system are required.

Here, we present a device-agnostic methodology for training networks of interconnected dynamical systems, using a pair of spintronic platforms (interconnected magnetic nanorings [3], artificial spin-vortex ices [4]) as case studies. The responses of the systems are modelled via Neural Stochastic Differential Equations (NSDE) [5], creating a differentiable 'digital-twin' capable of reproducing device-realistic responses to inputs, including experimental noise. Networks of the digital twins are trained in simulation, with the learned parameters transferred to networks constructed of real devices, vastly improving the performance in both classification and regression tasks compared to RC implementations. This approach enables a new generation of spintronic computing platforms, exploiting the power of modern machine learning techniques for physical systems.

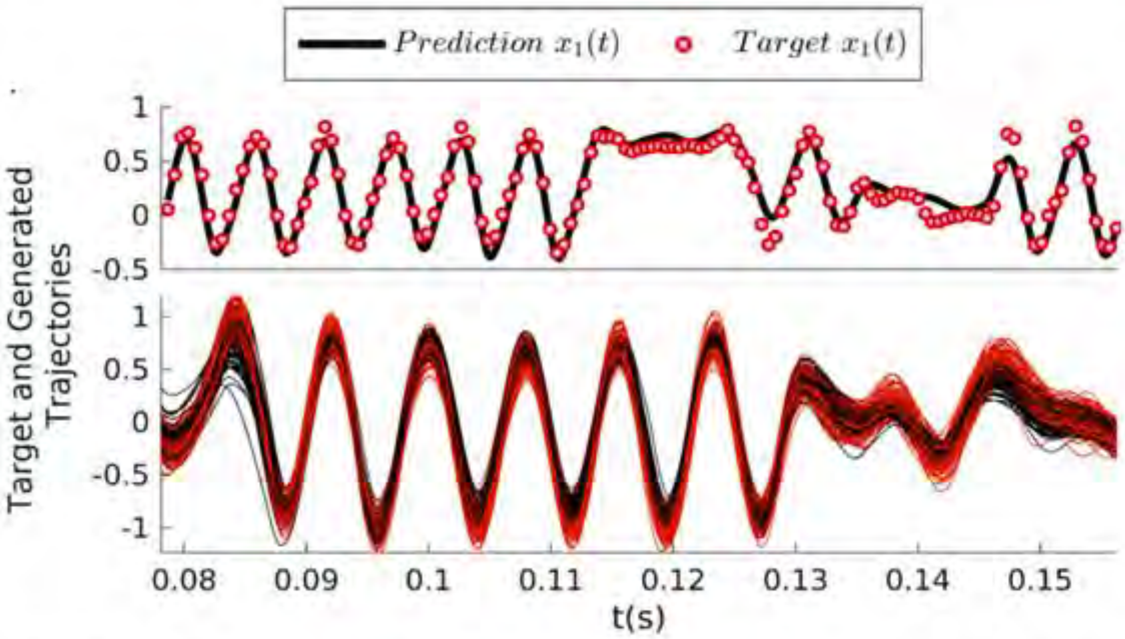

Figure 1- Upper: Experimentally recorded magnetoresistance measurement of magnetic nanoring array (red), compared to a prediction made by the Neural Stochastic Differential Equations (NSDE) model when provided with the same input (black). Lower: Example distributions of 100 repetitions of a random input sequence for experimentally gathered data (black) compared to simulated distributions via the NSDE.

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Investigating the effect of Ga+ ion irradiation on a synthetic antiferromagnetic multilayer of [Pt/CoFeB/Ru/Pt/CoB/Ru]

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[1]University Of Glasgow, United Kingdom, [2]University of Leeds, United Kingdom

Session 10: Novel Techniques in Magnetism, March 26, 2024, 15:00 - 17:00

Skyrmions are circular magnetic structures that have attracted a lot of attention due to their topologically protected nature, making them suited for the development of novel non-volatile information storage devices that are power efficient [1]. In ferromagnetic samples, skyrmions arise stochastically with applied magnetic field, with nucleation generally occurring at defects. This is not ideal for spintronic applications, where the nucleation and manipulation of skyrmions need to be controlled effectively. One way to achieve this, is by creating artificial point-like defects using a focused ion beam (FIB) microscope, which act as nucleation sites for the skyrmions [2]. The present work applies this method to a synthetic antiferromagnetic (SAF) multilayer, given the advantages of SAF skyrmions over their ferromagnetic counterparts [3]. An array of point-like defects of varying doses has been irradiated on the sample using the 10 nm probe in a Ga+ FIB. Analysis under Lorentz Transmission Electron Microscopy (L-TEM) revealed nucleation and pinning of skyrmions at the location of the higher dose defects. This behaviour occurs on both sides of the hysteresis loop (Fig.1). Whilst we note that, in the non-irradiated state, skyrmion nucleation was observed under the application of fields from a saturated state, and only when the field had passed through zero and had become negative with respect to the intial saturation field. The field regime indicates that the skyrmions are likely to be ferromagnetic in nature in this initial study. Further effects of ion irradiation on the SAF phase are under investigation.

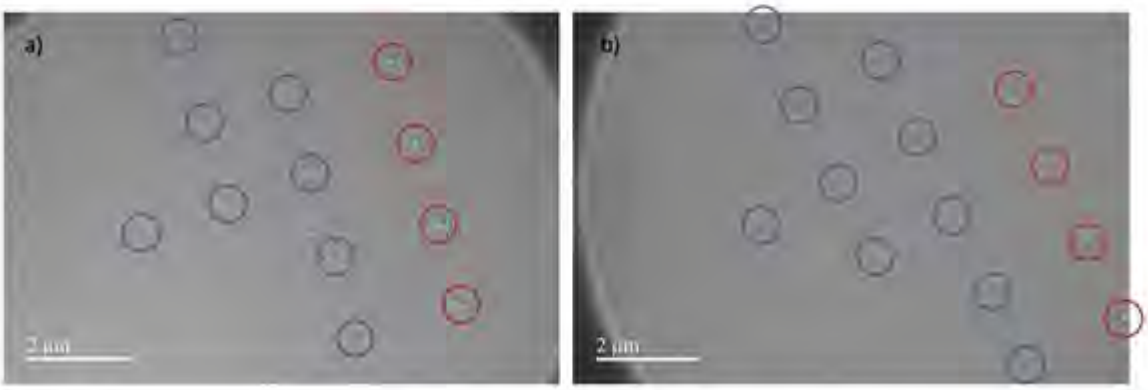

Figure 1 L-TEM images of the SAF sample showing skyrmions (circled in blue) at the locations of the artificial FIB defects with a a) positive and b) negative out of plane biasing field. Some electrostatic contrast (circled in red) is also visible. This is indicative of a row of defects that has been irradiated with a dose strong enough to cause surface damage.

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THz-driven dynamics of spins and orbitals in TbFeO3

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Session 6: High Frequency Spin Dynamics, March 25, 2024, 15:30 - 17:15

Rare-earth orthoferrites, RFeO3 (R=rare-earth element), exhibit unique magnetic properties, such as weak ferromagnetism, spin reorientations, magneto-optical effects, and terahertz (THz) spin dynamics. Their significance has resurged in recent years, bolstered by their prominence in ultrafast magnetism experiments. For instance, ultrashort THz radiation enables the study of spin and orbital dynamics [1], large-amplitude magnons [2], and control of nonlinear spin dynamics and magnetization switching [3].
TbFeO3 features unique interplay between an antiferromagnetic resonance and a Tb electronic transition, suggesting a potential for Dicke superradiant phase transition [4]. Our time-resolved THz-pump optical-probe experiments have validated this dynamic interaction, as evidenced by the avoided crossing between the modes. We developed a theoretical model of THz-driven nonlinear spin dynamics and low-energy electronic states in TbFeO3. This model accurately predicts resonant frequencies across various magnetic temperature phases and clarifies conditions for spin reorientation phase transitions. Our research, aligning with experimental data, positions TbFeO3 as a candidate system for simulating quantum electro-dynamics phenomena, including Dicke cooperativity and superradiance [4].

Figure 1. a. THz-driven dynamics in the TbFeO3 measured as Faraday rotation of a probe pulse. b. The cyan circles show the spin oscillation frequencies retrieved from a, and the calculated behaviour of Fe and Tb resonance frequencies, both with (solid) and without dynamic coupling (dashed).

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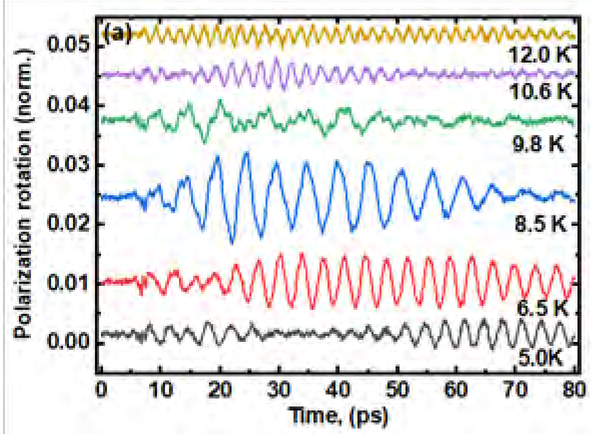

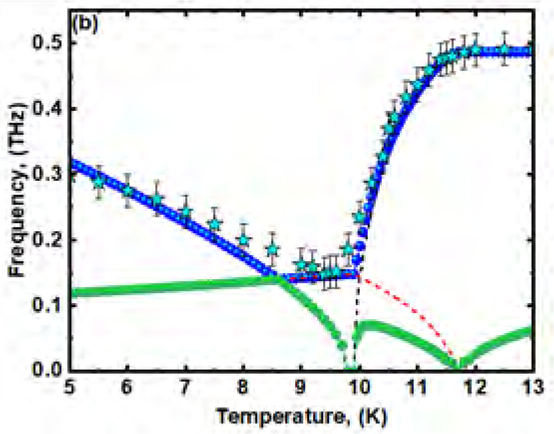

Towards Racetrack Neural Networks

Alexander Welbourne[1], M. O. A. Ellis[1], M. Chambard[1], S. J. Kyle[1], M. Drouhin[1], L. T. Haigh[1], A. M. Keogh[1], A. Mullen[1], P. W. Fry[1], F. Maccherozzi[2], T. Forest[2], E. Vasilaki[1], D. A. Allwood[1], T. J. Hayward[1]

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Session 7: Intelligent Computing, March 26, 2024, 10:30 - 12:15

Non-volatile logic and memory devices based on domain wall (DW) motion have technological promise [1,2], but stochastic behaviour has impeded development [3]. We have demonstrated, with a tunable stochastic pinning site (Fig. 1(a)), how this behaviour can be used to perform handwritten digit recognition in mixed CMOS/magnetic architecture (Fig. 1(b)) [4]. Here, we explore use of this stochastic-element to perform computation in all-magnetic networks.

Fig. 1(c) shows how a nanowire notch-defect provides the tunable stochastic-element: varying the propagation field tunes the passing probability of a DW continuously from 0%–100%. Binary inputs are encoded as DWs pinning (0) or passing (1) the notch. Analogue values are then encoded as averages of DW bit-streams, which tend to the value of the passing probability: mimicking the analogue weighting of synapses in neural networks. Furthermore, the “stochastic computing” paradigm allows for complex operations to be performed by individual logic gates, allowing assembly of neurons from chains of nanowire junctions with AND or OR functionality for DWs. Fig. 1(d) demonstrates AND gate functionality with single inputs, whilst Fig. 1(e) demonstrates how this performs as a multiplier when acting on probabilistic inputs, mimicking the multiplication of a network input by a synaptic weight.

Here, we will present experimental demonstration of nanowire-based synaptic tuning, AND gates, OR gates, and then discuss how they may be connected together to form “racetrack neural networks”: neural networks composed entirely from magnetic nanowire devices. Our work demonstrates how intrinsically stochastic DW pinning allows realisation of alternative computing paradigms natively in hardware.

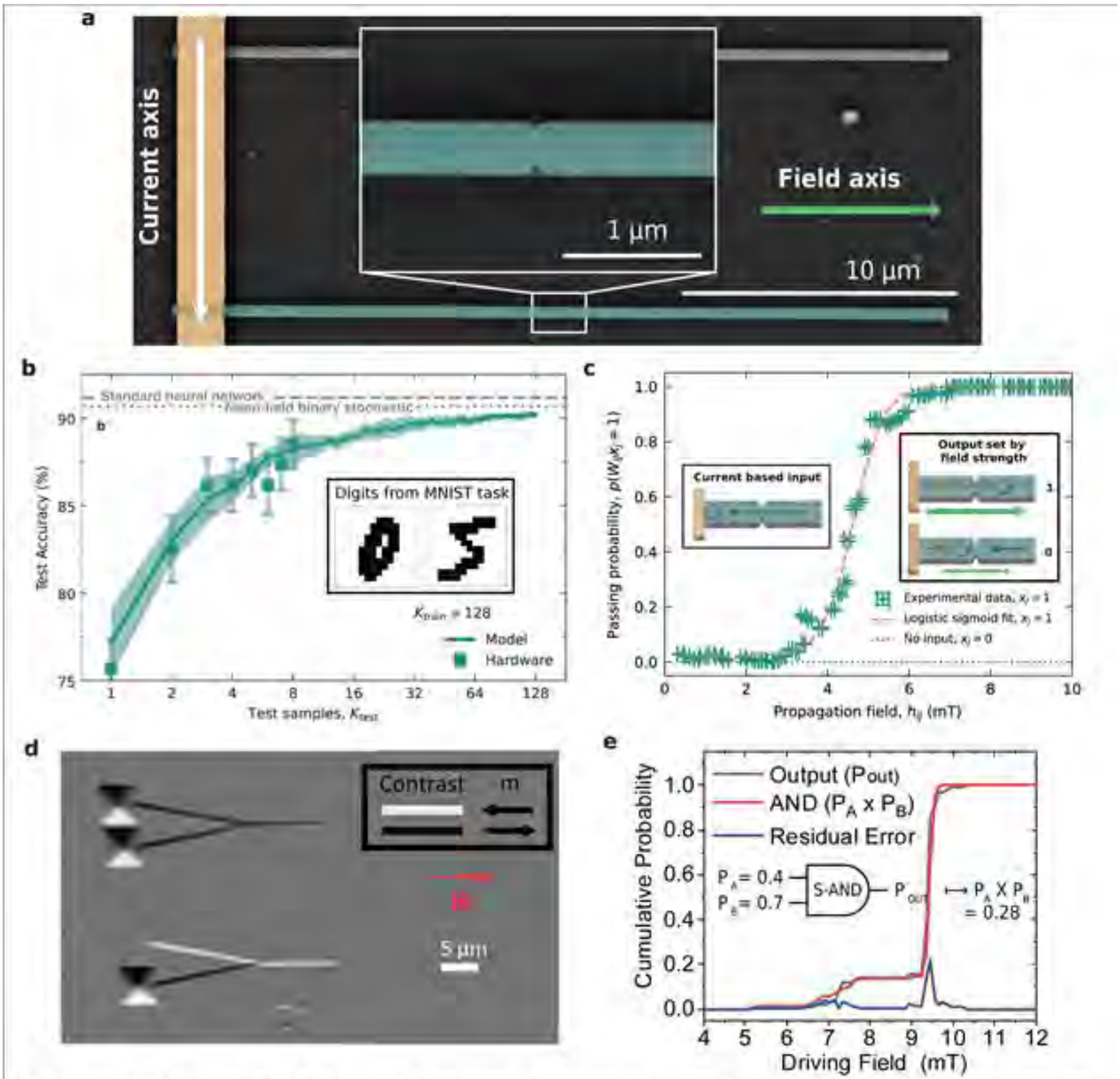

Fig. 1: (a) SEM of a notch defect in a 400 nm wide (54 nm thick) permalloy nanowire that provides a site with tunable pinning probability. (b) Performance of a neural network (recognising digits, MNIST) built using the elements in (a) as binary stochastic synapses. Performance of the network increases as the number of samples (repeats) of the network increases, approaching the level of a standard neural network. The hardware performance agrees well with a modelled network. (c) DWs driven through the stochastic element under increasing propagation fields pass with a probability following a logistic sigmoid-like increase. This results in an output given by domain wall passing (1) or pinning (0). (d) PEEM images demonstrating single-shot functionality of a domain-wall AND gate. (e) Demonstation of multiplicative operation of the AND gate on stochastic bit-streams. The AND gate acts as a probability multiplier.

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Poster Presentations

Exploring magnetic domain wall movement and pinning in Permalloy nanowires by magnetic force microscopy

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

This study investigates various magnetic nanostructure designs of permalloy nanowires with a particular focus on understanding the behaviour of domain walls using magnetic force microscopy (MFM). To observe these domain walls, nanowires were designed in scale of 50 nm to 1 μm width, greater than 5 μm length and up to 50 nm thickness. The samples were made using a variety of lithographic techniques, including photon, electron and ion beam exposures of resists. In order to study the behaviour of domain walls and compare these with experiments, simulations were conducted using the Mumax software. An atomic force microscopy (AFM) instrument was also employed to deliberately scratch the top of nanowires with a diamond AFM tip to reduce their cross section and thus create pinning sites. Through the controlled application of various magnetic field values and directions, notable pinning site effects were revealed. This study contributes to shedding light on the intricate movement of domain walls and informs the potential utility of such structures for advanced data storage purposes.

Current-induced resonance in finite length magnetic nanowires

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Magnetic nanowires have gained importance in research due to their unique magnetic properties and wide-ranging applications in fields such as spintronics, magnonics, magnetic data storage, and biomedical technologies. Their high aspect ratio and curvature introduce significant shape anisotropy, enabling the customization of magnetisation dyanmics. Central to our investigation is the behaviour of these nanowires under the influence of electric currents, particularly how current affects the resonance frequency of spin waves in cylindrical nanowires. The cylindrical magnetic nanowires exhibit inherent magneto-chirality and the ability to support magnetic vortex structures. The spin-torque effect, induced by electric currents, plays a pivotal role in controlling these vortex structures and coupled with the Oersted field, influences the rotation direction of vortex domains, thereby affecting the resonance frequency within the nanowire.
The dependence of the ferromagnetic resonance frequencies and modes on the nanowire size, current magnitude, and magnetocrystalline anisotropy direction investigated theoretically for Co nanowires with diameters 10- 100 nm, highlighting the role of spin transfer coupling in these processes. This work involves solving the coupled system of the (LLG) equation, including the spin current, and quasi-static Maxwell’s equations using the finite-element method in COMSOL Multiphysics. This approach includes the contributions of magnetocrystalline anisotropy, exchange fields, magnetostatic fields, and eddy currents, offering a comprehensive understanding of the dynamic magnetization and absorption spectra. The study's findings are important for advancing our understanding of nanoscale magnetic systems and their potential applications in modern technological domains, particularly in tailoring magnetic nanowires and devices for targeted microwave electromagnetic applications.

Electromagnetic wave induced resonance in cylindrical magnetic nanotubes

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Ferromagnetic nanowires and nanotubes are functional constituents in many technologically-important materials and applications including microwave devices [1], magnetic memories [2], and in biotechnology [3]. This is primarily due to the ability to tune their static and dynamic functions through their size and shape, magnetic properties (via composition and synthesis) and through external bias.

Analysis of spin-resonance modes in ferromagnetic nano-wires/tubes often assume alignment of the magnetocrystalline anisotropy with the axis of the nano-structures for simplicity [4,5]. High-resolution microscopy and diffraction measurements of electrodeposited nano-wires/tubes, however, indicated the magnetocrystalline easy-axis is mostly perpendicular to the nanowire axis [6]. This is expected to break the circular symmetry of the local energy distribution and spin-wave modes.

In this work, we theoretically investigate the spin-resonance modes and their dependence on the magnetocrystalline anisotropy angle in cylindrical cobalt nanotubes with large axial ratio, excited by a pulsed electromagnetic plane wave (Fig. 1). This is achieved through numerical solution of the coupled system of Maxwell's and Landau-Lifshitz-Gilbert equations using a stable algorithm based on the finite-difference time-domain (FDTD) method [5].

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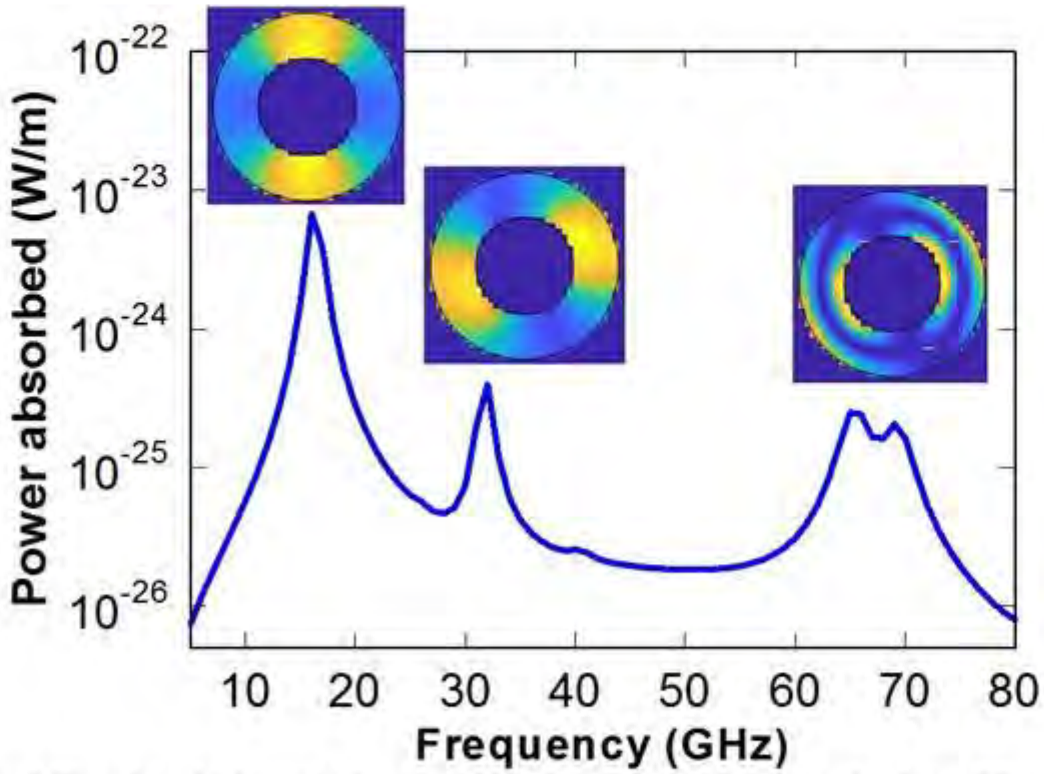

Fig. 1 Simulated integrated and local power absorption spectra for a 80 nm outer-diameter cobalt nanotube with 20 nm wall thickness with perpendicular easy-axis, excited using a 70 GHz, normally incident plane wave. The local power absorption spectra show break in symmetry in spin-resonance modes.

Flux jumps, cluster distribution model and vortex phase diagram of oxygenated Al-YBCO single crystal

Ms Ashna Babu[1]
[1]*IISER Thiruvananthapuram, India*

Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

We present the vortex phase diagram for an oxygenated Al-doped YBCO, a type -II superconductor, by analysing the anomalies observed in its magnetization response. One such anomaly is the second magnetization peak (SMP) anomaly expected from the order-disorder transition of the vortex lattice. The thermal evolution of the anomaly differs from that of the as-grown crystal response, which arises due to differences in the pinning characteristics of oxygen-deficient clusters that are proposed to lie in the basal plane of Al-YBCO. The presence of clusters was revealed from the XPS spectra. These clusters also explain the flux jumps observed in the odd quadrants of magnetic hysteresis. The field values of the flux jumps is similar to which a symmetry reorientation transition has previously been reported in the vortex lattice of YBCO via small angle neutron scattering measurements. We propose that the field-induced symmetry reorientation transition in the vortex lattice of Al-YBCO, with clusters having currents in opposite directions triggers the annihilation of the domains and hence a flux jump. Finally, a phase diagram depicting various phases evolved to correspond to the dominant energy on vortices, has been made for the oxygenated crystals, with most of the region independent of the direction of the field, which makes it different from the as-grown crystal vortex phase diagram.

Coherent Phonon Stimulated Fast Inverse Spin Hall Effect in Pt:YIG

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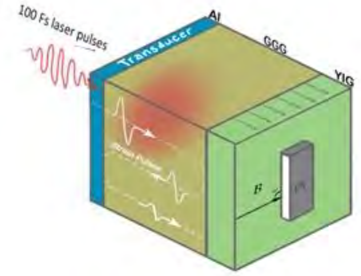
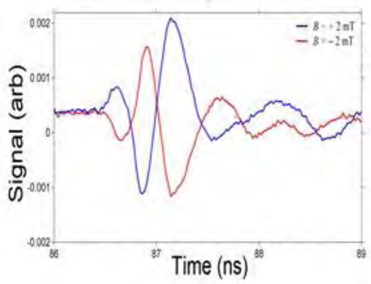
[1]University Of Nottingham, United Kingdom, [2]University of Jeddah, Saudi Arabia, [3]Loughborough University, United Kingdom, [4]Universität Konstanz, Germany

Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Owing to its favourable magnetic properties, the insulating ferrimagnetic compound Yttrium Iron Garnet (YIG) has long found application in microwave technologies and acoustics,. This study explores fast coherent acoustic phonon-driven Inverse Spin Hall Effects (ISHE) in the YIG-Pt system, offering potential applications in high-frequency acousto-electric devices.
The experimental samples comprised an 830 nm-thick YIG film on a Gadolinium Gallium Garnet (GGG) substrate, with a 5 nm-thick Pt strip on top. On the back surface of the substrate, a 100 nm-thick Al film optoacoustic transducer was deposited, Fig.1 (a). Coherent phonon pulses, generated in the Al transducer by 100 fs light pulses from a Ti:Sapphire laser, induced magnons in the YIG film. The spin current was converted to a measurable electrical signal in the Pt strip via the ISHE [1,2].
The experiment was operated within an optical cryostat with Helmholtz coils used to apply a vectorial magnetic field in the plane of the YIG film. With a magnetic field applied perpendicular to the Pt strip, a fast electrical pulse was measured, its polarity reversing with field direction, Fig.1 (b). No signal was observed using a lower spin-orbit coupling material, e.g. Al, in place of Pt, confirming IHSE's role in acousto-electric conversion. Above a threshold optical pump power of about 4mW, we observed GHz oscillations following the initial signal pulse. We believe this is due to ferromagnetic resonance (FMR) being induced by the pulse.
We have detected phonon-induced FMR, and the FMR frequency follows the predictions of the Kittel equation.





Growth and Structure of Fe3Sn2 Intermetallic Alloy Thin Films

Mr Callum Brennan-rich[1], Professor Stephen McVitie[3], Dr Trevor Almeida[3], Professor Rik Drummond-Brydson[2], Dr Sean Collins[2], Professor Christopher Marrows[1]
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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

The Fe3Sn2 is a frustrated ferromagnet [1] with an exotic electronic structure [2]. Fe3Sn2 has also been identified as a candidate material for hosting magnetic skyrmions stabilised by frustration rather than the Dzyaloshinskii–Moriya interactions [3]. However, other phases exist that differ only in the stacking sequence of the layers, for instance, FeSn is an antiferromagnet [4].
We report epitaxial growth of FeSn thin films on c-plane sapphire using co-sputtering. Fig. 1(a) shows an X-ray diffraction (XRD) pattern of a 30 nm Fe¬xSn1-x film. The Fe3Sn2 peaks (0006) and (0009) are well resolved with FWHM of 0.21±0.03 degrees and 0.29±0.03 degrees respectively. Fig. 1(b) shows the Pt/FexSn¬¬1-x interface, imaged through aberration-corrected high angle annular dark field (HAADF) TEM, showing the epitaxial growth of the film on the seed layer, of comparable quality to films grown by MBE [5].
Fig. 1(c) plots the position of the XRD peak near 40°: this is (0002) for FeSn and (0009) for Fe3Sn2 as the Fe sputter power is varied for fixed Sn power of 10 W. A near linear behaviour is observed, consistent with Vegard's law. Tuning this power was found to directly control whether films of FeSn or Fe3Sn2 were deposited with all other growth conditions being identical.

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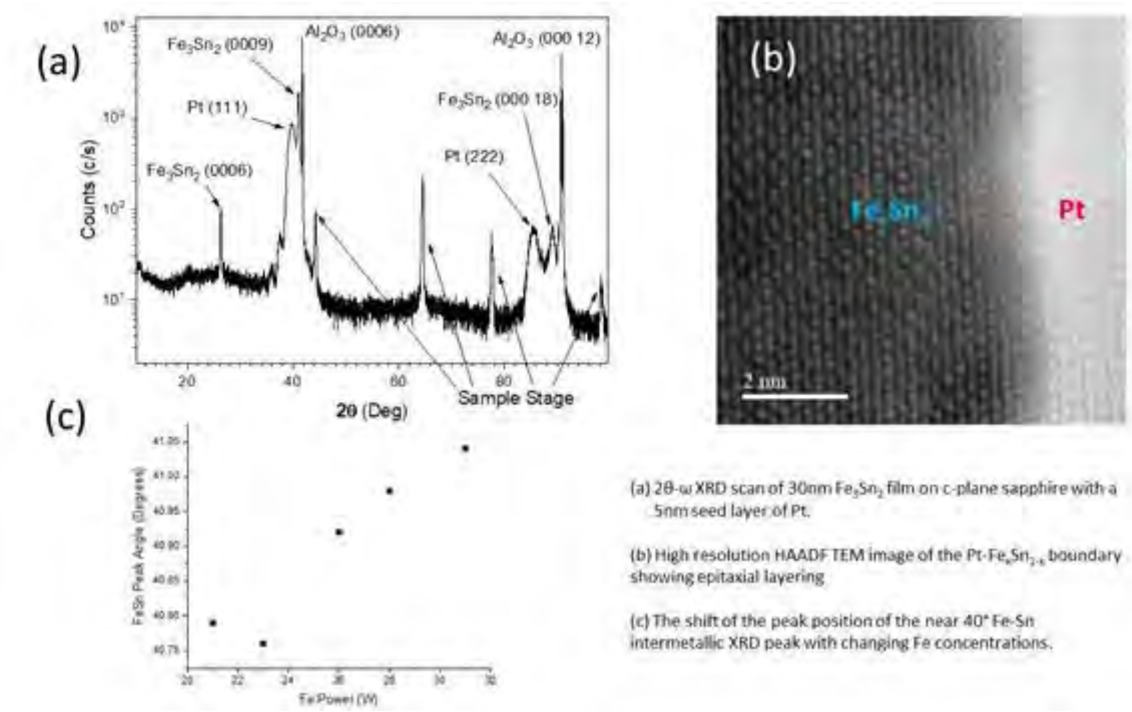

(a) 2θ-ω XRD scan of 30nm Fe_3Sn_2 film on c-plane sapphire with a 5nm seed layer of Pt.

(b) High resolution HAADF TEM image of the Pt-Fe_xSn_{1-x} boundary showing epitaxial layering

(c) The shift of the peak position of the near 40° Fe-Sn intermetallic XRD peak with changing Fe concentrations.

Topological insulator/magnetic multilayer heterostructures for skyrmion dynamics

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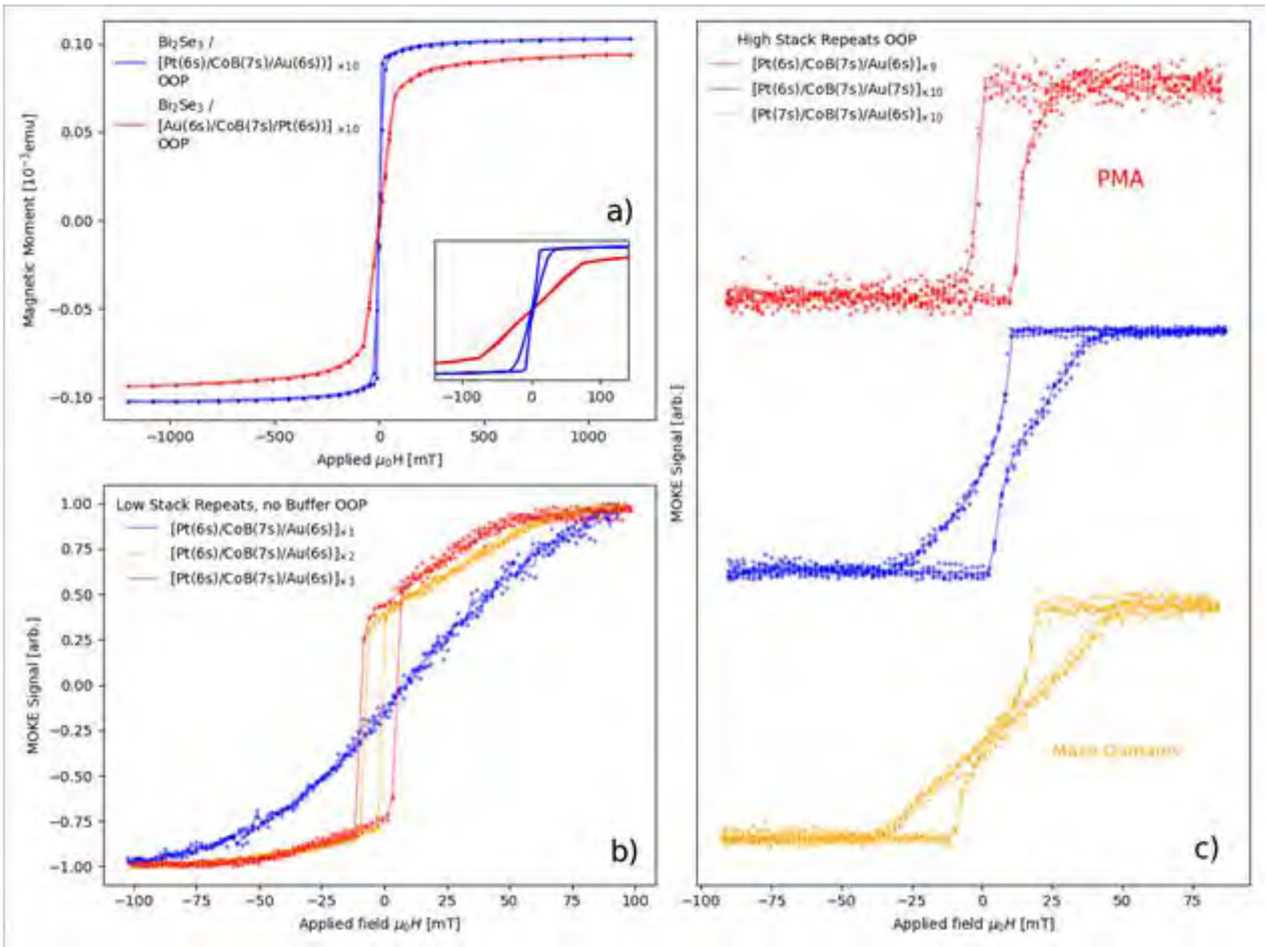
Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Ever since their first observation over a decade ago [1], magnetic skyrmions have offered a new frontier in magnetic data storage within low dimensional systems. These vortex-like configurations of magnetic spin benefit from their small size and solitonic character reinforced by their non-trivial topology [2]. Topological insulators (TIs) are another such material: their spin-locked momentum states allow for injection of spin currents and exertion of spin-orbit torques to nearby spin textures [3]. As magnetic skyrmions are known to be movable by these spin-orbit torques [4], it follows they should also be driveable by TIs.

To do so requires the construction of a skyrmion-multilayer/TI heterostructure. The well-established TI Bi2Se3 was grown in the University of Leeds' Royce deposition system through molecular beam epitaxy (MBE) and upon which a [Pt/CoB/Au] multilayer stack was grown by magnetron sputtering. The magnetic properties were studied through SQUID-VSM and magneto-optical Kerr effect (MOKE) microscopy. From this we demonstrate tailorable hysteresis loops, as seen in figure 1c, through manipulation of the multilayers properties with particular emphasis placed on ensuring the perpendicular magnetic anisotropy (PMA) of the sample as well as indicating the presence of chiral maze domains through a distinctive "bow-tie" shape to the hysteresis loop. The main variables available to us comprise of the element compositions, the stack repetition number and layer chirality seen demonstrated in figure 1b. Difficulties arise at the TI/multilayer or substrate/multilayer boundary where anisotropy tends to be strongly in-plane (seen in figures 1a-b respectively) ; potential solutions for this will be suggested.



Bi$_2$Se$_3$ / [Pt(6s)/CoB(7s)/Au(6s))]$_{\times10}$ OOP
Bi$_2$Se$_3$ / [Au(6s)/CoB(7s)/Pt(6s))]$_{\times10}$ OOP
Magnetic Moment [10^{-3}emu]
Applied μ_0H [mT]
a)
Low Stack Repeats, no Buffer OOP
[Pt(6s)/CoB(7s)/Au(6s)]$_{\times1}$
[Pt(6s)/CoB(7s)/Au(6s)]$_{\times2}$
[Pt(6s)/CoB(7s)/Au(6s)]$_{\times3}$
MOKE Signal [arb.]
Applied field μ_0H [mT]
b)
High Stack Repeats OOP
[Pt(6s)/CoB(7s)/Au(6s)]$_{\times9}$
[Pt(6s)/CoB(7s)/Au(7s)]$_{\times10}$
[Pt(7s)/CoB(7s)/Au(6s)]$_{\times10}$
PMA
Maze Domains
MOKE Signal [arb.]
Applied field μ_0H [mT]
c)

Ballistic spin injection via 1D nanomagnet/graphene interfaces

Mr Daniel Burrow[1], Mr Jesus C. Toscano-Figueroa[1], Dr Victor H. Guarochico-Moreira[1,2], Professor Tom Thomson[1], Dr Ivan J. Vera-Marun[1]
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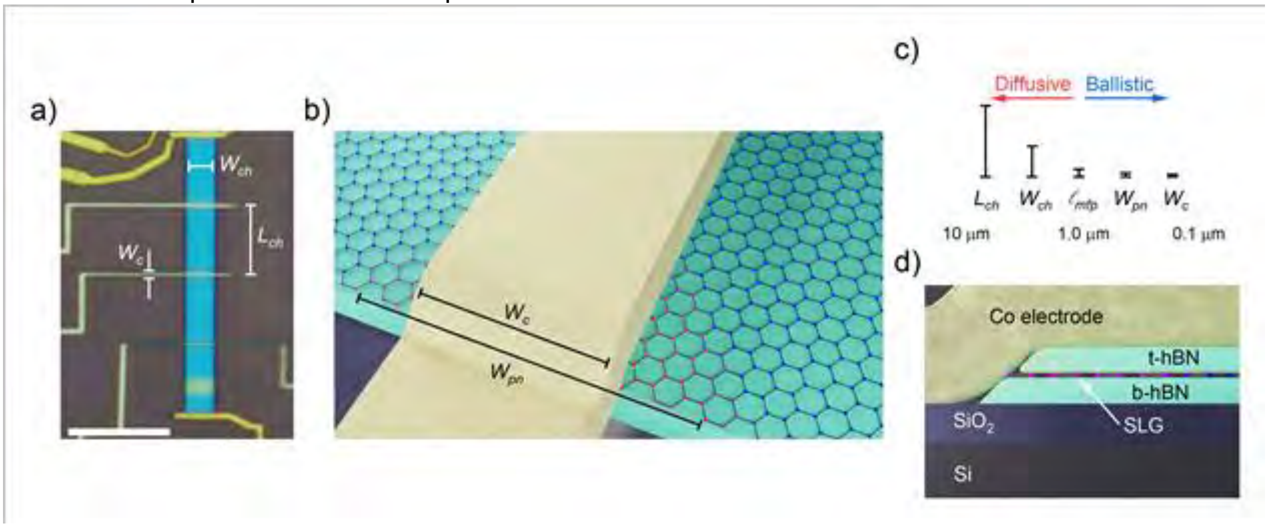
Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Our group recently reported encouraging results from a state-of-the-art spintronic device architecture, constituting a fully encapsulated single layer graphene channel with nanoscale, one-dimensional (1D) ferromagnetic contacts, in which we observed record high charge mobility for a spintronic device, and long-range spin transport (Fig. 1a). Full encapsulation of the channel in hexagonal boron nitride preserves the quality of the graphene, giving rise to high charge mobilities and long mean free paths, while 1D contacts mitigate the high levels of doping associated with tunnel contacts. Here, we exploit the geometry of the nanomagnet/graphene interfaces (Fig. 1b,d) to investigate ballistic charge injection and its effects on diffusive spin transport in the graphene channel. Conductance data taken at the interfaces, in the absence of an external magnetic field, displays 1D energy subbands at low temperature (20 K), implying the quantization of transport due to confinement of carriers on a length scale below their mean free path. Analysing this data with the Landauer equation allows us to extract the length scale of the 1D constrictions and the energy spacing of the emergent subbands, thus confirming the ballistic nature of transport via the 1D contacts, which occurs with a transmission probability, T ~ 0.25. Furthermore, we observe weak signatures of the ballistic injection in spin transport measurements of the graphene channel. Quantized conductance via 1D nanomagnet/graphene interfaces, in the absence of a deliberate graphene nanoconstriction, is a previously unreported result and demonstrates a path for the development of ballistic spintronics.



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

Dr Andrew Caruana[1], Dr Mathieu Doucet[2], Dr Paul Kienzle[3], Dr Brian Maranville[3]
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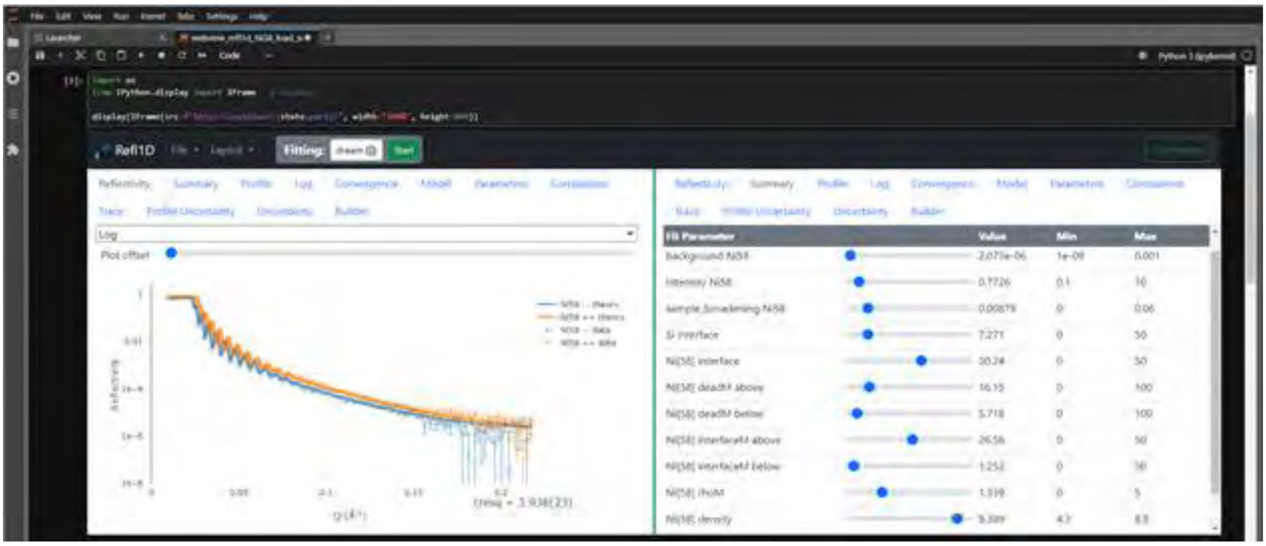
Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

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 uncertainty 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.



Reproducible reservoir computing with thermally driven superparamagnets: controlling temperature sensitivity

Zhengfei Chen[1], Dr A. Welbourne[1], A. L. R. Levy[3], Dr M. O. A. Ellis[2], H. Chen[1], M. J. Thompson[1], Professor D.A. Allwood, Professor N. A. Morley[1], Professor E. Vasilaki[2], Professor T. J. Hayward[1]
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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

The rising energy demands of AI, particularly for training artificial neural networks, are concerning amid urgent calls to cut greenhouse gas emissions. Reservoir computing (RC) looks set to be a promising solution due to their low training energy cost compared to the conventional recurrent neural networks (RNNs), with only output layers needing to be trained. Physical RC systems, especially magnetic systems with a single hardware-based node with non-linearity and fading memory, show promise to act as a reservoir [1]–[3].

We have recently proposed a superparamagnetic ensemble-based reservoir, driven by strain-induced magnetoelectric coupling stimulated by voltage, which has promise to provide extremely energy efficient performance (Fig. 1a) [4]. However, as the dynamics of these devices are thermally driven, changes in device temperature post-training are likely to reduce performance. Therefore, a thorough and quantitative understanding of thermal sensitivity of superparamagnetic reservoirs is critical.

Here we present a series of simulations that investigate the effect of temperature on the behaviour and computational performance of our voltage-controlled superparamagnetic device. First, we illustrate the competitive performance of the device in reservoir computing by performing two benchmark machine learning tasks: spoken digit recognition and chaotic time series prediction. Then, we demonstrate that there is an inverse correlation between the thermal stability of the device and the temperature at which the device is trained, when there is a temperature variance (Fig. 1b). Finally, we tentatively propose an idea: thermally-driven superparamagnetic devices hold potential as intelligent sensing. given the significant response between magnetization and temperature (Fig. 1c).

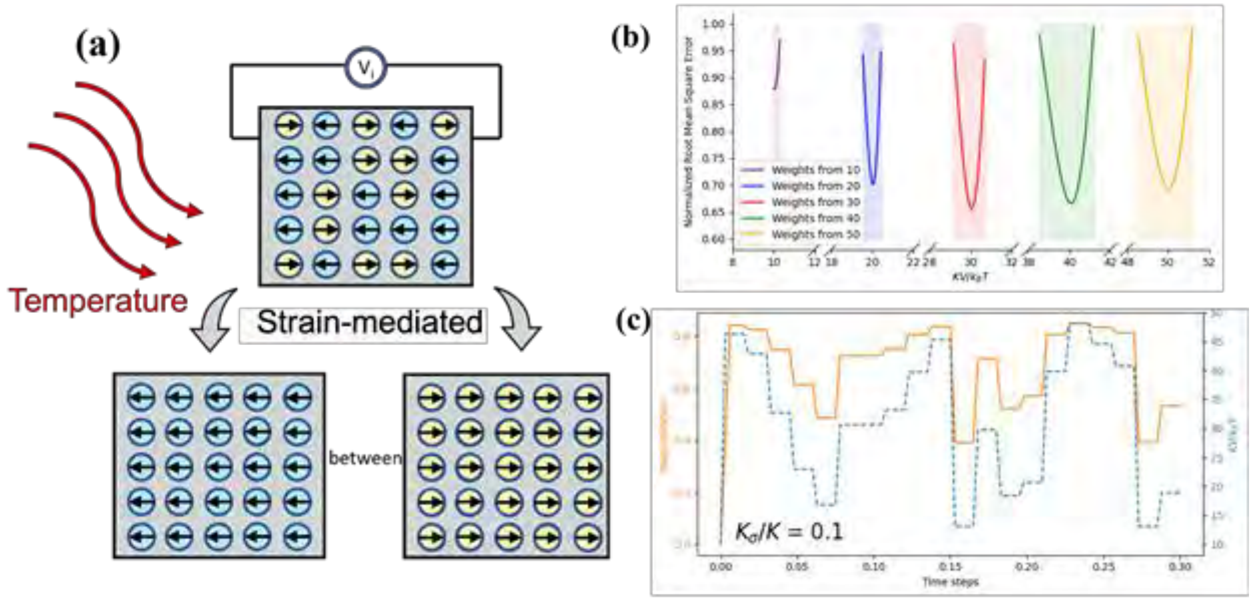

Figure 1: (a) A schematic diagram of voltage-controlled superparamagnetic nanodot ensemble subjected to temperature variations, (b) The computing performance changes of the device on NARAM10 task in response to Training-Testing temperature discrepancy and (c) Reservoir magnetization over time in response to a related-temperature input sequence.

Exploring spin-orbit torques on 50mm WS2/ferromagnet heterostructures

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Using 2-dimensional materials to produce functional spintronic devices is a rapidly expanding area of research, as tunnel barriers for magnetic tunnel junctions (MTJ) e.g. h-BN or as layers capable of generating spin orbit torques (SOT) [1]. Conventionally, SOT is a charge-to-spin current conversion that occurs in a normal metal (NM) that then exerts a magnetic torque on an adjacent ferromagnet (FM) in a NM/FM heterostructure. Recent demonstrations of heterostructures exhibiting large SOT efficiencies rely on a nonmagnetic material with large spin-orbit coupling, such as platinum. An alternative for charge-to-spin conversion are 2D transition metal dichalcogenides (TMDs, see Figure 1). TMDs possess the chemical formula MX2, where M is a transition metal and X a chalcogen. Previous work on TMD SOTs has focused on pristine flakes of TMDs [2] but such approaches are not scalable. Understanding the potential of wafer-scale TMD as SOTs layers is essential for developing viable SOT-MRAM using TMDs. Here, we explore WS2/permalloy bilayers, where the WS2 is grown by chemical vapor deposition (CVD) on 50mm wafers. This represents an emerging approach and understanding the challenges involved is essential to fabricate defect-free thin films and thus control their properties. We present results on the physical and electrical characterisation of CVD grown TMDs and observe spin-charge conversion via SOT-FMR measurements [3].

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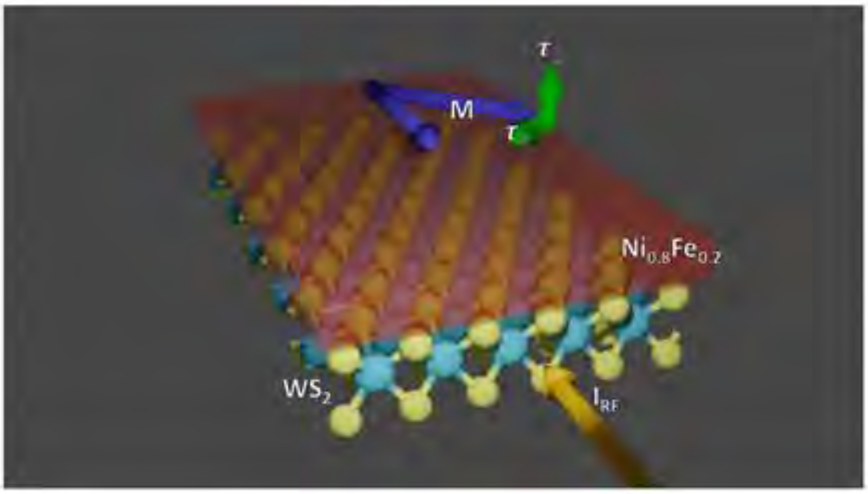

Figure 1: Permalloy/WS_2 heterostructure. A charge current is applied, which is converted into a perpendicular spin current. This exerts a parallel and perpendicular torque on the magnetisation of the permalloy. If this is large enough, the magnetisation of the film can be flipped.

Complex magnetism and spin dynamics of Mn5Si3 and Mn5Ge3

<u>Manuel Dos Santos Dias -</u>

[1]*STFC Daresbury Laboratory, United Kingdom*

Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Intermetallic compounds of Mn and Si or Ge show a rich variety of magnetic behaviour and transport effects of great interest for potential spintronics applications.
Here we present an overview of our combined experimental and theoretical investigations of the isostructural compounds Mn5Si3 and Mn5Ge3.
Mn5Si3 has a complex magnetic phase diagram with at least three distinct antiferromagnetic states depending on temperature and applied magnetic field.
Its spin dynamics have been probed with inelastic neutron scattering and shown to drive its inverse magnetocaloric effect [1], which led us to analyse its spin-wave modes in detail both in the intermediate temperature collinear antiferromagnetic phase and in the low-temperature noncollinear phase [2-4].
In contrast, Mn5Ge3 is well-known to be ferromagnetic, but our calculations unveiled the presence of Dzyaloshinskii-Moriya interactions in its centrosymmetric structure.
These interactions are responsible for the opening of a magnon energy gap at the K-point, a signature of their topological nature, which has been experimentally verified and can be controlled by a magnetic field [5].
Our findings pave the way for the engineering of the magnetic properties by chemical alloying of Si and Ge or intercalation of carbon, and for the rational design of magnetic heterostructures which are compatible with conventional semiconductors.

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Multi-Q magnetic phases from frustration and chiral interactions

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[1]*Loughborough University, United Kingdom*

Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

We investigate the effect of Dzyaloshinskii-Moriya (DM) interactions in the planar pyrochlore (checkerboard) antiferromagnet, one of the paradigmatic models of spin frustration, and establish the classical phase diagram using a combination of analytical and numerical approaches. While anisotropic interactions generally tend to remove the frustration, here we show that a high degree of frustration survives in a large region of the phase diagram. In conjunction with the fixed handedness introduced by the DM anisotropy, this spawns a cascade of incommensurate and double-twisted multidomain phases, consisting of spatially intertwined domains of the underlying competing phases of the isotropic frustrated point. The results underpin an interesting mechanism of generating multi-Q phases in systems that combine high degree of frustration and chiral interactions.

Anisotropy in magnetism and magnetocaloric effect in Gd2NiMnO6 double perovskite thin films

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

The magnetism and magnetocaloric effect in double perovskites (R2BB'O6) are extensively studied topics. Particularly, the local ordering of B-B' sublattices and B-O-B' superexchange interactions are sensitive to chemical substitution, synthesis/ growth conditions, strain etc. In this study, we present the effect of interfacial strain on the magnetic ground state, magnetic anisotropy and magnetocaloric effect in Gd2NiMnO6 thin films grown by pulse laser deposition on SrTiO3 substrates. We observe a change in the relative-spin orientation of Ni and Mn from antiparallel to parallel configuration with increasing strain. This is further supported by density functional theoretical calculation. We also observe perpendicular magnetic anisotropy arising due to interfacial tensile strain between Gd2NiMnO6 film and SrTiO3 substrate. The anisotropic nature persists in magnetocaloric effect as well. In fact, the magnetic entropy change along the in-plane orientation is found to be twice of that along the our of plane orientation. Existence of larger magnetic entropy change along the easy axis direction has been previously observed in Gd2CoMnO6 and Tb2CoMnO6 single crystals as well.

Enhanced Non-Reciprocity of SAW-FMR in Magnetic Multilayer Films

Dr Emma Gilroy[1], Dr Yat-Yin Au[2], Dr Andrey Shytov[2], Prof Volodymyr Kruglyak[2], Prof Thomas Hayward[1]
[1]University Of Sheffield, United Kingdom, [2]University of Exeter, UK

Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

The development of spin wave devices promises exciting new advancements in many aspects of computer technology but are limited by short spin waves propagation distances in metallic materials. In contrast, surface acoustic wave (SAW) devices are well established and propagate over millimetre length scales with little dissipation. Integrating SAWs with spin wave research provides novel methods of manipulating spin waves for technological applications.

When magnetic materials couple magneto-elastically to SAWs, magnetic resonance can be observed, which is known as SAW-FMR[1], and in the Damon-Eshbach geometry this exhibits non-reciprocity due to broken time reversal and spatial inversion symmetries[2]. However, in thin film devices coupling is limited due to the elliptical precession caused by shape anisotropy. Compensating this with a modest perpendicular anisotropy may create a more circular precession, and stronger coupling. In particular, ultrathin Ni/Co multilayers are promising material systems as they exhibit PMA, and have damping similar to that of Ni[3].

By varying Co thickness (tCo = 0.3-0.5nm) in these layers, a transition from out-of-plane to in-plane anisotropy was observed, with tCo = 0.45nm appearing to be close to the point of transition. In fig.1a MOKE data indicates out-of-plane hard axis behaviour, with an easy axis in-plane. However, FMR data (fig.1b) highlights a significant reduction in Ms, suggesting the magnetisation is canted. By measuring SAW devices which include [Ni(0.6nm)/Co(tCo)]6 films (as in fig.1c), we explore how coupling and non-reciprocity very close to this compensation point.

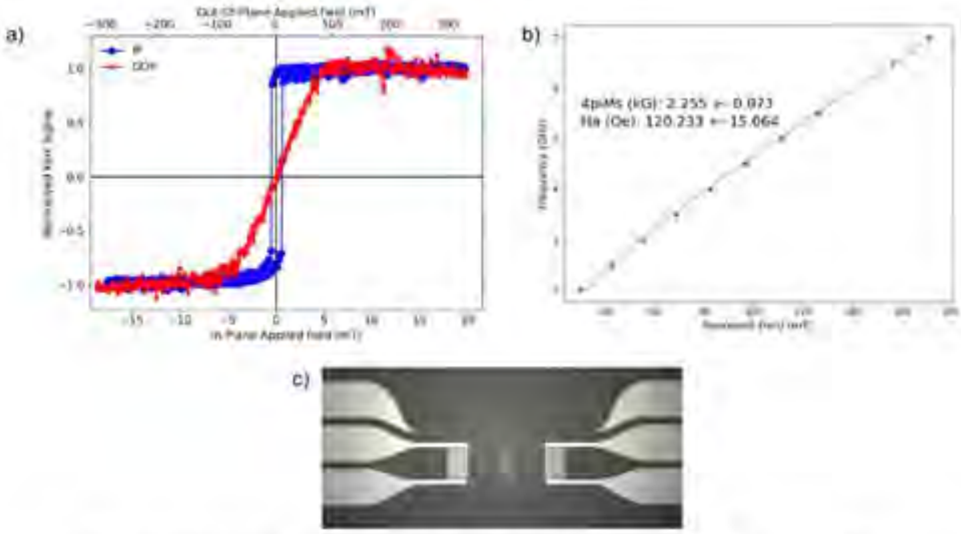

Fig.1 Characterisation of Ni/Co thin films and a standard SAW-FMR device.
a) In-plane (blue) and out-of-plane (red) MOKE loops of $[Ni(6Å)/Co(4.5Å)]_6$ multilayer, highlighting that the magnetisation does appear not preferentially lie out-of-plane. b) Kittel curve of of $[Ni(6Å)/Co(4.5Å)]_6$ multilayer. M_s is much smaller than expected, suggesting that the magnetisation does not lie fully in-plane. c) Aluminium IDTs on LiNbO3 with magnetic thin film placed in the path of the SAW propagation.

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Analogue and digital circuit design for computing with skyrmionic artificial synapses

Maciej Lewandowski[1], Will Griggs[1], Ioannis Charalampidis[1], Vasilis Pavlidis[2], Christoforos Moutafis[1]
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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Magnetic skyrmions are attractive candidates as information carriers in next-generation logic and memory devices owing to their nm-scale size, topological stability, and high mobility. There is much optimism that skyrmions may be leveraged for novel computing paradigms such as in reservoir [1], probabilistic, [2], and neuromorphic [3-5] computing. Recent research has focused on using skyrmions to encode discrete states in artificial synapse devices [4,5], which may be used to perform multiply-accumulate operations with greater energy efficiency compared to traditional CMOS technology. An advantage of this skyrmionic approach is its non-volatility, as the synaptic state is represented magnetically, eliminating the need for additional energy consumption and space-consuming refresh circuits.

While several studies have sought to optimise the design of skyrmionic synapses, considerations for the peripheral CMOS and analogue circuitry are seldom reported. In order for the advantages of these devices to be realized, it is essential that they are integrated into low power, compact circuits for current scaling, implementing activation functions, and efficient propagation of signals to downstream layers.

Here we present our work to design CMOS and digital circuitry which is compatible with our previously proposed skyrmionic synapses [4,5]. We proceed with systematic QSPICE/FineSim simulations to optimise peripheral circuitry which converts signals from an array of synapses into spikes for downstream processing according to a leaky integrate and fire neuron model (Fig. 1). We show that with our design it should be possible to achieve inference with a power consumption in the tens of fJ per spike.

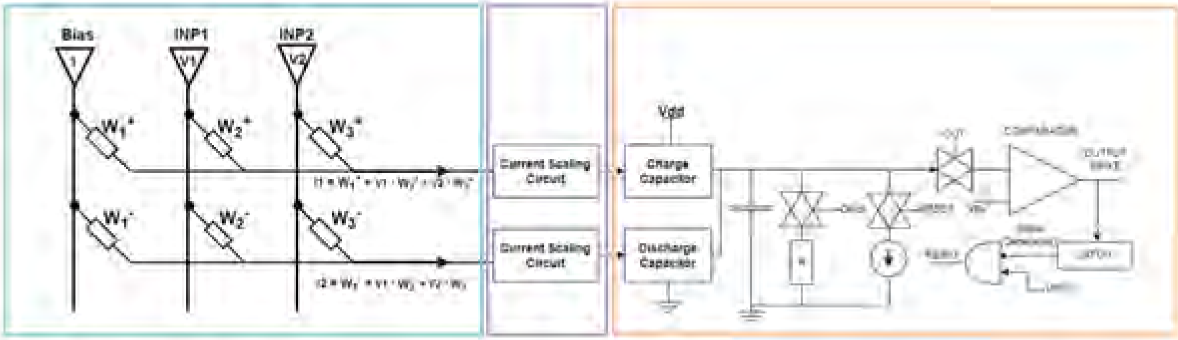

Figure 1. A schematic representation of the skyrmionic synapses and leaky integrate and fire circuit design.

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Towards experimental realization of zero-field skyrmionic artificial synapses

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

The recent proliferation of highly resource-intensive artificial intelligence (AI) has underscored the growing need for innovative computational approaches that offer enhanced performance and efficiency. This demand is particularly evident in fields such as healthcare, autonomous driving, and robotics, where considerations such as data privacy, low latency, and operational reliability are critical. In neuromorphic computing, this problem is addressed by invoking principles inspired by the human brain, which achieves remarkable performance with a power consumption as low as ~20 W across a wide range of tasks.

Previously we have numerically demonstrated the possibility of using magnetic skyrmions to encode synaptic states in an artificial synapse device [1]. The device comprises a nanotrack partitioned into pre- and post-synaptic regions by a centrally positioned barrier of modified magnetic anisotropy (see Fig. 1) [1,2]. By driving skyrmions through the nanoconstrictions either side of the barrier using spin-orbit torques, the conductance of a magnetic tunnel junction (MTJ) situated in the post-synaptic region can be controllably modulated, emulating the long-term potentiation and depression processes observed in the human brain.

Here we present our progress towards experimental verification of our synapse design. We have nanofabricated skyrmionic synapses from a structure comprising [Pt(2.4)/CoFeB(1.0)/Ir(0.5)]8 (thicknesses in nm inside parentheses), which are characterised through magnetic force microscopy (MFM) measurements with custom-engineered in-situ perpendicular magnetic fields. We demonstrate that skyrmions are stable even at zero applied field (MFM middle layer of Fig. 1) and show progress towards modifying magnetic domains or skyrmions in the post-synapse region through applied programming current pulses.

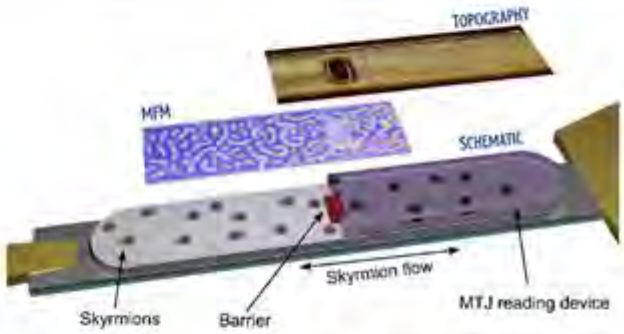

Fig. 1. A schematic of a skyrmionic synapse device. Pre- and post-synapse regions are separated by a barrier region of modified magnetic anisotropy. Also shown (middle layer) is an MFM image from a nanofabricated synapse at zero magnetic field.

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Nanomagnetism seen with neutrons: Small-angle Neutron Scattering

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

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.

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First-Principles Calculation of Surface Anomalous Nernst Effect in Antiferromagnet

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

The thermoelectric effect, which generates an electric field from a temperature gradient, holds significant potential in the field of energy conservation by harnessing waste heat. This phenomenon, known as the anomalous Nernst effect in magnetic materials, produces a transverse thermoelectric effect, generating an electric field aligned with the cross-product of the material's temperature gradient and magnetization or virtual magnetic field. While anomalous Nernst effect was previously observed in ferromagnetic materials with finite spontaneous magnetization, there has been a growing number of reports on anomalous Nernst effect in antiferromagnetic materials.

We have developed first-principles methodology to compute the anomalous Hall conductivity based on local Berry phases [1]. In this study, we have extended this methodology to calculate Hybrid Wannier functions, enabling us to decompose the contributions of anomalous Hall and Nernst effects in van der Waals layered materials on a per-layer basis. As an application of this method, we have decomposed the anomalous Hall and anomalous Nernst coefficients in the carrier-doped metallic phases of MnBi2Te4 [2] and Cr-doped Bi2Se3[3], thus allowing us to compute surface anomalous Hall and Nernst effects. These calculations have expanded the possibilities of anomalous Nernst effect within antiferromagnetic materials.

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

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

$xBiFeO_3$-(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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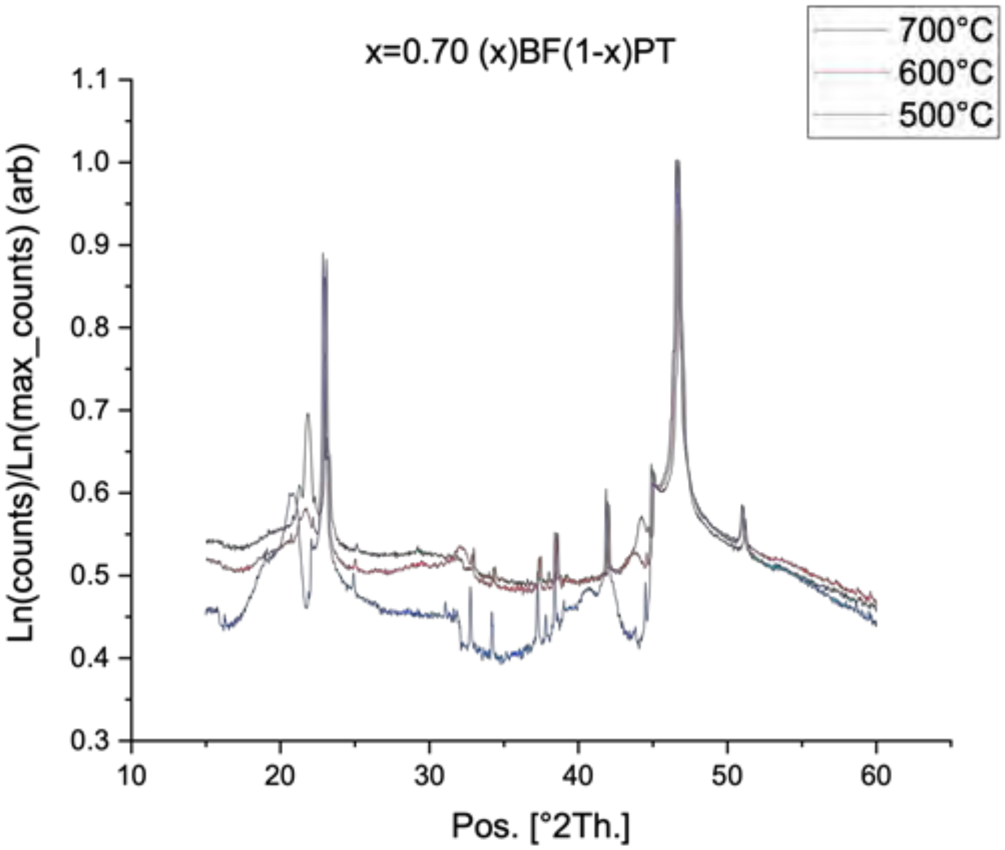

Figure 1: XRD data collected for x=0.70 (x)BF-(x-1)PT where deposition chamber temperature varied

Magneto-optical Kerr effect characterisation of static and dynamic processes in a Thulium Iron Garnet film

Dr Paul Keatley[1], Prof Robert Hicken[1], Prof Caroline Ross[2], Dr Miela Gross[2], Prof Atulasimha Jayasimha[3], Mr Fahim Chowdhury[3]
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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Thulium Iron Garnet (TmIG) films have recently shown promise for ultralow switching current density in spintronic applications[1]. Understanding the TmIG equilibrium state and corresponding sub-nanosecond magnetization dynamics will allow further optimisation for spintronic devices. Here we use a combination of wide-field and time-resolved scanning Kerr microscopies to characterise the ferrimagnetic domain structure and magnetization dynamics of 6.4 nm thick TmIG grown by pulsed laser deposition on a (111)-oriented Gadolinium Gallium Garnet substrate. Out-of-plane and in-plane magnetometry (hysteresis loops and domain imaging) was carried out for two principal wavelengths of 400 nm and 520 nm to identify the optimum magneto-optical contrast. The resonance frequency as a function of in-plane magnetic field was then extracted from time-resolved measurements at the optimum wavelength. Hysteresis loops demonstrate a clear out-of-plane magnetic anisotropy with a low coercivity below 1 mT. The magnetization can be pulled in-plane with only moderate applied fields indicating a low perpendicular magnetic anisotropy. The domain images reveal a combination of large area uniform magnetization domains punctuated with regions of finer labyrinth-type domains that may be correlated with local variations of strain, for which TmIG has a significant dependence[1]. Such variations would not be readily detectable in bulk characterisation techniques. Time-resolved measurements of precession of the magnetization biased in-plane show an almost linear dependence on in-plane magnetic field, and a low precession frequency into the sub-GHz regime. These results show that magneto-optical Kerr effect measurements will be a critical tool for the continued optimisation of such materials for spintronic applications.

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Magnetic contacts to probe helical edges states in InAs/GaSb coupled quantum wells

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

The quantum spin Hall effect (QSHE) defines a two-dimensional topological insulating state[1],[2]. The characteristic spin-momentum locked helical edge states offer potential for novel spintronic devices. Evidence for the QSHE in coupled InAs/GaSb quantum wells (QWs), a III-V grown by molecular beam epitaxy, has been demonstrated[3],[4].
Here, we report the fabrication and transport characteristics of dual gated InAs/GaSb devices, with the aim of tuning carrier populations to the QSH insulator state and probing edge transport. This will be achieved via spin-current injection into the edge regime, by integrating ferromagnetic contacts into standard Hall bar devices. Figure 1(a) shows a generalised wafer structure, varying by QW thickness and buffer layer composition. Figure 1(b) shows the top-gate voltage dependent sheet resistance of a device, where the resistance peak corresponds to a charge neutral region in which the topologically non-trivial insulating band gap may be found. We have attached Permalloy magnetic contacts in a transmission line measurement geometry, shown in Figure 1(c), both on top of and spanning the mesa. Therefore, we also present preliminary Py contact testing data, comprising fabrication optimisation and TLM measurements. Py contacts have shown both Ohmic and Schottky behaviour. Kerr microscopy reveals 13.6 Oe (easy axis) and 1.1 Oe (hard axis) coercivities that are in agreement with evaporated Py thin films on Si substrates[5].

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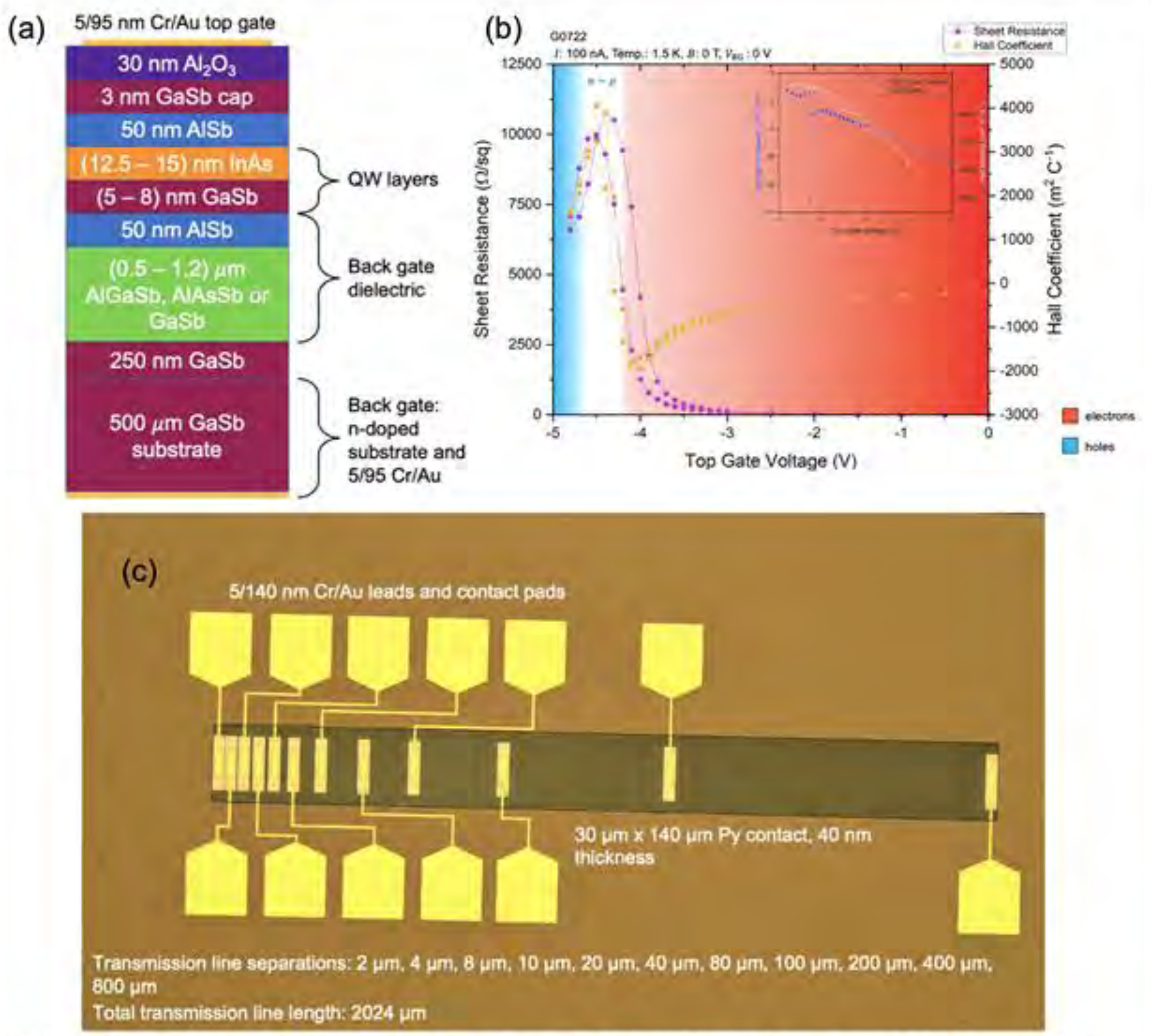

Figure 1: **a.** General QW wafer structure. **b.** Sheet resistance and Hall coefficient with varying top gate voltage for an AlGaSb buffer device. **c.** Micrograph of Py TLM device.

Structural and Magnetic depth profiling of Magnetic Thin Films with the POLREF reflectometer

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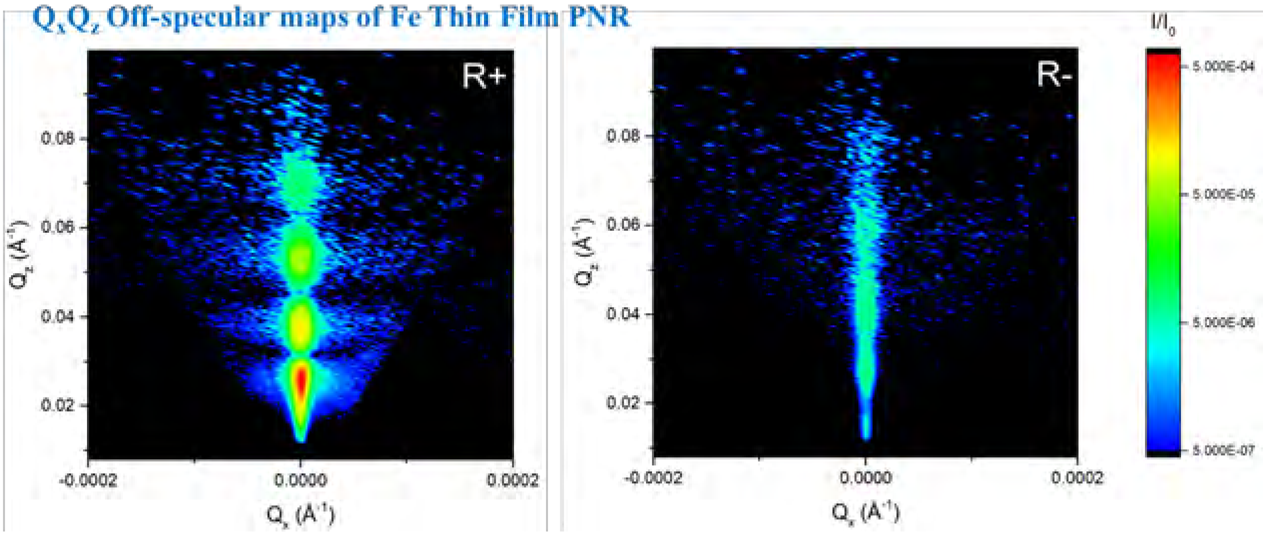
Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

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. Here, we will present the current capabilities of the POLREF beamline, including science highlights and how to get access to the ISIS neutron facility and POLREF beamline.



Magneto-acoustic metamaterials: From bulk to surface acoustic waves

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[1]*University of Exeter, United Kingdom*

Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Owing to magneto-elastic coupling, acoustic waves may be scattered resonantly by magnetic elements [1]. The scattering may be further enhanced via the Borrmann effect when the elements form a periodic array [2]. Here, we report on the use of finite-element modelling to explore how the findings above map onto surface acoustic waves [3]. Specifically, we consider single- and double-layer Ni stripe arrays patterned on top of a LiNbO3 substrate that carries Love SAWs. We observe enhancement of the coupling for single-layer stripes, but only for Gilbert damping below its realistic value. For double-layered stripes, a weak yet clear and distinct signature of Bragg reflection is identified far away from the acoustic band edge, even for a realistic damping value. Double-layered stripes also offer better magnetic tunability when their magnetic period is different from the periodicity of elastic properties of the structure because of staggered magnetization patterns. The results pave the way for the design of magneto-acoustic metamaterials with an enhanced coupling between propagating SAWs and local magnetic resonances. Such metamaterials may lead to development of reconfigurable SAW-based data circuits and unconventional computing approaches, such as artificial neural networks and reservoir and in-memory computing.

The research is funded by EPSRC (projects EP/L019876/1 and EP/636 T016574/1).

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Pressure-induced, strain-tuned Kondo response in Pd2MnIn Heusler alloy

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Over the past few decades Heusler alloys have provided a rich ground for exploration and discovery of half-metal candidates resulting in the progress of diverse spintronic applications. The current investigation in Heusler alloy Pd2MnIn demonstrates how the application of pressure could be used to introduce local deformational strain into the lattice and its effect of magneto-electronic properties in these systems. The results, showcasing high-pressure neutron diffraction experiments, X-ray diffraction and magnetisation studies, indicate that cycling to ≃70 kbar irreversibly locally deforms the crystal lattice leading to the formation of ferromagnetic, glassy Kondo islands that persist up to high temperatures and ambient pressure conditions.

The newly discovered strain-driven Kondo response could lead to breakthroughs in the search for half-metals, Kondo metals and other unconventional spintronic materials. The ability to manipulate magnetic and electronic properties through strain-controlled Kondo response is an attractive approach to engineer and design novel materials for spintronic and related applications. The implications of this discovery reach far beyond the field of Heusler alloys and could be particularly relevant in low-dimensional materials [1], their derivatives and nanostructures which are, due to their reduced dimensionality, more susceptible to strain and deformation.
Utilising strain-controlled magneto-electric-elastic phenomena may create a road map towards innovative technological applications to help address the global challenges that we face today.

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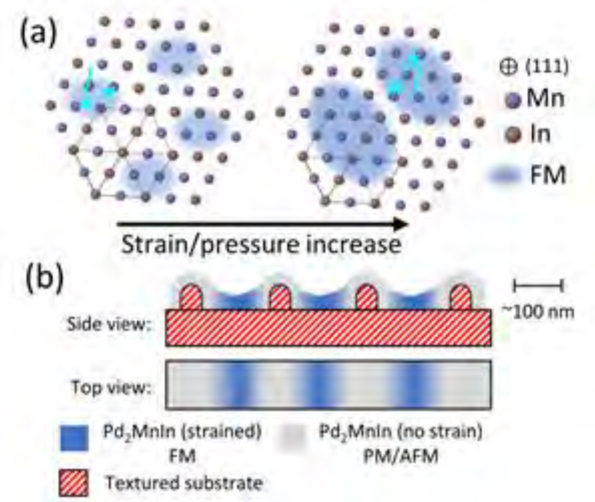

Triple coil setup for studies of magnetic properties at high pressure

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

In modern high-pressure research there is growing demand for reliable, sensitive methodology to measure magnetic
properties of materials at high pressure. Numerous approaches of varying complexity exist in this field [1]. Here, we have
developed a new AC susceptometer set-up consisting of only three coils, concentrically wound onto one former. The
susceptometer is compact and reusable and can be readily combined with the Diacell® ChicagoDAC. The new AC susceptometer technique is used to follow the magnetic transitions in Fe2MnSi Heusler alloy through a range of pressures 0 - 9 GPa. Fe2MnSi shows both a ferromagnetic transition TC=225K on the Fe-site and antiferromagnetic transition TN=67K on the Mn-site. [2]

The new approach to measure magnetisation at high pressure demonstrates a sensitivity of the order of ~10-8 emu, making it comparable to standard commercial magnetometers. The methodology is also time-efficient, cost-effective and reliable. Whilst the technique was primarily developed for high-pressure use, due to its compact design and high sensitivity it may be equally applicable for studies of magnetic thin-films, nanostructures and spintronic devices.

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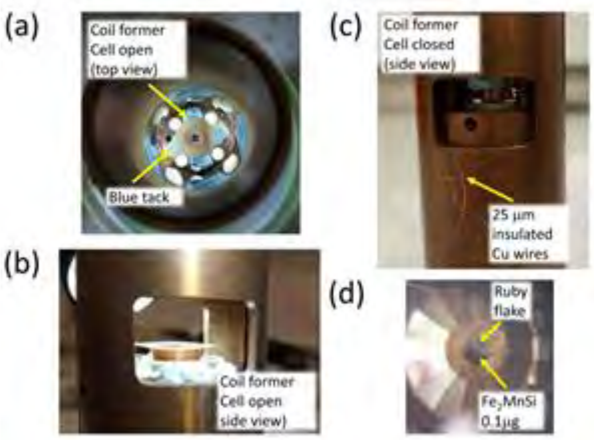

Perspectives for Light-Controlled Nanomagnetic Computing via Magneto-Thermoplasmonics

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Neuromorphic-inspired computing aims to create new paradigms and energy-efficient hardware to solve demanding computational problems. Magnetic metamaterials offer themselves as a platform for such unconventional computing approaches, with highly versatile and tuneable nanoscale spin textures combining rich dynamics, non-volatile data retention, and energy-efficient spintronic readout. Schemes for nanomagnetic data processing rely on effectively encoding the input, setting the boundary conditions for the problem to solve, as well as efficient methods to control and steer the spin dynamics at the heart of computation.

While heat conventionally does not directly affect the magnetisation state, it however has a profound influence on saturation magnetisation, anisotropy, and magnetisation dynamics as well as switching kinetics. As such, local heating provides an interesting control pathway which can be achieved on nano- to millimetre length scales in hybrid magneto-thermoplasmonic devices. In these, localised plasmon resonances enable efficient (up to several 100 K), reconfigurable (via light polarisation), and fast (down to ps) light-controlled heating [1] for versatile remote-controlled nanomagnetic computation schemes. One such example application are optically reconfigurable nanomagnetic Boolean OR/AND gates with nanosecond operation at picojoule energies that result in a non-volatile state [2]. Here, further ideas for magneto-thermoplasmonic computational devices will be discussed, highlighting the versatility of thermal-based optical control for future non-conventional computing.

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Enhancing spin signals in pure spin currents

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Reducing heat in IT systems is one of the challenges we are facing in order to improve and develop new ways to conduct and storage energy. Cooling is an approach but it is not only too energy consuming but also quite harmful for the environment. Taking advantage of spintronics by using pure spin currents, which are able to transfer angular momentum without charge and hence avoid Joule heat, offers a feasible solution to minimize heat creation during electron transport in devices. The purpose of this project is to develop ways in which spin currents may be enhanced. We have used lateral spin valves of Ag with magnetic electrodes in order to investigate the effects of doping on the magnitude of the spin current and the spin diffusion length of the Ag-doped material. We have found that the effect of the dopants depends on the chemical nature and the position of the dopants in the wire, i.e. whether the wire is doped at the surface or in the bulk of the material. We have found that there is a combination of dopant and position that results in a significant increase in spin currents at room temperature suggesting the potential of applications.

DEVELOPING NOVEL MAGNETIC L10 ALLOYS FOR SPINTRONICS

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Ferromagnetic thin films consisting of binary alloys with L10 crystal structure can have both high saturation magnetization and high anisotropy [1]. Examples includes FePt, which is currently used as the medium in heat assisted magnetic recording (HAMR) and FePd having significant potential in spintronic devices. Another L10 alloy with significant potential is the τ-phase MnAl, with its high magnetic moment, Curie temperature of 650K and large magneto crystalline anisotropy constant [1]. However, the τ-phase Mn–Al formed by the transformation from the high-temperature ε phase is metastable and requires specific conditions with a finite compositional window in the Mn-Al binary phase diagram to be stable [2].
The structural and magnetic properties of L10 ordered Mn-Al multi-layered films prepared by DC magnetron sputtering alternately stacks of Mn and Al layers on Si/SiO2 films were investigated (fig 1a). In order to understand the effect of annealing temperature, we have investigated Si/SiO2/[Mn(2.2nm)/Al(1.62nm)]10 multilayer film. Fig 1b shows that annealing at 100°C for 2 hrs results in a small magnetic moment. The interfacial ferromagnetic region and magnetization is expected to increase with annealing temperature due to further intermixing. The effect of annealing at temperatures in the range of 50°C to 500°C will be presented.

Fig 1
a) Multilayer deposition
b) Initial results (annealed the multilayer at 100°C for 2 hrs)

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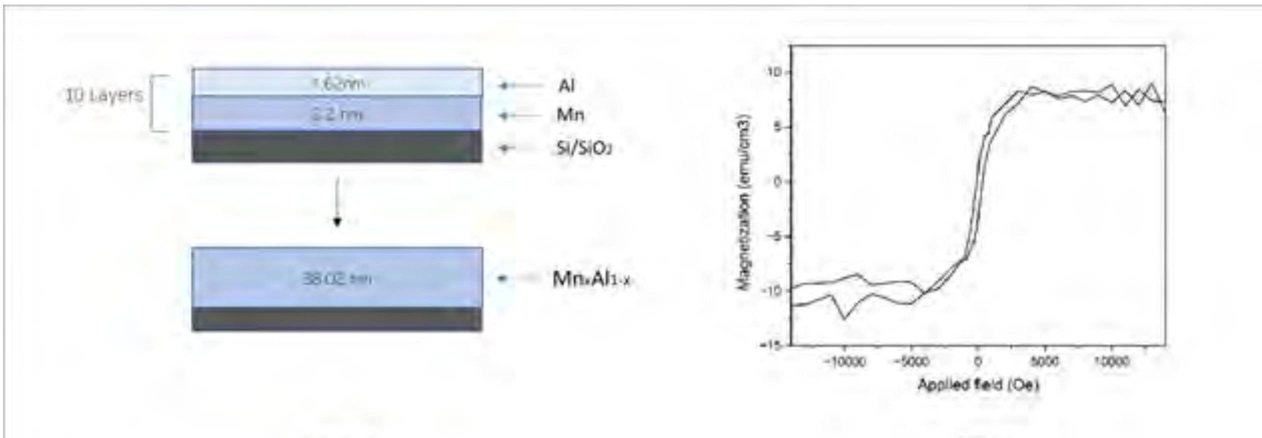

Fig 1a   Fig 1b

Quantum thermal expectation values from an effective atomistic spin dynamics model using path integrals.

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[1]University Of Leeds, United Kingdom

Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Atomistic spin dynamics, combined with ab-initio methods or experimental characterisation, for proper parametrisation of interactions within a given magnetic compound, has proven to be a very useful tool within the magnetism community, from fundamental understanding of the dynamics of complex phenomena, to proper engineering of device properties.

This method is, however, fundamentally based on classical assumptions and struggles to capture direct consequences of the intrinsic quantum nature of magnetism. A simple example of these are zero-point fluctuations in antiferromagnets, which arise due to the fact that the classical Néel state is not a ground state of the quantum system.

In previous work, we have developed a model based on a path integral approach to derive an effective field to use in classical atomistic simulations, which enables to recover quantum thermal expectation values for a single spin in an external magnetic field [1].

We are now extending this work to include the exchange interaction in the Hamiltonian of the quantum system so as to be able to recover quantum fluctuations of a non-local nature. This is a first step to adapting this model for real magnetic compounds and potentially provide an efficient way of including effects due to quantum fluctuations for materials where these are fundamentally more important such as frustrated antiferromagnets.

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

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

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

Here we develop Pt(40Å)/Co68Fe22B10(t)/Ru(10Å) single layer thin films [3] for use in SAW skyrmion motion devices. We use wide field Kerr microscopy to measure hysteresis loops and image magnetic domains. The hysteresis loops become bow tie shaped in the range t = 7.0Å – 7.8Å (Fig. 1). Within this range maze domains have been observed (Fig. 2) with domain widths on the scale of 1 μm, making these films good candidates for directly observing the interaction between SAWs and skyrmions.

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Figure 1: Si/SiOx/Ta(500Å)/Pt(40 Å)/Co68Fe22B10(t)/Ru(10 Å)/Pt(40 Å) thin film hysteresis loops measured with Kerr microscopy.

Figure 2: Kerr microscope image of a Si/SiOx/Ta(500Å)/Pt(40Å)/Co68Fe22B10(7.5Å)/Ru(10Å)/Pt(40Å) thin film at 0 (mT) after ac demagnetisation. The domains have formed a maze-like structure.

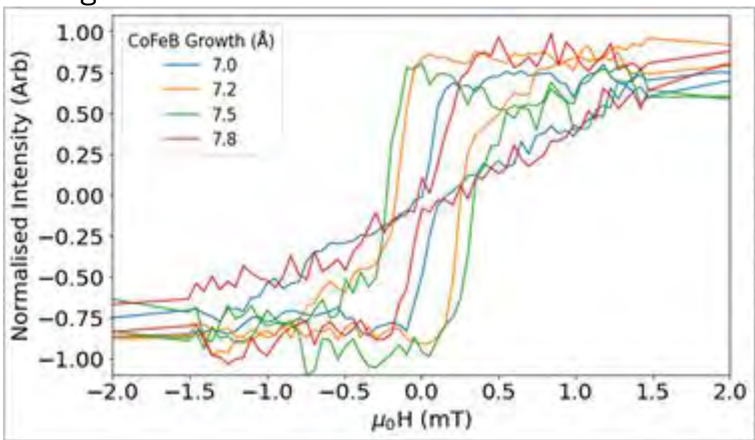

Figure 1

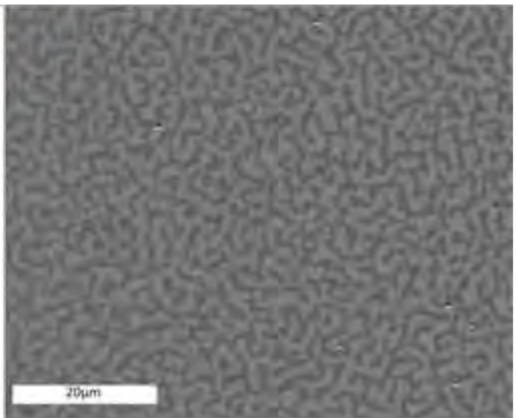

Figure 2

Recent Developments on Materials & Magnetism Beamline, I16 at Diamond Light Source Ltd

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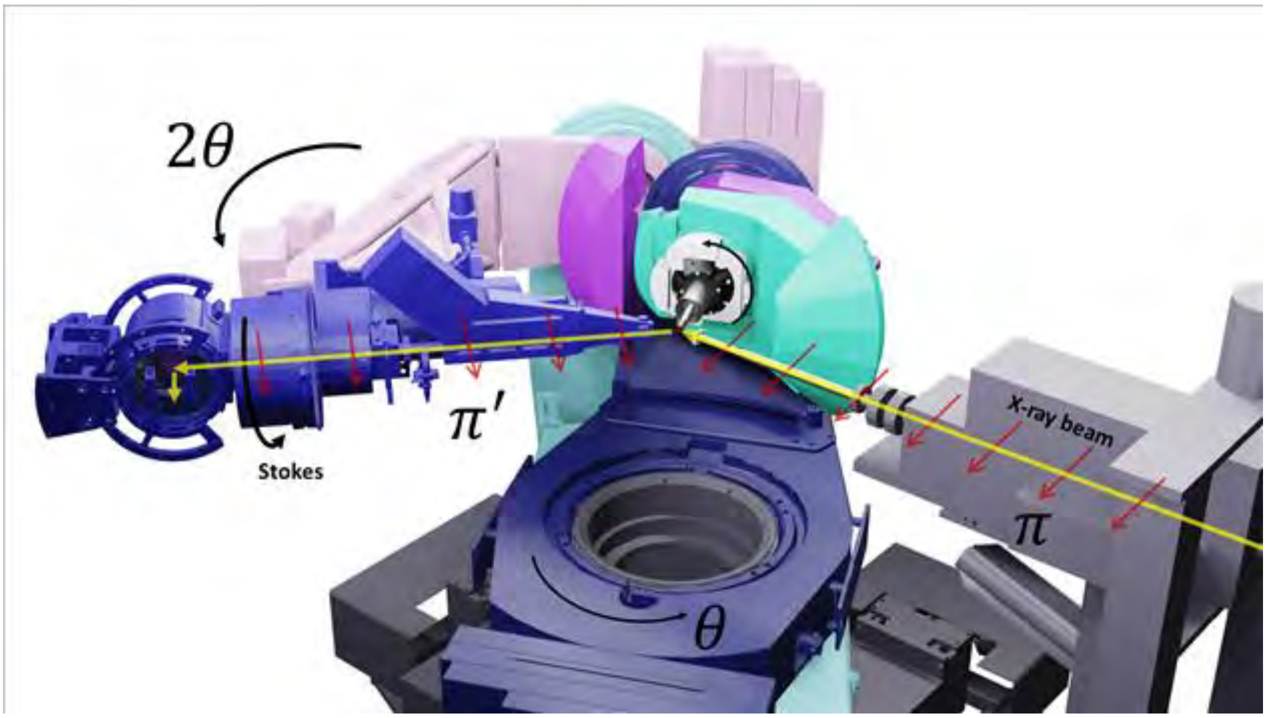
Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

I16 is a medium-energy high-resolution diffraction facility optimized for the study of resonant and magnetic scattering processes from single crystal samples with the goal of characterizing various electronic ordering processes such as magnetism, charge, and orbital ordering. The main scientific focus of the beamline is the study of complex ordering phenomena in strongly correlated electron system via resonant scattering processes and non-resonant magnetic diffraction as well as the study of fundamental x-ray physics mostly in relationship with exotic scattering processes.

The beamline has been highly successful in examining weak scattering phenomena, either from exotic scattering processes or from very small samples, in extreme environments, from 6-800 K and in electric or magnetic fields. Recent improvements to the beamline have provided increased stability of the beamline and many “ease of life” and automation features, speeding up data collection and allowing for more experimental time to be spent looking at the intended physical phenomena. As well as this, new equipment allows in situ strain measurements to be performed.

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



Testing the capacity of microcoil devices for pulsed magnetisation reset in pump-probe measurements

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Time-resolved pump-probe measurements of magnetisation dynamics are critical to the understanding of a wide range of magnetic phenomena, notably that of ultrafast demagnetisation [1], and all-optical switching [2].

Time-resolved experiments are usually performed with the sample continuously exposed to an external magnetic field with the purpose of resetting its magnetic state in between each pair of optical pump-probe pulses. This constant external field can obscure the intrinsic magnetisation dynamics [3], which are particularly relevant to the study of multiple pulse all-optical magnetisation switching and other dynamics excited in a cumulative manner.

This work shows the viability of microcoil devices [4] in combination with a pulsed laser diode driver for producing magnetic pulses suitable for magnetisation reset. These have the capacity to produce pulses with durations variable between 100ns and 2.1μs, and rise/fall times on the order of 50ns. The magnitude and repetition rate of those pulses are readily tuneable up to the order of 200mT and 200kHz respectively, with potential for integration into time-resolved magneto-optical studies of ultrafast magnetic behaviour.

The dynamics of magnetisation reset is compared between three different samples with out-of-plane magnetisation using a high-speed balanced photodetector. Clear differences in response are observed between metallic multilayer [Ni/Pt] and [Co/Pt], and insulating magnetic garnet.

[1] Beaurepaire, E. et al. Physical Review Letters 76, 4250–4253 (1996).
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Tuning into the Quantum Spin Hall Insulator state of InAs/GaSb quantum well

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

The quantum spin Hall insulator phase characterized by dissipation-less spin-polarized helical edge states [1] is a potential candidate for spintronics application. Inversion of bands in the InAs/GaSb coupled quantum well gives rise to band gap opening [2] and the creation of linearly dispersed helical edge states within the band gap [3]. These nontrivial sub-gap states can be accessed by tuning the Fermi level employing top and back gates. In the present work, double-gated devices with an active region constituting InAs(15 nm)/GaSb(5 nm) coupled quantum well sandwiched between AlSb barrier layers (50 nm) have been studied. The molecular beam epitaxy (MBE)-grown semiconductor wafers were patterned into micron scale Hall bar devices using optical lithography techniques and processed by conventional wet etching methods. While the top gate dielectric (Al_2O_3) was deposited using atomic layer deposition, the back gate dielectric (AlAsSb) constituted the layer beneath the quantum well sandwich of the MBE-grown heterostructure. Transport measurements were performed on these devices at a temperature of 1.5 K, within ±8 T magnetic field. One of the studied devices exhibited a carrier type crossover from n-type to p-type at an applied gate voltage configuration of +3.5 V back gate and -11 V top gate, indicating bandgap crossing of the Fermi level. The longitudinal sheet resistance was also found to reach a maximum of 1950 Ω/sq near these applied gate voltages, as shown in figure 1. The carrier density and the mobility of carriers were found to be $9.6(\pm0.1)\times10^{11}/cm^2$ and $2.4(\pm0.2)\times10^5\ cm^2/Vs$, respectively.

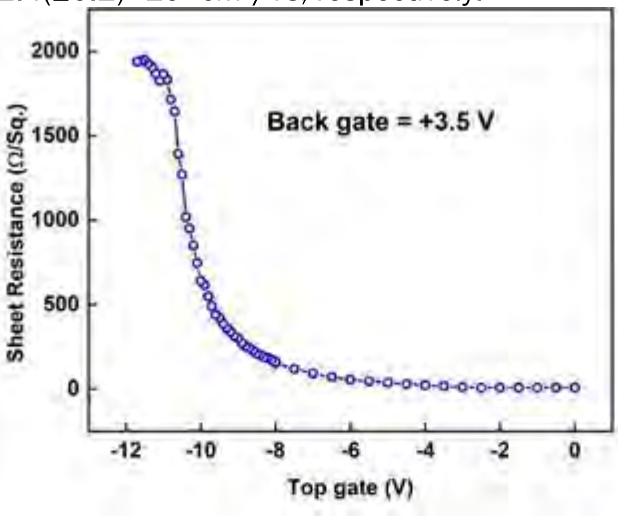

Figure 1. Variation of sheet resistance of InAs/GaSb quantum well device (micron scale) as a function of top gate voltage at a fixed back gate voltage value of +3.5 V and at a temperature of 1.5 K.

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Transverse thermoelectric materials obtained by powder metallurgy

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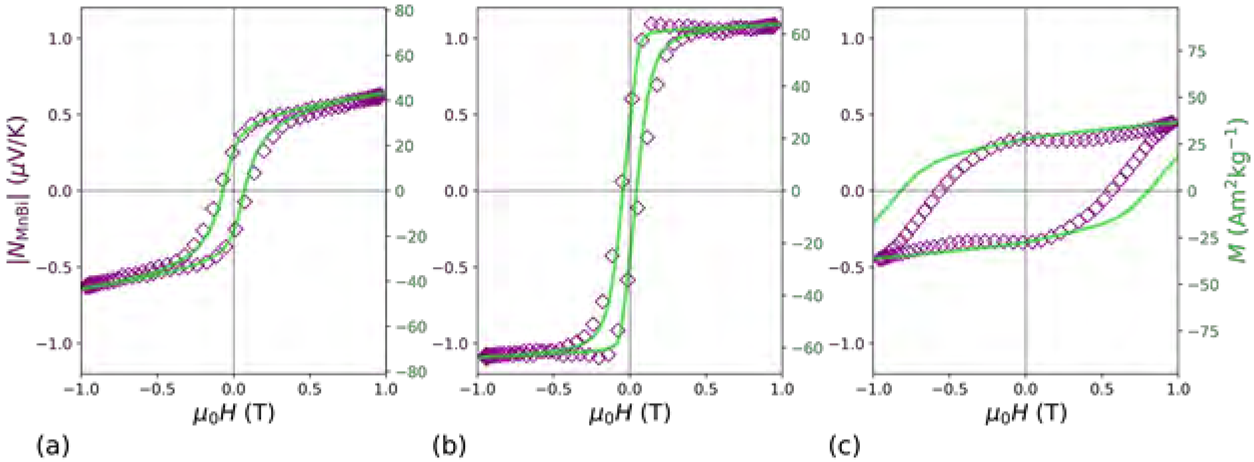
Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

In the field of thermoelectricity, the focus on transverse thermoelectric effects is increasing, following the renewed interest in the anomalous Nernst effect (ANE). This refers to the thermoelectric generation inside a magnetic material where thermal gradient, magnetic field and generated voltage are perpendicular to each other. Despite the low thermopowers, this configuration opens to new possibilities for the design of devices, like thin or flexible sensors and heat-sensing coatings of surfaces with arbitrary shapes. Advances in materials towards the production of ferromagnets that could be easily shaped, such as polycrystalline materials, are crucial.

Powder metallurgy is a versatile tool for the preparation of samples both for fundamental investigation and for practical applications and it has no limiting requirements in terms of technology and costs. We recently proved that in the case of the ferromagnetic MnBi compound, polycrystalline samples obtained by powder metallurgy exhibit ANE in the μV/K range, the same order of magnitude of the single crystals. As a further advantage, in polycrystals it is possible to tune the magnetic properties, i.e. coercive field and remanent magnetization, by means of process parameters, as well as to produce composite materials, aiming at the optimization of the thermoelectric conversion.

The figure shows the comparison between magnetization curves (green line) and the absolute values of ANE thermopowers (purple diamonds) for MnBi. The polycrystalline samples are prepared by three different procedures: (a) zero-field annealing, (b) annealing under a magnetic field of 1 T and (c) milling of the material obtained by the zero-field annealing.



Multi-Output Heterogeneous Magnetic Nanoring Arrays for High-dimensional Reservoir Computing

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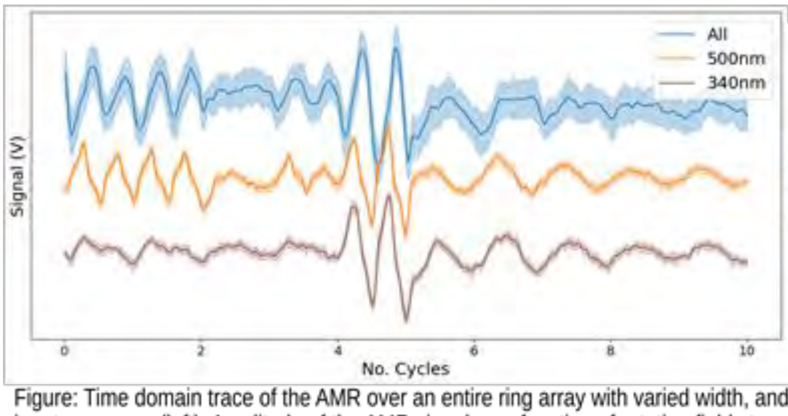
Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Neural networks on conventional silicon hardware are incredibly inefficient, with a substantial amount of energy used to train weights between nodes, primarily due to the energy wasted on shuffling data between processing and memory units. Reservoir Computing (RC) offers a potential solution, in which the network is replaced by a physical dynamical system, where only a limited output layer is trained. Magnetic materials are ideal candidates for in-materio RC devices due to their underlying inherent non-linear and hysteretic properties. In recent years, several magnetic systems have been proposed as RC platforms, not limited to the dynamic response of spin-oscillators [1], states within artificial spin ices [2] and spin wave interactions in magnonic crystals [3]. However, such devices are often limited by their low-dimensional readout. An alternative approach is to combine heterogenous nanoscale devices with varying physical properties, such as the dimensions of individual elements or material composition, alongside multiple readouts to produce higher dimensional state representations.

Recently, we have shown the competitive performance of interconnected magnetic nanoring arrays [4,5] as reservoir computers, using magnetoresistance as a readout method [5]. However, this provides a single output across the ensemble, which hinders its capability as a material based computational platform. This is particularly problematic in heterogeneous systems, as the response obtained is an averaged behaviour across the ensemble. In this work, we show how simultaneously measuring the magnetoresistance of a heterogeneous nanoring ensemble at multiple spatial locations provides a much richer representation of device state and a more powerful computational device.



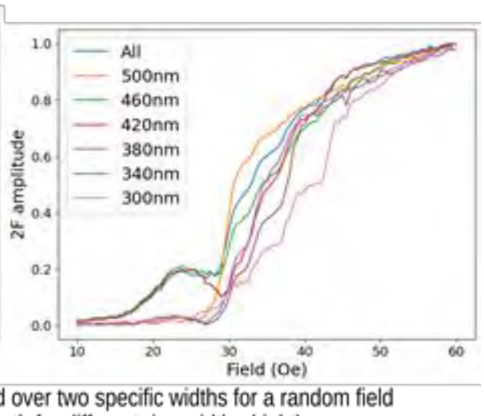


Figure: Time domain trace of the AMR over an entire ring array with varied width, and over two specific widths for a random field input sequence (left). Amplitude of the AMR signal as a function of rotating field strength for different ring widths (right).

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Exploring physical and digital architectures in magnetic nanoring array reservoir computers

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Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Stochastic behaviour has been a limiting factor in developing nanomagnetic technology. Recently, we have shown complex emergent behaviour in interconnected nanowire ring arrays (NRAs) [1-3] that is useful for reservoir computing (RC) [4]. We have demonstrated state-of-the-art performance for several benchmark tasks, including signal transformation, spoken digit recognition and time series prediction with the NRAs [3].

Here we explore how changing the lattice arrangement of NRAs with three different time-multiplexed RC architectures [3], change their physical behaviours and resulting RC computational properties. We consider three different $Ni_{80}Fe_{20}$ NRA lattices (Fig. 1(a)): (a) Square (b) Trigonal and (c) Kagome. X-PEEM imaging showed that the lattices exhibit differing evolutions of microstates and NRA magnetisation (Fig. 1(b)) with applied rotating field strength. We used anisotropic magnetoresistance measurements to probe the global responses of each NRA lattice and evaluate task agnostic metrics, computational quality (CQ) and memory capacity (MC) [3]. We observe that the RC architecture has a more profound influence on CQ and MC than the type of NRA lattice used, suggesting that our global readout does not allow differences in the rich microstate behaviours to be fully captured. However, reservoirs constructed using the combined outputs of different lattice NRAs do show enhanced computational metrics (Figs. 1(c) & (d)) compared to single NRA reservoirs, indicating the utility of combining the dynamics of multiple material reservoirs for improved computational performance.

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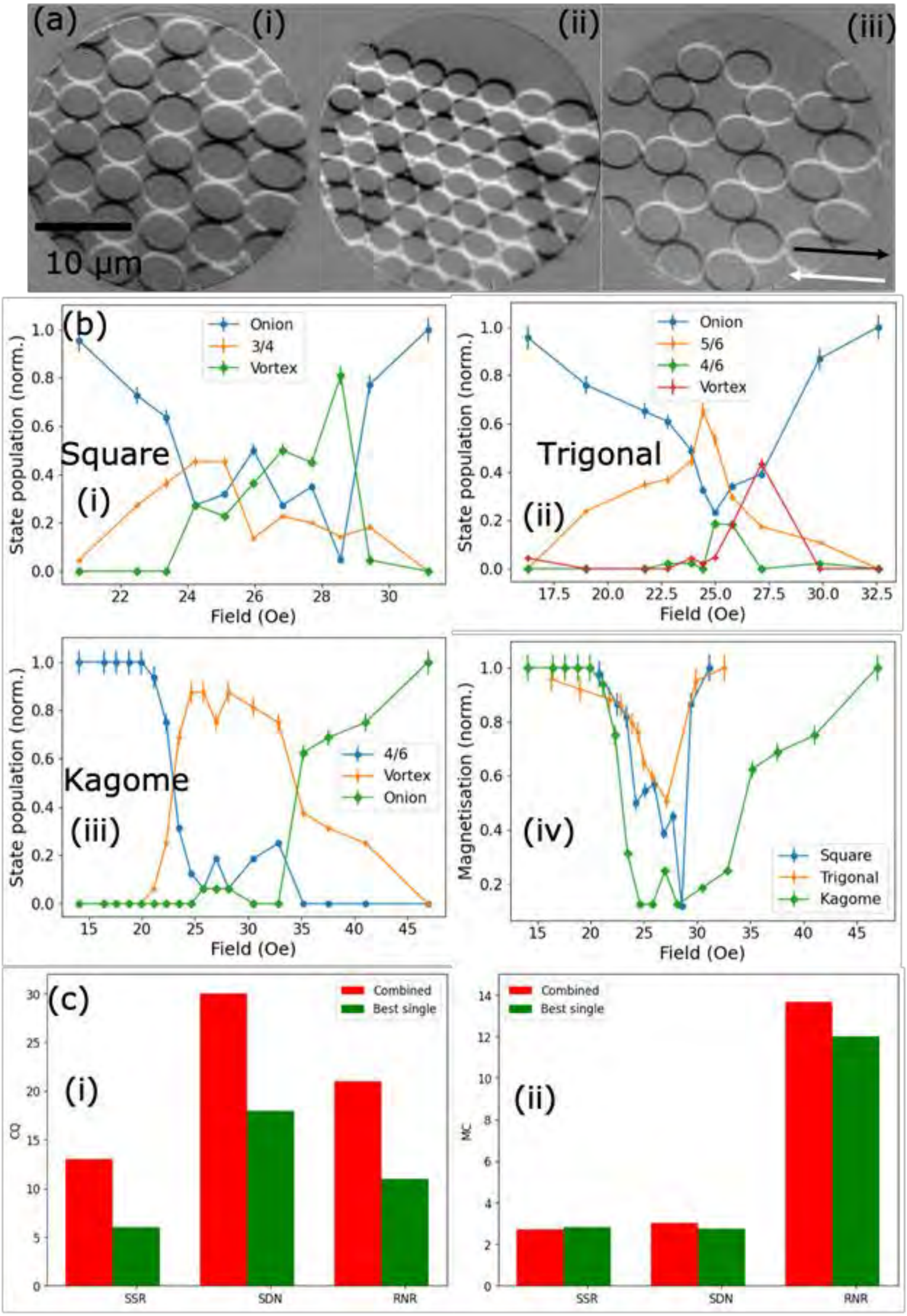

Figure 1:(a) An X-PEEM image of the (i) Square (NN=4), (ii) Trigonal (NN=3) and (iii) Kagome (NN=3) NRAs showing multiple magnetic states (b) The variation of magnetic state populations with rotating field strengths for the (i) Square, (ii) Trigonal and (iii) Kagome NRAs. (iv) shows the variation in NRA magnetisation for the different lattices. (c) The highest (i) CQ and (ii) MC available by combining the output of the different lattice NRAs showing the effects of the different RC architectures.

Thermal scanning probe lithography for nanoscale magnetic domain switching

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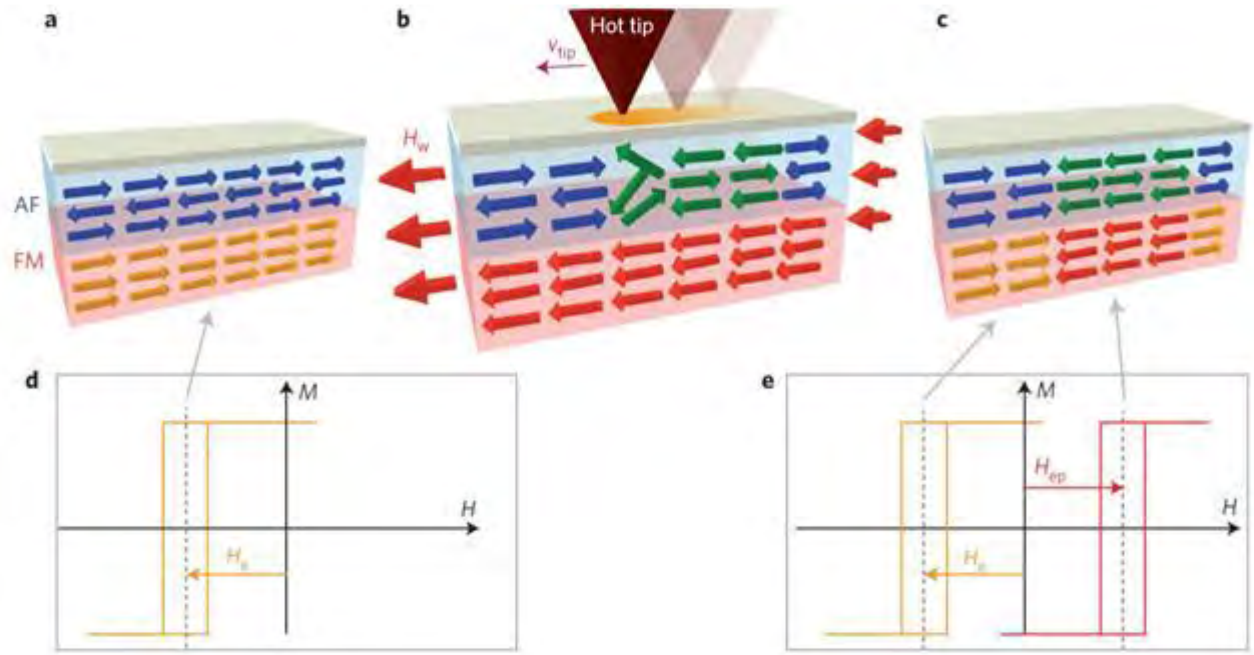
Lunch, Poster Session 1 and Exhibition, March 25, 2024, 13:00 - 14:00

Thermal scanning probe lithography (t-SPL) uses a heatable ultra-sharp tip for nanoscale physical or thermal modification and simultaneous imaging of materials. The technology has proven its value as an enabler of new kinds of ultra-high resolution nanodevices as well as for improving the performance of existing device concepts [1]. The range of applications for t-SPL is very broad including ultra-high resolution 2D and 3D patterning. Nanometer-precise markerless overlay and non-invasiveness to sensitive materials are among the key strengths of the technology. In addition, an integrated laser write head has been introduced to increase the throughput of lower resolution patterning and to enable the fabrication of systems where feature sizes range from nanometers to millimeters [2].
Recently, t-SPL has been used to define nanoscale magnetic domains into arbitrary shapes and directions of magnetization by locally heating multilayer ferro-magnetic/antiferromagnetic thin film stacks under an external magnetic field [3]. Accurate control over individual domain walls enables the creation of, e.g. vortex/antivortex pairs and Bloch lines, guiding spin waves and defining versatile, optics inspired magnonic circuits for spin waves demonstrating engineered wavefronts, focusing and robust interference with nanoscale wavelength. [4]
In this poster, we demonstrate the abilities of thermal scanning probe lithography not only as a high-resolution nanolithography tool that can replace or complement electron beam lithography in challenging applications, but also as a versatile instrument for studying magnetic phenomena at the nanoscale.



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