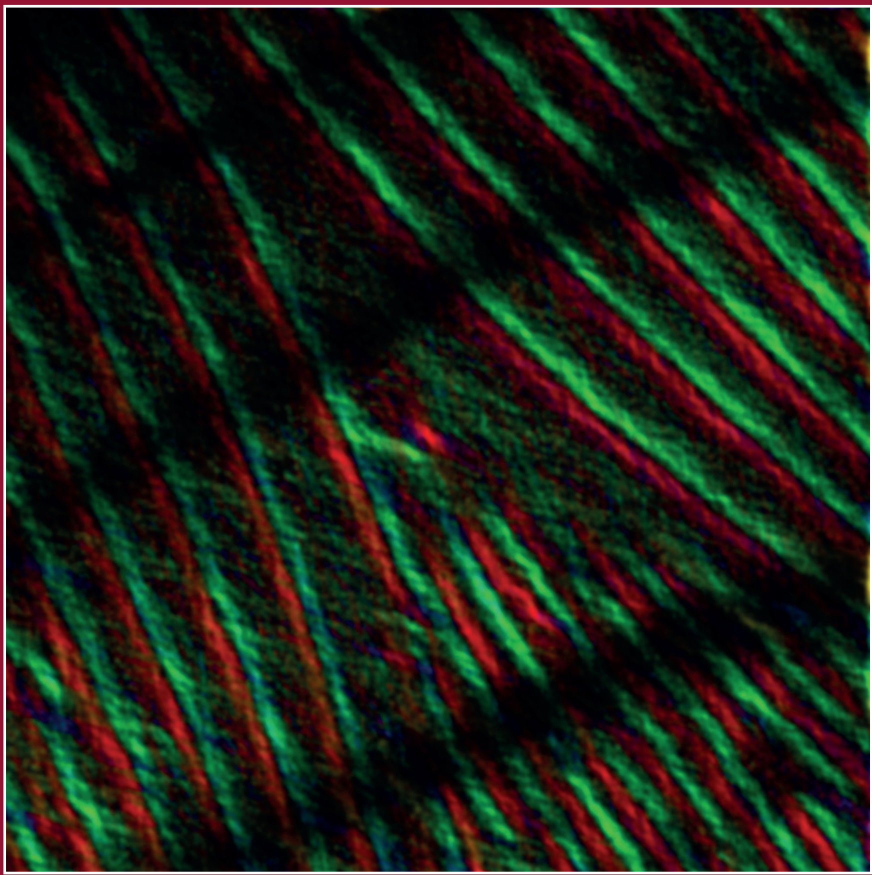
Programme and abstracts



Magnetism 2015

30–31 March 2015
University of Leeds, Leeds, UK

Organised by the IOP Magnetism Group
Co-sponsored by IEEE UK & RoI Magnetics Society Chapter

http://magnetism2015.iopconfs.org

IOP Institute of Physics

Welcome

On behalf of the conference organisers we would like to welcome you to Magnetism 2015. This is the second in a series of annual conferences established last year to embrace the breadth and quality of magnetism research in the United Kingdom (UK). Magnetism 2015 aims to be an inclusive meeting for the magnetism communities of both the UK and the Republic of Ireland (RoI). We are also delighted to welcome attendees from further afield.

This year's meeting is hosted by the University of Leeds and builds on the success of last year's meeting in Manchester. The conference will be held in the Michael Sadler and Parkinson Buildings at the University with two sessions running in parallel over two days. We have received over 160 high quality abstracts so we expect not only a series of high quality oral sessions but also a lively poster session full of fruitful discussions. We are delighted to have a wide selection of invited speakers covering a broad range of topics, both theoretical and experimental. This highlights the significant range of activities currently being pursued by the magnetism community in the UK. There is also a strong international participation at the meeting.

The IEEE Magnetics Society Distinguished Lecturer (DL) Programme aims to celebrate achievements in magnetics and honour the finest researchers and communicators in the field. We are delighted that two of the 2015 Magnetics Society DLs, Professor Ivan Schuller and Professir Russell Cowburn, have accepted our invitation to present their respective lectures in Leeds. Similarly, the Peter Wohlfarth Memorial Lecture will be presented during the second day of the meeting. This is an annual event held to mark the significant contribution of Peter Wohlfarth to the understanding of magnetism and magnetic materials. This lecture is open to the general public and conference registration is not required to attend. The lecture is organised by the IoP Magnetism Group committee in conjunction with the IEEE UK & RoI Magnetics Society Chapter. We are pleased to announce that this year's lecture will be presented by Dr Laura Heyderman from the Paul Scherrer Institute in Zurich. We are also delighted to welcome Professor Stuart Parkin of the Max Planck Institute of Microstructure Physics in Halle and 2014 Millennium Technology prize winner who will be giving a Plenary Lecture in a specially convened evening session.

We would also like to thank our industrial exhibitors and sponsors for their generous support. We encourage you to come and talk to them during the conference. The exhibition space will be located in the Parkinson Building, the same space that will be used for the poster session as well as the lunch/coffee breaks. In particular we would like to thank Oxford Instruments for sponsoring the conference dinner, Zurich Instruments for sponsoring the lanyards and Society of Electron Microscope Technology for co-sponsoring the event. Finally, the poster prizes were generously provided to us by Nature Communications.

On behalf of the IOP Magnetism Group and the IEEE UK & RoI Magnetics Society Chapter and we wish you an enjoyable and fruitful meeting.

Dan Allwood and Gonzalo Vallejo Fernández

Programme

Monday 30 March

09:00 Registration and refreshments
Location: Parkinson Court

	Session 1: Spin currents *Location: Michael Sadler Building, Rupert Beckett Lecture Theatre*	Session 2: Spin ice *Location: Michael Sadler Building, Room LG10*
09:50	**Welcome**	**Welcome**
10:00	**Magnetic properties of high quality nanometer thick sputtered yttrium iron garnet films** Arpita Mitra, University of Leeds, UK	**(invited) Delicate magnetic ground states: the local view** Stephen J Blundell, University of Oxford, UK
10:15	**Electric valley control of the spin-hall effect in GaAs** Hidekazu Kurebayashi, University College London, UK	
10:30	**Spin pumping in ferromagnet - topological insulator heterostructures** Alexander Baker, University of Oxford, UK	**The AC Wien effect and non-linear non-equilibrium susceptibility in spin ice** Peter Holdsworth, Ecole Normale Supérieure de Lyon, France
10:45	**Spin relaxation through magnetic scattering in Cu/Py lateral spin valves** Joseph T Batley, University of Leeds, UK	**Critical dynamics and finite-time scaling in spin ice systems** James Hamp, University of Cambridge, UK
11:00	**Femtosecond optical pump-probe study of the spin Seebeck effect within a YIG/Cu/$Ni_{81}Fe_{19}$ trilayer** Haidar Mohamad, University of Exeter, UK	**A quantum Kasteleyn transition in a spin-ice-like model** Christopher Andrew Hooley, University of St Andrews, UK

11:15 **Refreshments, exhibition and posters**
Location: Parkinson Court

Monday 30 March - continued

	Session 3: Vortices *Location: Michael Sadler Building, Rupert Beckett Lecture Theatre*	Session 4: Ab initio, bio and organic magnetism *Location: Michael Sadler Building, Room LG10*
11:45	**(invited) 35 years of magnetic heterostructures** Ivan K Schuller, University of California, San Diego, USA (IEEE Distinguished Lecturer)	**First-principles investigation of magnetism in lanthanide compounds** Leon Petit, Daresbury Laboratory - Science and Technology Facilities Council, UK
12:00		**Compositional tuning of the magnetic anisotropy of Ni_2MnGa-based compounds** Rudra Banerjee, University of Warwick, UK
12:15	**Magnetic switching and structure in nanoscale FePd Circular Islands** David Greving, University of Warwick, UK	**Quasi-one dimensional magnetic chain in Cu-guanidinuim formate studied by μSR** Shuo Han, Queen Mary, University of London, UK
12:30	**Strain induced vortex core switching in planar magnetostrictive nanostructures** Stuart A Cavill, University of York, UK	**The magnetic ground state of two isostructual polymeric quantum magnets, $[Cu(HF_2)(pyrazine)]SbF_6$ and $[Co(HF_2)(pyrazine)]SbF_6$, investigated with neutron diffraction** Jamie Brambleby, University of Warwick, UK
12:45	**Magnetic vortex states in highly anisotropic nanoislands** Jose M Porro Azpiazu, ISIS - Science and Technology Facilities Council, UK	**The magnetic field dependent crossover between hyperfine and spin-orbit interactions in organic semiconductors** Ke Wang, Queen Mary, University of London, UK
13:00	**Lunch, exhibition and posters** *Location: Parkinson Court*	

Monday 30 March - continued

	Session 5: Spin torque and spin-orbit effects *Location: Michael Sadler Building, Rupert Beckett Lecture Theatre*	Session 6: Superconductors *Location: Michael Sadler Building, Room LG10*
14:00	**Universal magnetic Hall circuit based on paired spin heterostructures** Shilei Zhang, University of Oxford, UK	**(invited) Magnetic vortices: a probe of the superconducting state** Elizabeth Blackburn, University of Birmingham, UK
14:15	**Spin orbit torques in epitaxial MnSi** Chiara Ciccarelli, University of Cambridge, UK	
14:30	**Magneto-optical observation of mutual phase-locking in a pair of spin-torque vortex oscillators** Paul S Keatley, University of Exeter, UK	**Charge-stripe Magnetic Interactions of the checkerboard charge order state** Paul G Freeman, University of Central Lancashire, UK
14:45	**Asymmetry in anomalous Hall effect measurements of magnetic dots** Rhys A Griffiths, University of Manchester, UK	**Inducing magnetization at a non-magnetic interface by superconducting triplet correlations** Machiel G Flokstra, University of St. Andrews, UK
15:00	**Room-temperature spin-orbit torque and AMR in NiMnSb** Laurel Anderson, University of Cambridge, UK	**Evidence of spin triplet superconductivity in superconductor/ferromagnet heterostructures** Christy J Kinane, ISIS - Science and Technology Facilities Council, UK

15:15 **Refreshment break and poster session**
Location: Parkinson Court

16:00 **(invited) Updates and opportunities from EPSRC**
James Dracott, Atomic, Molecular and Optical Physics - EPSRC, UK
Location: Michael Sadler Building, Rupert Beckett Lecture Theatre

Monday 30 March - continued

	Session 7: Magnetism and structure *Location: Michael Sadler Building, Rupert Beckett Lecture Theatre*	Session 8: Skyrmions and topological effects *Location: Michael Sadler Building, Room LG10*
16:15	**Understanding the proximity induced magnetism in Pt using interface engineering through the addition of heavy metal interlayers** Richard M Rowan-Robinson, Durham University, UK	**Helical magnetic structure in $Fe_{1-x}Co_xGe$ epilayers** Charles S Spencer, University of Leeds, UK
16:30	**Motion of the antiferromagneic-ferromagnetic interface in a dopant-graded FeRh thin film** Timothy Charlton, ISIS - Science and Technology Facilities Council, UK	**Magnetic Cr doping of Bi_2Se_3: Evidence for divalent Cr from x-ray spectroscopy** Liam Collins-McIntyre, University of Oxford, UK
16:45	**Tunable response in α'-FeRh films** Laura H Lewis, Northeastern University, USA	**Transverse field muon-spin rotation signature of the skyrmion lattice phase in Cu_2OSeO_3** Robert C Williams, Durham University, UK
17:00	**Understanding the YIG/Pt Interface** Amy L Westerman, University of Leeds, UK	**Nanometer resolution imaging of Helical and Skyrmion states in FeGe** Damien McGrouther, University of Glasgow, UK

17:15 **IOP Magnetism Group AGM**
Location: Michael Sadler Building, Rupert Beckett Lecture Theatre

17:45 **(plenary) Racetrack Memory: Highly efficient current induced domain wall motion in synthetic antiferromagnetic racetracks**
Stuart S P Parkin, Max Planck Institute of Microstructure Physics and Martin Luther University Halle-Wittenberg, Germany
Location: Michael Sadler Building, Rupert Beckett Lecture Theatre

18:45 End of day one

19:30 Arrive for conference dinner
Location: Leeds Marriott Hotel, 4 Trevelyan Square, Board Lane, Leeds, LS1 6ET

20:00 **Conference dinner**
Location: Leeds Marriott Hotel, 4 Trevelyan Square, Board Lane, Leeds, LS1 6ET

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OXFORD INSTRUMENTS

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Tuesday 31 March

08:30 Registration and refreshments
Location: Parkinson Court

09:00 **Wohlfarth Lecture**

(invited) Shedding light on artificial ferroic systems
Laura Heyderman, ETH Zürich - Paul Scherrer Institute, Switzerland (Wohlfarth Lecturer)
Location: Michael Sadler Building, Rupert Beckett Lecture Theatre

10:00 **Refreshments, exhibition and posters**
Location: Parkinson Court

	Session 9: Domain walls Location: Michael Sadler Building, Rupert Beckett Lecture Theatre	Session 10: Bio and organic magnetism Location: Michael Sadler Building, Room LG10
10:30	**Control of domain wall depinning fields in nanowires using induced uniaxial anisotropy** Andrew W Rushforth, University of Nottingham, UK	**(invited) Chemical compass magnetoreception: how migratory birds might navigate** Peter Hore, University of Oxford, UK
10:45	**2D control of field-driven magnetic bubble movement using Dzyaloshinskii-Moriya interactions** Rhodri Mansell, University of Cambridge, UK	
11:00	**Imaging the equilibrium state and magnetisation dynamics of hard disk write heads** Rob A J Valkass, University of Exeter, UK	**Manipulation of the photoluminescence of C_{60} via ferromagnetic resonance** May C Wheeler, University of Leeds, UK
11:15	**Strain control of domain wall creep motion in Pt/Co/Pt and Pt/Co/Ir/Pt thin films** Philippa Shepley, University of Leeds, UK	**Patterning biologically controlled magnetic nanoparticle arrays: it's a fine line** Scott M Bird, University of Sheffield, UK
11:30	**Finding energy barriers of skyrmionic configuration in ferromagnetic nanodisks and nanotracks** David Cortés-Ortuño, University of Southampton, UK	**Manipulating the magnetic properties of molecular/ non-magnetic transition metal interfaces** Fatma Al Ma'Mari, University of Leeds, UK
11:45	**Thermally-induced stochastic domain wall dynamics in $Ni_{80}Fe_{20}$ nanowires** Tom J Hayward, University of Sheffield, UK	**Unexpected antiferromagnetic exchange coupling between a Cr-porphyrin and a bare cobalt substrate** Jan Nowakowski, Paul Scherrer Institute, Switzerland
12:00	**Dzyaloshinskii-Moriya interaction in perpendicularly magnetized thin films** Ales Hrabec, University of Leeds, UK	**Observation of antiferromagnetic coupling at organic semiconductor/ferromagnetic interfaces** Andrew Pratt, University of York, UK

Tuesday 31 March - continued

12:15 **Lunch, exhibition and posters**
Location: Parkinson Court

Time	Session 11: Dynamics Location: Michael Sadler Building, Rupert Beckett Lecture Theatre	Session 12: Artificial spin ice Location: Michael Sadler Building, Room LG10
13:15	**(invited) Perpendicular magnetic anisotropy: from ultralow power spintronics to cancer therapy** Russell Cowburn, University of Cambridge, UK (IEEE distinguished Lecturer)	**Thermal behaviour study of an artificial magnetic quasi-crystal** Dong Shi, University of Leeds, UK
13:30		**The propagation of magnetic domain walls in interconnected artificial spin ice structures** David M Burn, Imperial College London, UK
13:45	**Energy efficient Thermally Induced Magnetization Switching by tailoring the electron and phonon dynamics** Thomas Ostler, University of York, UK	**Lorentz transmission electron microscopy study of three dimensional artificial spin ice** Solveig Felton, Queen's University Belfast, UK
14:00	**Electrical manipulation of a ferromagnet by an antiferromagnet** Vahe Tshitoyan, University of Cambridge, UK	**Speckle dynamics in artificial spin ice** Sophie Morley, University of Leeds, UK
14:15	**Enhancing the magneto-optical Kerr effect with a near field plasmonic antenna** Thomas H J Loughran, University of Exeter, UK	**Low temperature behaviour of honeycomb artificial spin ice** Katharina Zeissler, Imperial College London, UK
14:30	**Thermally induced magnetization switching in Gd/Fe multilayers** Chudong Xu, University of York, UK	**Micromagnetic studies of nanostructure gadolinium** Matthew McMullan, Queen's University Belfast, UK
14:45	**Element- and site-resolved magnetization dynamics in a YIG/Cu/Co trilayer measured by x-ray detected ferromagnetic resonance** Leigh R Shelford, University of Exeter, UK	End of session

15:00 **Refreshment break**
Location: Parkinson Court

Tuesday 31 March - continued

	Session 13: Magnonics Location: Michael Sadler Building, Rupert Beckett Lecture Theatre	Session 14: Magnetic structure and properties Location: Michael Sadler Building, Room LG10
15:30	**Coupling of magnetisation dynamics and heat currents** Thomas Bose, University of York, UK	**(invited) The dynamics of a quantum spin liquid** John Chalker, University of Oxford, UK
15:45	**Ferromagnetic resonance of patterned chromium dioxide thin films grown by selective area chemical vapour deposition** Chris Durrant, University of Exeter, UK	
16:00	**Long-range coupling between magnets using magnon quantum electrodynamics** Nicholas J Lambert, University of Cambridge, UK	**Designed magnetic systems based on the 2D-XY ferromagnet** Aidan T Hindmarch, Durham University, UK
16:15	**Exploring spin-wave systems at the single magnon level** Alexy D Karenowska, University of Oxford, UK	**α-CoV_2O_6 a prototype Ising antiferromagnet on a zigzag ladder** Jonathan Alaria, University of Liverpool, UK
16:30	**Towards graded-index magnonics: Steering spin waves in magnonic networks** Carl S Davies, University of Exeter, UK	**Core/shell magnetism in NiO nanoparticles** Adrian Ionescu, University of Cambridge, UK
16:45	**Curved magnonic waveguides based on domain walls** Pablo Borys, University of Glasgow, UK	**Disentangling the spin and orbital moments in the heavy fermion system $CeRu_2Al_{10}$ using polarised x-rays** Philip R Dean, Durham University, UK
17:00	**Closing remarks**	**Closing remarks**
17:05	Conference close	

Poster programme

Ab initio

P.01 **Non-Fermi-liquid behavior and anomalous suppression of Landau damping in layered metals close to ferromagnetism**
Sam Ridgway, University of St Andrews, UK

P.02 ***Ab initio* study of magnetoelastic and elastocaloric effects in Mn-antiperovskites**
Jan Zemen, Imperial College London, UK

P.03 **Towards a simple description of magnetism in heavy rare earths: application to magnetic refrigeration**
Eduardo Mendive Tapia, University of Warwick, UK

Bio and organic magnetism

P.04 **Magnetoresistance and doping effects in conjugated polymer-based organic light emitting diodes**
Hang Gu, Queen Mary, University of London, UK

P.05 **Hydrazinium metal-formate frameworks of $[NH_2NH_3][M(HCOO)_3]$ (M = Fe^{2+} and Co^{2+}): Framework polymorphism, structural phase transitions, and dielectric and magnetic properties**
Sa Chen, Peking University, China

P.06 **Erbium organometallic single-ion magnets with half-sandwich structure**
Yinshan Meng, Peking University, China

P.07 **Quantifying long-time thermal relaxation decay in clusters of magnetic particles**
Oliver Laslett, University of Southampton, UK

P.08 **SQUID magnetometry measurements of magnetic polynuclear metal clusters synthesised in acetate ionic liquids**
Suzanne Gray, Queens University of Belfast, UK

P.09 **Organic spintronic field effect transistors**
Hadi Alqahtani, King Saud University, Saudi Arabia

P.10 **A dysprosium(III) SMM based on naphthyridine-like ligand**
Ye Bi, Peking University, China

P.11 **Novel spin injection into graphene**
Jack L Warren, University of Manchester, UK

P.12 **Spin doping and induced molecular magnetism studied via a ferrimagnetic spin donor**
Timothy Moorsom, University of Leeds, UK

P.13 **Investigation of the magnetic exchange coupling between spin-bearing molecules and ferromagnetic substrates by X-ray photo-emission electron microscopy**
Jan Nowakowski, Paul Scherrer Institute, Switzerland

P.14 **A scanning TMR microscope for magnetic elements in biosensor applications**
Justin Llandro, University of Cambridge, UK

P.15 **The photoexcited μSR technique probes of electronic state of excited molecules**
Koji Yokoyama, Queen Mary University of London, UK

C60 / graphite

P.16 **Phase diagram of a semimetal in the magnetic ultra-quantum limit**
Aldo Isidori, Royal Holloway, University of London, UK

Domain walls

P.17 **Injection of 360 degree domain walls in magnetic nanostructures via MFM tip**
Jack C Gartside, Imperial College London, UK

P.18 **Racetrack memory using exchange bias**
Ioan Polenciuc, University of York, UK

P.19 **Micromagnetic simulations of DW states and dynamics in rare earth doped NiFe nanowires**
Thomas J Broomhall, University of Sheffield, UK

P.20 **Measuring Dzyaloshinskii-Moriya interaction (DMI) in Ta/CoFeB/MgO thin films**
Risalat A Khan, University of Leeds, UK

P.21 **Effects of deposition temperature on the creep velocity of epitaxial Co/Pt**
Adam W J Wells, University of Leeds, UK

P.22 **Lorentz imaging of Domain wall motion in fabricated nanowires**
Raymond Lamb, University of Glasgow , UK

Dynamics

P.23 **Ferromagnetic resonance measurements of multilayer films using a Vector Network Analyser**
August Johansson, University of Manchester, UK

P.24 **Magnetisation dynamics of confined magnetic nanostructures controlled by voltage-induced mechanical strain**
Stuart Bowe, University of Nottingham, UK

P.25 **Dispersive read-out of ferromagnetic resonance in strongly coupled magnon-microwave photon system**
James A Haigh, Hitachi Cambridge Labs, UK

P.26 **Understanding the thickness dependence of Gilbert damping in ferromagnetic thin films with non-magnetic capping layers**
Sinan Azzawi, Durham University, UK

P.27 **Thickness, crystallinity and single interface contribution to ferromagnetic resonance of polycrystalline Co thin-films**
Mustafa Tokac, Durham University, UK

P.28 **Time-resolved holographic imaging of magnetic vortex dynamics**
Nicholas Bukin, University of Exeter, UK

P.29 **Controlling ferromagnetic resonance using three dimensional exchange biased antidot lattice stacks**
Robert Stamps, University of Glasgow, UK

Magnetic structure and properties

P.30 **Magnetic anisotropy of $Fe_{1-y}X_yPt$ [X=Cr,Mn,Co,Ni,Cu] bulk alloys**
Ramon Cuadrado, University of York, UK

P.31 **Two-step magnetic ordering in intercalated niobium disulphide Mn_xNbS_2**
Fedor Mushenok, University of Exeter, UK

P.32 **Development of a technique to determine anisotropy axes in soft magnetic materials using a standard vibrating sample magnetometer**
Steven Bourn, University of Central Lancashire, UK

P.33 **Erbium, a magnetic spin spiral for the future**
Joshaniel Cooper, Science and Technology Facilities Council, UK

P.34 **Magnetic properties of vanadium doped chromium dioxide $Cr_{1-x}VxO_2$ $x \leq 0.5$**
Otto Mustonen, Aalto University, Finland

P.35 **The effect of non-magnetic phases on the development of new rare-earth permanent magnetic materials utilizing the Spark Plasma Sintering powder metallurgy process**
Alex Mackie, University of Sheffield, UK

P.36 **Rotational excitations of cold polar molecules emulating ferromagnetic order**
Michal P Kwasigroch, University of Cambridge, UK

P.37 **Atomistic modelling of $Nd_2Fe_{14}B$-Fe core/shell nanoparticles for high performance permanent magnet applications**
Samuel C Westmoreland, University of York, UK

P.38 **Collective properties of frustrated nano-disk arrays**
Megha Chadha, Imperial College London, UK

P.39 **Investigation of polar and non-polar interfaces in EuO(001) based heterostructures**
Razan O Aboljadayel, University of Cambridge, UK

P.40 **Competing interactions in doped rare-earth manganites nano-structural materials**
Wiqar Hussain Shah, International Islamic University, Pakistan

Magnetism and structure

P.41 **Assessment of magnetic contribution of metallic Co nanoparticles to the total magnetizationin Co doped In_2O_3**
Marzook S Alshammari, KACST, Saudi Arabia

P.42 **Energy and magnetic characteristics of multilayer magnetic films**
Marina Mamonova, Omsk State University, Russia

P.43 **Electric-field control of magnetic properties in a multiferroic heterostructure**
Wei-Gang Yang, University of Sheffield, UK

P.44 **Dimensional effects in ultrathin magnetic films**
Pavel V Prudnikov, Omsk State University, Russia

P.45 **The effects of different precursors in the production of PLD targets on the magnetism of cobalt doped ZnO films**
Wala Dizayee, University of Sheffield, UK

P.46 **Substitutional and metallic Cobalt in ZnO films**
Gillian A Gehring, University of Sheffield, UK

P.47 **Extracting intrinsic switching field distribution in granular system**
Sergiu Ruta, University of York, UK

P.48 **Temperature and distance dependence of intergranular exchange coupling**
Matthew O A Ellis, University of York, UK

P.49 **Atomistic spin model simulations on the indirect exchange interactions of Co-doped ZnO**
Muhammet Arucu, University of York, UK / Marmara University, Turkey

P.50 **Angular dependence of switching fields of L10 $(Fe_{0.5}Mn_{0.5})_{68}Pt_{32}$ ferromagnetic-paramagnetic dot pattern fabricated by Mn ion irradiation**
Takashi Hasegawa, Akita University, Japan

P.51 **Atomistic modelling of magnetic reversal mechanisms in CoFeB-MgO tunnel junctions**
Andrea Meo, University of York, UK

P.52 **Electric field control of magnetic thin film properties using ionic liquid electric double layers**
Jonathan Wood, University of Sheffield, UK

P.53 **Fabrication and characterisation of remote plasma sputtered $L1_0$ FePt thin films and bit patterned media**
Smaragda Zygridou, University of Manchester, UK

P.54 **Towards atomic scale characterisation of perpendicular anisotropy materials for spintronics**
David Huskisson, University of Manchester, UK

P.55 **Fluence study of Co_2MnSi thin films for suitability in spin seebeck devices**
Chris Cox, Loughborough University, UK

P.56 **Optimisationof Fe_3O_4 nanostructures for atom trapping applications**
Ruth C Bradley, University of Sheffield, UK

P.57 **Magnetic and structural properties of Ni_2MnAl alloy grown at elevating temperatures**
Haokaifeng Wu, University of York, UK

P.58 **Growth of Fe/MgO/GaN(0001) heterostructure by molecular beam epitaxy**
Jun-young Kim, University of Cambridge, UK

P.59 **Effect of Fe Underlayer in Ultrathin FeRh films**
Craig Barton, University of Manchester, UK

P.60 **Surface relaxation, Ga segregation and electronic structure in MnSb (0001) epitaxial films on GaAs(111)A from first principles**
Haiyuan Wang, University of Warwick, UK

P.61 **Direct band-gap measurement on a NiMnSb Heusler alloy at room temperature**
Tariq Alhuwaymel, University of York, UK

P.62 **Characterisation of pollycrystalline heusler alloys**
Teodor Huminiuc, University of York, UK

P.63 **Exchange bias induced at a $Co_2FeAl_{0.5}Si_{0.5}$ /Cr interface**
Nga Tung Chris Yu, University of York, UK

P.64 **Crystallographic optimisation of Co_2FeSi with perpendicular anisotropy**
William Frost, University of York, UK

P.65 **Characterisation of néel transitions in heusler alloys**
John Sinclair, University of York, UK

P.66 **Amorphous glass-coated nanowires and submicron wires prepared by rapid quenching from the melt**
Tibor-Adrian Ovari, National Institute of Research and Development for Technical Physics, Romania

P.67 **The effect of post-annealing conditions on the iron oxides thin films grown on MgO(100)**
Balati Kuerbanjiang, University of York, UK

P.68 **Exchange bias films with perpendicular anisotropy**
Kelvin Elphick, University of York, UK

P.69 **Hexapod Hall scanner for high-resolution magnetic imaging**
Mikhail Kustov, Imperial College London, UK

P.70 **Determining the anisotropy of bit patterned media for optimal performance**
Jen Talbot, University of Manchester, UK

Magnetocaloric, ferroelectrics and magnonics

P.71 **Optimization of magnetocaloric properties of arc melted and spark plasma sintered $LaFe_{11.6}Si_{1.4}$**
Precious Shamba, University of Sheffield, UK

P.72 **Magnetoelastic coupling in $EuTiO_3$: An examination by resonant ultrasound spectroscopy**
Jason Schiemer, University of Cambridge, UK

P.73 **Magnetic and Magneto-optical properties of films of multiferroic $GdMnO_3$ grown on $SrTiO_3$ and LSAT (100) and (111)**
Hasan Albargi, University of Sheffield, UK

P.74 **Exploring the mechanism of relaxation across the first-order metamagnetic phase transition in magnetocaloric $La(Fe,Si)_{13}$**
Edmund Lovell, Imperial College London, UK

P.75 **Magnonic beam splitter: The building block of parallel magnonic circuitry**
Carl Davies, University of Exeter, UK

Skyrmions and topological effects

P.76 **Itinerant magnetism in highly spin polarised B20 ε-$Fe_{1-x}Co_xSi$ epilayers**
Priyasmita Sinha, University of Leeds, UK

P.77 **Superconductor skyrmion proximity in $Fe_{0.7}Co_{0.3}Si$/Nb bilayers**
Nathan Satchell, University of Leeds, UK

P.78 **Depth profiling of the magnetic order in Cr-doped Bi_2Se_3 thin films**
Nina-Juliane Steinke, ISIS - Science and Technology Facilities Council, UK

Spin currents, spin torque and spin-orbit effects

P.79 **Temperature dependence of spin Hall magnetoresistance in W/YIG thin films**
Scott Marmion, University of Leeds, UK

P.80 **Magnetic, structural and electrical characterisation of CoFeTaB/Pt bilayer films**
Oto-obong Andrew Inyang, Durham University, UK

P.81 **Spin accumulation and relaxation characterisation in isolated CoFe nanoparticles**
Rowan C Temple, University of Leeds, UK

P.82 **Perpendicular anisotropy in ultrathin Co based layers sandwiched by large spin hall angle heavy metals**
Kowsar Shahbazi, University of Leeds, UK

P.83 **Microwave emission characteristics of spin-Hall nano-oscillators**
Tim Spicer, University of Exeter, UK

P.84 **Fabrication and measurement of a lateral spin-transfer nano-oscillator**
Benedict A Murphy, University of York, UK

Spin ice and artificial spin ice

P.85 **Induced magnetoresistance in hybrid semiconductor / artificial spin ice systems**
Susan Riley, University of Leeds, UK

P.86 **Influence of disorder on critical ageing in 3d ising-like ferromgnets**
Vladimir Prudnikov, Omsk State University, Russia

Superconductors

P.87 **The superconducting spin valve containing highly spin polarized $Fe_{0.8}Co_{0.2}Si$**
Benjamin Steele, University of Leeds, UK

P.88 **Development of 22 T VSM system using novel improvements in HTS conductor**
Darko Bracanovic, Cryogenic Ltd, UK

Vortices

P.89 **Detection of asymmetry circular gyration of the vortex core via second order harmonic magnetoresistance oscillation**
Satoshi Sugimoto, University of Leeds, UK

P.90 **Lorentz microscopy study of possible interfacial exchange interactions in thin films with planar magnetisation**
Stephen McVitie, University of Glasgow, UK

Abstracts

Plenary Lecture

(plenary) Racetrack Memory: Highly efficient current induced domain wall motion in synthetic antiferromagnetic racetracks

S S P Parkin

Max Planck Institute of Microstructure Physics and Martin Luther University Halle-Wittenberg, Germany / IBM Research – Almaden, USA

Memory-storage devices based on the current controlled motion of domain walls in magnetic racetracks promise performance and reliability beyond that of conventional magnetic disk drives and solid state storage devices [1]. Racetracks that are formed from atomically thin, perpendicularly magnetized nano-wires, interfaced with adjacent metal layers with high spin-orbit coupling, give rise to domain walls possessing a chiral Néel structure [2]. These domain walls can be moved very efficiently with current. However, high capacity racetrack memory requires closely-packed domain walls whose density is limited by dipolar coupling from their fringing magnetic fields. These fields can be eliminated using a spin-engineered synthetic antiferromagnetic (SAF) structure composed of two magnetic sub-layers, exchange-coupled via an ultrathin antiferromagnetic-coupling spacer layer. We show that nano-second long current pulses can move domain walls in SAF racetracks that have nearly no net magnetization. Surprisingly, we find that the domain walls can be moved even more efficiently and at much higher speeds of up to ~750 m/sec compared to similar racetracks in which the sub-layers are coupled ferromagnetically [3]. The origin of these giant current induced domain wall velocities is discussed.

[1] S. S. P. Parkin and S.-H. Yang, *Nature Nanotech. (Commentary),* (March, 2015)
[2] K.-S. Ryu, L. Thomas, S.-H. Yang, S. S. P. Parkin, *Nature Nanotech.* 8, 527 (2013)
[3] S.-H. Yang, K.-S. Ryu and S. S. P. Parkin, *Nature Nanotech.* (February 24th, 2015)

Wohlfarth Lecture

(invited) Shedding light on artificial ferroic systems

L Heyderman

ETH Zürich, Switzerland / Paul Scherrer Institute, Switzerland

In artificial ferroic systems [1], novel functionality can be engineered through the combination of structured ferroic materials and tailored interactions between the different components. With both careful design of the structures and appropriate selection of materials, artificial ferroic systems offer prospects for the discovery of new physics, both static and dynamic, as well as the development of novel devices.

I will present our work employing synchrotron x-rays to probe two classes of artificial ferroic systems. I will begin with hybrid mesoscopic structures incorporating two different ferromagnetic layers, which display magnetization dynamics that results from the mutual imprint of the magnetic domain configurations [2]. I will also discuss work on multiferroic composites, which have the potential to provide control of the state of the magnetic component with an electric field [3, 4]. Finally, I will describe our progress in a second class of artificial ferroic systems, artificial spin ice, which consists of arrays of dipolar-coupled nanomagnets arranged in frustrated geometries. This includes observation of emergent magnetic monopoles in magnetic-field-driven systems [5] and more recent work on cooperative moment reorientations in thermally active systems [6, 7, 8].

[1] L.J. Heyderman and R.L. Stamps, J. Phys.: Condens. Matter 25, 363201 (2013)
[2] G. Heldt et al. Appl. Phys. Lett. 104, 182401 (2014); P. Wohlhüter et al. Submitted (2014)
[3] R.V. Chopdekar et al. Phys. Rev. B 86, 014408 (2012)
[4] M. Buzzi et al. Phys. Rev. Lett. 111, 027204 (2013)
[5] E. Mengotti et al. Nature Physics 7, 68 (2011)
[6] A. Farhan et al. Nature Physics 9, 375 (2013)
[7] A. Farhan et al. Phys. Rev. Lett. 111, 057204 (2013)
[8] V. Kapaklis et al. Nature Nanotechnology 9, 514 (2014)

Session 1: Spin currents

Magnetic properties of high quality nanometer thick sputtered yttrium iron garnet films

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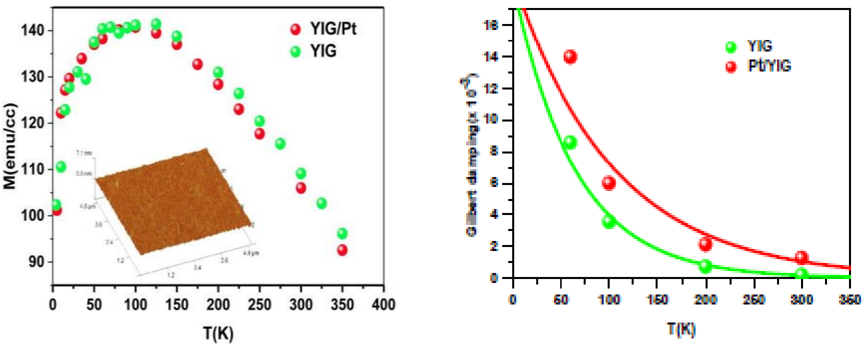
Generation of spin currents in magnetic insulators by spin pumping and spin Seebeck effect has led to dramatic advances in spin currents research and its applications for insulator based spintronics devices. Here we report deposition of high quality nm-thick yttrium iron garnet (YIG) film on gadolinium gallium garnet (GGG) by RF magnetron sputtering. The morphology and magnetic properties of the films were studied by using atomic force microscopy (AFM) and SQUID VSM respectively. 10-60 nm thick films have surface roughness of 1-3Å, and (111) orientation. Our results show that magnetic properties of YIG depend strongly on thickness: magnetic moment has linear dependence at room temperature. The saturation magnetization and coercive field observed in thick films are 136 emu/cc and 0.50 Oe, respectively. Temperature dependence of magnetization of nm-thick YIG films has revealed an interesting result, which can be attributed to an additional magnetic phase forming at the YIG/GGG interface. The downturn of magnetization in YIG at low temperatures has not been reported so far, but has significant relevance to the spin hall magnetoresistance (SMR) at low temperature. Our results on the temperature dependence of Gilbert damping factor of YIG and YIG/Pt films will lead to new physics, to understand its effect on spin mixing conductance and hence on SMR in YIG/Pt bilayer structure.



(a) (b)

Fig.1 (a) Temperature dependence of magnetisation in YIG (40nm) and YIG/Pt (40nm/10nm) thin films. (b) Temperature dependence of Gilbert damping factor in YIG (40nm) and YIG/Pt (40nm/10nm) thin films.

Electric valley control of the spin-hall effect in GaAs

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Controlling spin-related material properties by electronic means is a key step towards future spintronic technologies. The spin Hall effect (SHE) has become increasingly important for generating, detecting and using spin currents, but its strength—quantified in terms of the SHE angle—is ultimately fixed by the magnitude of the spin–orbit coupling (SOC) present for any given material system. However, if the electrons generating the SHE can be controlled by populating different areas (valleys) of the electronic structure with different SOC characteristic the SHE angle can be tuned directly within a single sample. Here we report the manipulation of the SHE in bulk GaAs at room temperature by means of an electrical intervalley transition induced in the conduction band. The spin Hall angle was determined by measuring an electromotive force driven by photoexcited spin-polarized electrons drifting through GaAs Hall bars. By controlling electron populations in different (Γ and L) valleys, we manipulated the angle from 0.0005 to 0.02 [1]. This change by a factor of 40 is unprecedented in GaAs and the highest value achieved is comparable to that of the heavy metal Pt.

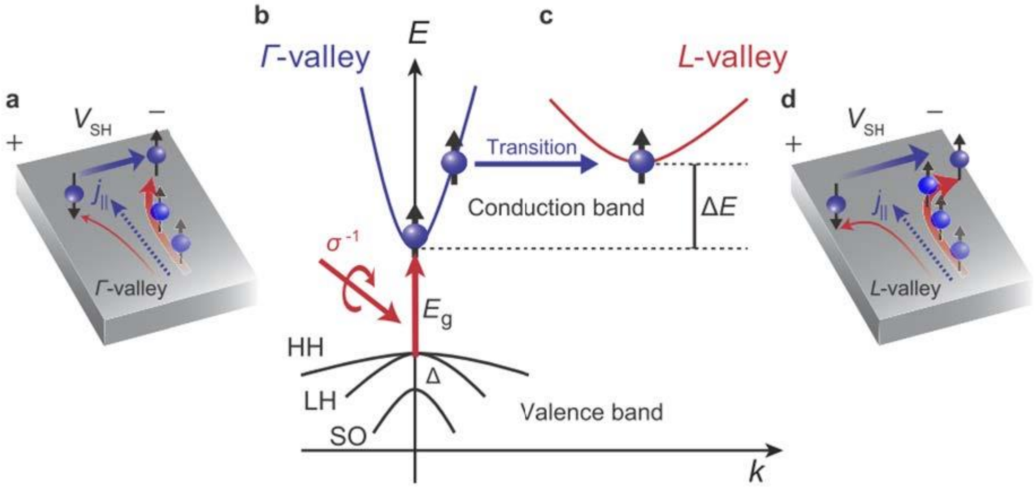

Figure 1: The GaAs band structure and schematics of the inter-valley transition and spin-Hall effect. Optically-generated spin-polarised electrons (at the Γ valley) are accelerated by an applied electric field and transferred to the L-valley. We experimentally deduced the spin-Hall angle for the two valleys and found a significant increase when the transport is dominated by electrons in the L-valley.

Spin pumping in ferromagnet - topological insulator heterostructures

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Ferromagnetic resonance (FMR) is a mature technique widely used to study the dynamic spin-transfer properties of magnetic multilayers. The generation of a pure spin current (without macroscopic charge flow) through spin pumping of a ferromagnetic layer is a key research area, both as a method of magnetisation reversal (through the spin transfer torque) and as a sensitive probe of the spin coherence properties of non-magnetic materials. Here, we demonstrate the incorporation of a topological insulator (TI) into a pseudo-spin valve heterostructure and study the time- and layer-resolved magnetodynamics. TIs have received widespread attention due to their large spin-orbit coupling and dissipationless, counterpropagating conduction channels in the surface state. To date, however, there has been only limited experimental research focussed on the development of TI-FM heterostructures and similar TI devices. We use vector-network analyser FMR and time resolved x-ray magnetic circular dichroism to demonstrate that TIs function as efficient spin sinks, while also allowing a limited dynamic coupling between ferromagnetic layers. These results shed new light on the spin dynamics of this novel materials class, and suggest future directions for the development of room temperature TI-based spintronics.

Spin relaxation through magnetic scattering in Cu/Py lateral spin valves

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A pure spin current is a flow of spin angular momentum in the absence of a net flow of charge, providing opportunities for information transport without dissipation from joule heating. A serious limitation to the exploitation of spintronics in technology is the short spin diffusion length within many materials. It is then crucial to obtain an understanding of effects which may alter the spin diffusion length. The spin diffusion length of Cu is commonly observed to have a non-monotonic dependence on temperature[3–7]. This does not correspond to the expected theory of Elliot-Yafet spin relaxation and no suggested alternative describes all current observations.

Nonlocal measurements in lateral spin valves provide an ideal situation for the study of pure spin transport due to the spacial separation of spin and charge currents[1, 2]. We have investigated nonlocal spin transport properties in lateral Py/Cu/Py spin valves, fabricated via shadow deposition, and have measured the spin diffusion length of Cu (λ_{Cu}, Fig. 1c).

We have isolated the different contributions to the spin flip scattering rate and provide evidence that the low temperature limit is dominated by magnetic impurities, due to the high chance of a spin flip occurring at a magnetic scattering site (25%).

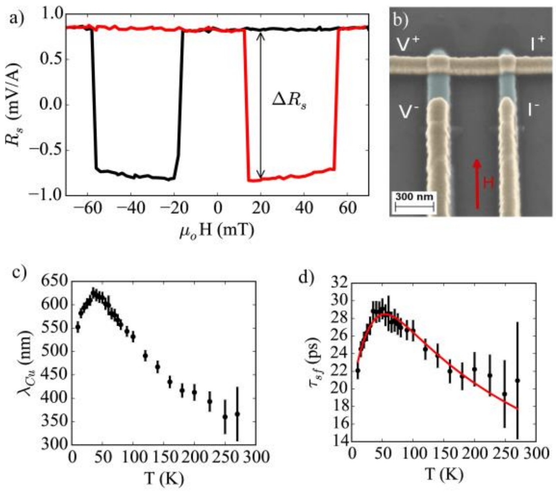

FIG. 1. a) Normalised nonlocal spin voltage measured at 5 K for a device with Py electrode separation of 425 nm. The red and black curves indicate increasing and decreasing field sweeps. b) SEM of a lateral spin valve showing the nonlocal measurement configuration, direction of applied field and false colour indicating Py (blue) and Cu (orange). c) Spin diffusion length of the Cu obtained from fits to a Valet-Fert 1-D model. d) Spin flip scattering time within Cu. Red line is a based on magnetic impurities and phonon scattering.

[1] M. Johnson and R. H. Silsbee, Physical Review Letters, 55, 1790 (1985)
[2] F. J. Jedema, A. T. Filip, and B. J. van Wees, Nature, 410, 345 (2001)
[3] T. Kimura, T. Sato, and Y. Otani, Physical Review Letters, 100, 66602 (2008)
[4] H. Zou and Y. Ji, Applied Physics Letters, 101, 082401 (2012)
[5] E. Villamor, M. Isasa, L. Hueso, and F. Casanova, Physical Review B, 87, 094417 (2013)
[6] L. O'Brien, M. J. Erickson, D. Spivak, H. Ambaye, R. J. Goyette, V. Lauter, P. A. Crowell, and C. Leighton, Nature Communications, 5 (2014)
[7] M. Erekhinsky, F. Casanova, I. K. Schuller, and A. Sharoni, Applied Physics Letters, 100, 212401 (2012)

Femtosecond optical pump-probe study of the spin Seebeck effect within a YIG/Cu/$Ni_{81}Fe_{19}$ trilayer

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Laser heating has been predicted to generate spin transfer torque (STT) in magnetic trilayer structures by means of the spin Seebeck effect (SSE)[1]. Recently it has been reported that spin currents can be generated by ultrafast optical absorption in metallic multilayers by superdiffusive spin currents with a small contribution from the SSE[2,3]. In the present study, femtosecond optical pump-probe measurements using ultrafast laser have been performed upon GGG/YIG(66.5nm)/Cu(8nm)/$Ni_{81}Fe_{19}$(2nm)/Al(2nm) trilayer structures. Heating of the metallic overlayer by the optical pump pulse causes a partial demagnetization of the YIG and $Ni_{81}Fe_{19}$ layers and generates a large thermal gradient normal to the plane of the thin film structure. The SSE is then expected to drive a spin current between the magnetic layers and generate an associated STT. After the inclusion of damping and STT the equation of motion may be solved numerically in the macrospin limit to simulate the expected response of the sample. Simulations have reproduced a suppression of the optically-induced $Ni_{81}Fe_{19}$ precession observed at a time delay corresponding with the peak temperature gradient in the YIG layer, as determined by thermal modelling. The results suggest that the dominant factor in driving SSE is the temperature gradient in the YIG layer, rather than the YIG/Cu interfacial temperature difference.

[1] J. C. Slonczewski, Phys. Rev. B 82, 054403 (2010)
[2] A. J. Schellekens et al., Nat. Comms. 5, 4333 (2014)
[3] Gyung-Min Choi et al., Nat. Comms. 5, 4334 (2014)

Session 2: Spin ice

(invited) Delicate magnetic ground states: the local view

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The technique of muon-spin rotation has an excellent track record of uncovering unusual magnetic behaviour in a variety of novel systems. The disadvantage of the technique has always been that the determination of the muon site has been problematic. In this talk I will describe some strategies for tackling this problem and illustrate the results with reference to various materials with unusual and delicate ground states. Muon-spin rotation provides a local view, which contrasts with bulk magnetic susceptibility data, sometimes quite startlingly [1], and is also very useful when demonstrating that frustrated materials fail to order [2,3]. The local view can have some intriguing pitfalls, which can be illustrated by our recent work on a quantum spin ice system based on Pr ions [4]. The ground state of the Pr ion is a non-Kramers doublet, meaning that it is not protected from non-magnetic perturbations (as a Kramers doublet would be) and we have been able to show that the anisotropic distortion field produced by the presence of the muon is enough to split the doublet. Using recently developed DFT techniques [5], together with crystal-field calculations, we are able to quantify this effect and explain the observed data. This leads to some important conclusions concerning the use of μSR in probing delicate magnetic ground states.

[1] F. D. Romero, A. Leach, J. S. Mller, F. R. Foronda, S. J. Blundell and M. A. Hayward Angew. Chem.-Int. Ed. 53, 7556 (2014)

[2] J. P. Sheckelton, F. R. Foronda, LiDong Pan, C. Moir, R. D. McDonald, T. Lancaster, P. J. Baker, N. P. Armitage, T. Imai, S. J. Blundell, and T. M. McQueen Phys. Rev. B 89, 064407 (2014)

[3] F. L. Pratt, P. J. Baker, S. J. Blundell, T. Lancaster, S. Ohira-Kawamura, C. Baines, Y. Shimizu, K. Kanoda, I. Watanabe and G. Saito Nature 471, 612 (2011)

[4] F. R. Foronda, F. Lang, J. S. Mller, T. Lancaster, A. T. Boothroyd, F. L. Pratt, S. R. Giblin, D. Prabhakaran and S. J. Blundell Phys. Rev. Lett. 114, 017602 (2015)

[5] J. S. Möller, D. Ceresoli, T. Lancaster, N. Marzari and S.J. Blundell Phys. Rev. B 87, 121108(R) (2013)

The AC Wien effect and non-linear non-equilibrium susceptibility in spin ice

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[1]Ecole Normale Supérieure de Lyon, France, [2]University College London, UK, [4] Max-Planck-Institut Dresden, Germany

We show that the Coulomb fluid of magnetic monopoles in spin ice (a “magnetolyte") exhibits the second Wien effect in the presence of an AC magnetic field [1]. This involves an increase of the monopole density - a universal and robust enhancement for Coulomb systems in an external field [2] which in turn speeds up the magnetization dynamics. We predict that the monopole density increase is directly related to the non-linear magnetic response providing a signal of the Wien effect that is specific to magnetic systems. The non-linear non-equilibrium susceptibility is treated analytically within a phenomenological model. Through this study, we gain new insights into the AC version of the classic Wien effect. One striking discovery is that of a frequency window where the Wien effect for magnetolyte and electrolyte are indistinguishable, with the former exhibiting perfect symmetry between the charges as well as a new low-frequency regime where the growing magnetization counteracts the Wien effect and hinders any permanent currents. We discuss conditions required to observe our predictions of the AC Wien effect in the non-linear susceptibility of $Dy_2Ti_2O_7$.

[1] V. Kaiser, S. T. Bramwell, P. C. W. Holdsworth, R. Moessner, arXiv:1412.4981

[2] V. Kaiser, S. T. Bramwell, P. C. W. Holdsworth, R. Moessner, Nature Materials, 12, 1033-1037 doi:10.1038/nmat3729, (2013)

Critical dynamics and finite-time scaling in spin ice systems

J Hamp[1], A Chandran[2], R Moessner[3] and C Castelnovo[1]

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Spin ice materials such as Dy2Ti2O7 and Ho2Ti2O7 provide a rare instance of emergent gauge symmetry and fractionalisation in three dimensions. Magnetic frustration leads to highly degenerate yet locally constrained ground states. Their elementary excitations carry a fraction of the magnetic moment of the microscopic spin degrees of freedom and can be thought of as magnetic monopoles. One of the distinguishing manifestations of this emergent “Coulomb phase” is a liquid-gas phase diagram that appears in an applied magnetic field – a feature that is expected in itinerant charge liquids but unprecedented in localised spin systems. Monopoles act as facilitators to the spin dynamics. At low temperatures they are sparse and dynamics becomes slow, leading to an interplay between emergent topological properties and lattice scale physics in response and equilibration properties. In this work, we investigate the dynamics in spin ice close to the critical end point of the liquid gas phase diagram. Critically divergent length scales give rise to finite time scaling properties that reflect the universal scaling exponents at the critical point. We use our results to obtain these exponents by tuning the approach direction in the field-temperature plane.

A quantum Kasteleyn transition in a spin-ice-like model

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[1]University of St Andrews, UK, [2]Universidad Nacional de La Plata, Argentina

It was pointed out some years ago by Jaubert *et al.* [1] that spin-ice materials should exhibit a Kasteleyn transition when an external magnetic field is applied along the [100] direction. In this talk, we present a two-dimensional spin-ice-like model that exhibits the same Kasteleyn physics, but in which the low-temperature behaviour of the Kasteleyn transition may be modified by the application of a transverse field. We show that this suppresses the fully magnetised phase, and argue that this leads to a quantum critical point at a finite value of the longitudinal magnetic field. We offer some preliminary suggestions of how to write a field theory that describes this quantum critical point, and discuss the relationship to the physics of real spin-ice materials.

[1] PRL 100, 067207 (2008)

Session 3: Vortices

(invited) 35 years of magnetic heterostructures

I K Schuller (IEEE Distinguished Lecturer)

University of California, San Diego, USA

Hybrid heterostructured materials allow the development of new material properties by creative uses of proximity effects. When two dissimilar materials are in close physical proximity the properties of each one may be radically modified and occasionally a completely new material emerges. In the area of magnetism, controlling the magnetic properties of ferromagnetic thin films without magnetic fields is an on-going challenge with multiple technological implications for low-energy memory and logic devices. All these are based on basic discoveries, which provide the scientific foundation for important applications. Of course like with all basic research discoveries it is difficult to predict where and when these will make it into applications.

Roughly 35 years ago the development of metallic (magnetic in particular) superlattices started a quest to engineer novel properties unlike existing in naturally occurring materials. This has lead to a many studies related to metallic superlattices and led eventually to the development of a whole new field of spintronics. After a brief motivation and historic background I will describe some of the most recent developments in the field. Interesting magnetic proximity effects arise when ferromagnets (FM) are in contact with antiferromagnets (AFM), such as the shift of the hysteresis loop along the field axis. In this "exchange biased" configuration, a variety of unusual phenomena arise unlike in any other magnetic system; i) the reversal of the FM becomes asymmetric, ii) large exchange bias appears in nominally fully compensated surfaces, iii) positive exchange bias emerges for certain classes of bilayers, iv) at fast time scales (<300psec) the reversal is anomalous, and v) the phenomenon is affected by the bulk magnetic structure of the AFM. Another interesting possibility arises when ferromagnets are in proximity to materials that undergo metal-insulator and structural phase transitions. In this case, the coercivities and magnetizations of the ferromagnetic films grown on different oxides oxides are strongly affected by the phase transition in the oxide. Both of these phenomena have presently existing and future potential applications in the spintronics, sensors, magnetic recording and transformers areas.

Work supported by US-DOE and US-AFOSR.

[1] Novel Laser-Induced Dynamics in Exchange-Biased Systems, A. Porat, S. Bar-Ad, and I.K. Schuller, Euro. Phys. Lett. 87, 67001 (2009)

[2] Exhange Bias: The Antiferromagnetic Bulk Matters, Ali C. Basaran, T. Saerbeck, J. de la Venta, H. Huckfeldt, A. Ehresmann, and Ivan K. Schuller, Appl. Phys. Lett. 105, 072403 (2014)

[3] Coercivity Enhancement in V_2O_3/Ni Bilayers Driven by Nanoscale Phase Coexistence, J. de la Venta, Siming Wang, T. Saerbeck, J.G. Ramirez, I. Valmianski, and Ivan K. Schuller, Appl. Phys. Lett. 104, 062410 (2014)

Magnetic switching and structure in nanoscale FePd Circular Islands

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The structural and magnetic properties of FePd alloy islands of 450 nm diameter on a square lattice of pitch 513 nm have been investigated using resonant magnetic x-ray scattering tuned to the Pd L3 edge. The out-of-plane chemical and magnetic structures have been determined from simultaneous fitting of the charge and magnetic reflectivity scattering data obtained by reversing either the incident helicity or applied magnetic field. The patterned array gives rise to in-plane diffraction peaks observed in low-angle rocking curves which have been modelled using Kinematical diffraction theory and the distorted wave Born approximation. By recording hysteresis loops as a function of in-plane diffraction satellite order, the magnetic structure can be probed across a range of length scales. The patterned elements show hysteresis loops characteristic of a vortex state and we show how the fields associated with its nucleation and annihilation vary with both temperature and in-plane scattering angle. The scattering data is supported with finite difference micromagnetic simulations giving new insights into strongly interacting magnetic arrays and the metrology tools required to study them.

Strain induced vortex core switching in planar magnetostrictive nanostructures

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Magnetic vortex cores, often found in planar magnetic structures, arise from the complex interactions between the magnetostatic and exchange energy. In recent years the magnetization dynamics of the core have also been studied in great detail because the gyrotropic mode has applications in spin torque driven magnetic microwave oscillators, and also provides a means to flip the direction of the core for use in magnetic storage devices such as magnetic random access memory. The excitation of the core gyrotropic mode can be achieved using various stimuli such as RF or pulsed magnetic fields or spin-polarized currents. Here we propose a new means of stimulating magnetization reversal of the vortex core by applying a time-varying strain to planar structures of the magnetostrictive material, $Fe_{81}Ga_{19}$ (Galfenol), coupled to an underlying piezoelectric layer. Using micromagnetic simulations we have shown that the vortex core state can be deterministically reversed by electric field control of the time-dependent strain-induced anisotropy. These theoretical results can be used as a recipe for designing experimental setups and could pave the way for low energy devices based on the magnetic vortex core.

Magnetic vortex states in highly anisotropic nanoislands

J M Porro Azpiazu[1,2], M Pancaldi[2], V Metlushko[3] and P Vavassori[2,4]

[1]ISIS - Science and Technology Facilities Council, UK, [2]CIC Nanogune, Spain, [3]University of Illinois at Chicago, USA, [4]IKERBASQUE - Basque Science Foundation, Spain

We have fabricated arrays of elliptical ferromagnetic nanoislands, made of Permalloy, with different dimensions (smallest nanomagnets 500x120x25nm^3) and aspect ratios (length/width) of 4, 5.7, and 8. They are arranged in chiral square and rectangular units formed by four nanomagnets, so that the stray fields created by each pair of parallel nanomagnets interact asymmetrically on the nanomagnets perpendicular to them. Under the action of a uniform magnetic field the only possible magnetic configuration that is induced in the nanomagnets is a single-domain state, i.e. the nanomagnets have an Ising-like bistable behavior of the magnetization. Micromagentic simulations indicate that a vortex state, if induced, would be stable although energetically highly unfavoured with respect to the single-domain state (see phase diagram in Fig.1a). Here we demonstrate that indeed, under the action of asymmetric fields, it is possible to nucleate magnetic vortex states that are stable at remanence. We demonstrate experimentally [1] the existence of these vortex states by analyzing the magnetization reversal process by means of standard and diffracted MOKE magnetometry (Fig.1b) [2], and Magnetic Force Microscopy (Fig.1c). Our micromagnetic simulations, performed using OOMMF [3], replicate the obtained experimental results.

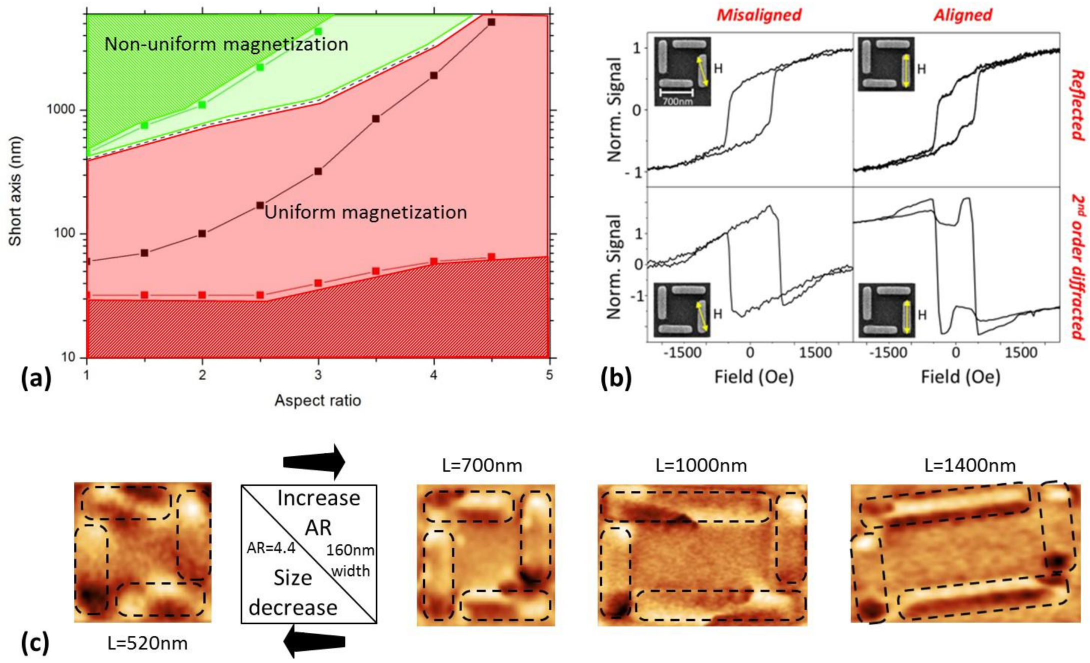

Fig.1: (a) phase diagram showing the energetically favored magnetic states in isolated nanomagnets with different lateral dimensions (thickness=25nm): above the black-dotted curve vortex states are energetically favored and below it uniform magnetization is favored. Dark green/red areas indicate regions in which only vortex/single-domain can exist, respectively. Light green/red areas indicate regions where the magnetic states found at remanence under the action of uniform magnetic fields are vortex/single-domain. (b) hysteresis loops from the reflected and second order diffracted beams in a sample made of 700x160x25nm^3 nanoislands, showing the differences in the magnetization reversal process depending on the orientation of the applied field: the shape of the loops in the right-column are indicative of a vortex state nucleation. (c) MFM images of vortex states at remanence in nanoislands with different dimensions after application of an external field as indicated for the loops in the right-column of panel (b).

[1] J.M.Porro *et al.*, J. Appl. Phys 11, 7 07B913 (2012)
[2] P. Vavassori and M. Grimsditch, J. Phys. Cond. Matt 16, 9 (2004)
[3] OOMMF code developed by NIST

Session 4: Ab initio, bio and organic magnetism

First-principles investigation of magnetism in lanthanide compounds

L Petit[1], D Paudyal[2], Y Mudryk[2], K A Gschneidner[2], V K Pecharsky[2], M Lueders[1], Z Szotek[1], R Banerjee[3] and J B Staunton[3]

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Using a combined density functional - disordered local moment approach [1, 2], we have investigated the magnetic ordering and critical temperatures of GdMg, GdZn, and GdCd. Excellent agreement with experiment is observed both at and away from equilibrium. In GdMg a transition from ferromagnetic to AF1 is observed with increasing pressure, whilst a canted magnetic state is seen to emerge from either the ferromagnetic or anti-ferromagnetic state with lowering the temperature. We find that despite being filled and situated at low binding energies, the non-lanthanide metal d-states strongly influence the electronic structure at the Fermi level and the magnetic ordering.

[1] M. Lüders, A. Ernst, M. Däne, Z. Szotek, A. Svane, D. Ködderitzsch, W. Hergert, B. L. Gyorffy, and W. M. Temmerman, Phys. Rev. B 71, 205109 (2005)

[2] B. L. Gyorffy, A. J. Pindor, J. B. Staunton, G. M. Stocks, and H. Winter, J. Phys. F: Met. Phys. 15, 1337 (1985)

Compositional tuning of the magnetic anisotropy of Ni_2MnGa-based compounds

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The Ni-based Heusler alloy Ni_2MnGa is an interesting material with a large magnetic-field-induced-strain and magnetocaloric effect around T_M, where T_M is the structural cubic to tetragonal transition temperature. In the ferromagnetic tetragonal phase below T_C, the alloy exhibits a magnetic shape memory effect which depends on its magnetic anisotropy.

Inspite of its promising properties, some problems remain however for practical applications. Ni_2MnGa has vary low $T_M \approx 200K$ and $T_C \approx 365K$. So, there is a long standing problem of how to increase T_M and T_C and keep its magnetic anisotropy energy(MAE) high.

Experimentally it has been found that off-stoichiometric $Ni_{2+x}MnGa_{1-x}$ compositions have higher T_M's. We have therefore carried out *ab-initio* electronic structure theory calculations of the MAE of these compounds and investigate how it varies with composition. T_c is also enhanced by replacing some Mn with Fe, $Ni_2Mn_{.5}Fe_{.5}Ga$, and we also study this doping effect on the MAE.

Quasi-one dimensional magnetic chain in Cu-guanidinuim formate studied by μSR

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$[C(NH_2)_3][Cu^{II}(HCOO)_3]$ (CuGF) is a perovskite ABO_3 metal-organic framework (MOF), which is also a multiferroic material possessing both antiferromagnetic and ferroelectricity. The magnetic MOFs attract intense research interest as their functional performance can be tuned by tuning and controlling the magnetic coupling inside. Cu^{2+} in this formate is a Jahn-Teller ion, thus it displays 4+2 elongated octahedral coordination geometry, with four short Cu-O bond lengths of 1.953 -2.003Å and two long Cu-O bond lengths of 2.360 and 2.382Å. The strong intrachain antiferromagnetic coupling through the anti-anti HCOO- bridge within the Cu formate chain makes CuGF a one dimensional magnetic material.

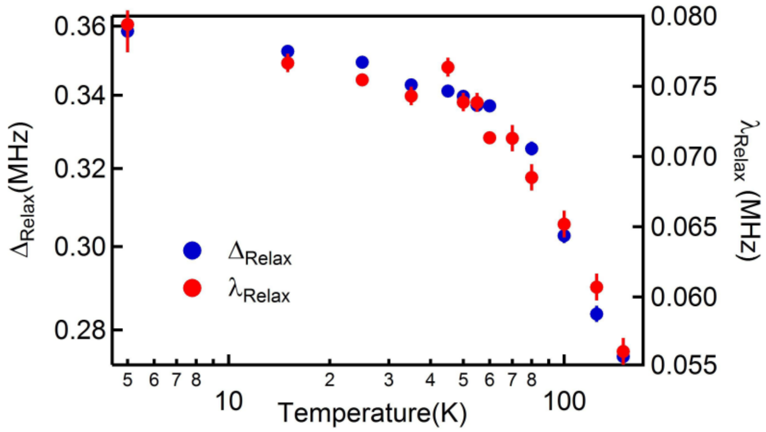

Fig 1. Field distribution and muon spin relaxation rate as a function of temperature in μSR measurement

CuGF is found to have long-range magnetic order below Neel temperature = 4.6K by both susceptibility and μSR measurements. Six muon sites is found in this formate. The critical fluctuation and exponents has been well investigated in CuGF. The susceptibility measurement also found a broad peak around 45K, which is believed to be related to the one dimensional magnetic chain[1]. In order to understand the one-dimensional magnetism physics, we performed more studies using μSR and magnetization measurements. The μSR measurements show an obvious field distribution change (shown in Fig 1) from 50K to 110K with an interesting field dependence. And similarly, a field dependence of the 45K susceptibility peak is also observed in the same field range. Ref [2] points out that, the field distribution change could be a signature of the one dimensional magnetic chain. We therefore believe that the μSR measurement could measure the quasi-one dimensional magnetic behaviour and we are now working on understanding the magnetic structure based on μSR measurements.

[1] Z. Wang et.al., Chem. Eur. J. 15, 12050 (2009)
[2] A. Yaouanc et. Al., Phys. Rev. B, 87, 134405 (2013)

The magnetic ground state of two isostructual polymeric quantum magnets, [Cu(HF_2)(pyrazine)]SbF_6 and [Co(HF_2)(pyrazine)]SbF_6, investigated with neutron diffraction

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Some of the best examples of macroscopic quantum magnets which preserve quantum fluctuations at low temperatures are low-dimensional antiferromagnets [1]. Co-ordination polymers, in which the magnetic exchange between metal ions is mediated by organic molecules, offers the means to test the properties of low-dimensional magnets by constructing three-dimensional lattices of ions with anisotropic exchange pathways. We present neutron powder diffraction experiments which compares the magnetic ground state of two coordination polymers: (i) [Cu(HF_2)($pyz)_2$]SbF_6 (where pyz = pyrazine), a quasi-two dimensional magnet based on planes of $S = 1/2$ moments arranged on a square lattice [2], and (ii) a new, isostructual polymer [Co(HF_2)($pyz)_2$]SbF_6.

We find the ordered moments of the Heisenberg $S = 1/2$ Cu(II) ions in [Cu(HF_2)($pyz)_2$]SbF_6 are 0.60 ± 0.10 μB. This reduced moment indicates the presence of quantum fluctuations preserved below the ordering temperature. We show from heat capacity and ESR measurements, that due to the crystal electric field splitting of the Co(II) ion in [Co(HF_2)($pyz)_2$]SbF_6, this isostructual polymer also behaves as an effective spin half magnet at low temperatures. Despite these similarities to the Cu sample, we show that the Co material shows evidence for more isotropic magnetic exchange, strong easy-axis anisotropy and neutron diffraction data which do not support the presence of quantum fluctuations on the ground state.

[1] N. Tsyrulin *et al.* Phys. Rev. Lett 102, 197201 (2009)
[2] J. Manson *et al.* J. Am. Chem. Soc 131, 6733 (2009)

The magnetic field dependent crossover between hyperfine and spin-orbit interactions in organic semiconductors

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Identifying the individual contribution of spin-orbit coupling (SOC) and hyperfine interaction (HFI) to electron spin relaxation (eSR) is a big issue in organic spinstronics. Measuring the electron spin relaxation rate (eSR) as a function of temperature, magnetic field, and targeted chemical substitution can differentiate between the individual contributions, which requires reliable method. The so-called avoided level crossing muon spin resonance (ALC-μSR) is an extraordinarily sensitive probe of dynamics in organic molecules, including the electron spin relaxation rate [1][2]. In the ALC field region where the HFI from nuclear spins is decoupled, the predominant mechanism of eSR is evidently SOC in organic molecules [2].

In order to achieve a full picture of field-dependent eSR, the off-resonance muon spin relaxation as a function of magnetic field can be used to obtain the electronic dynamics, though it is difficult to interpret and model, as all types of dynamics from all muonium states in the system contribute. Here we present the muon relaxation rate as a function of magnetic field (see figure 1), for both hydrogenated (H) and deuterated (D) pentacene, to try to disentangle the various mechanisms at play. From our data, it is clear that above a modest field, the muon's relaxation rate is identical within the experimental error for the H and D pentacene, suggesting only SOC is present. At lower intermediate fields, there is a significant difference in the muon spin relaxation rate, is suggesting that all HF relaxation processes directly or indirectly contribute to the electron spin relaxation. To fully understand the underlying mechanisms of muon relaxation at low fields, we performed simulations with the software QUANTUM [3]. A series of muon experiments on the acenes (anthracene, tetracene and pentacene) is also able to validate the simulation model due to their simplicity of chemical structures. By putting all these together we are developing a comprehensive understanding of HFI and/or SOC mediated eSR in organic spintronics.

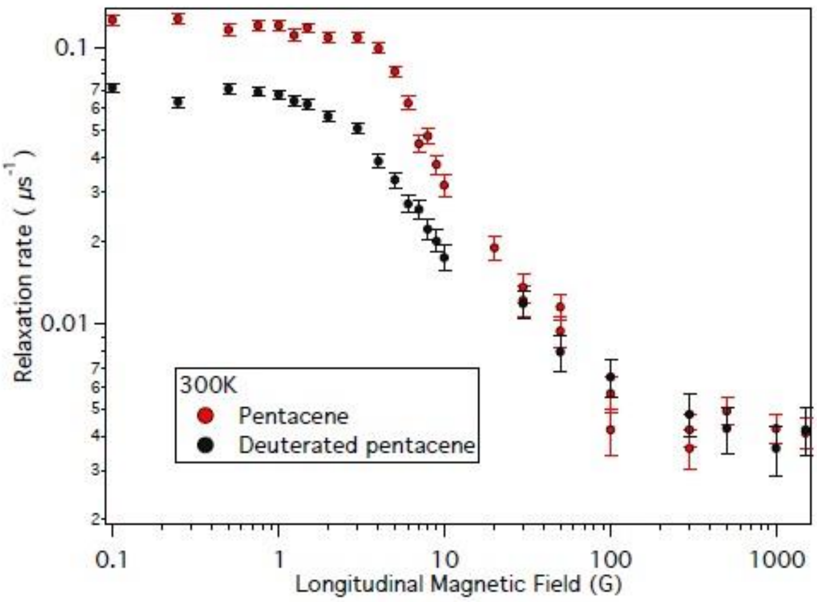

FIG 1: Muon relaxation rate as a function of magnetic field for both H and D pentacene at 300K.

[1] L. Schulz et al., Phys. Rev. B 84, 085209 (2011)
[2] L. Nuccio et al., Phys. Rev. Lett. 110, 216602 (2013)
[3] J. S. Lord, Physica B 374, 472 (2006).

Session 5: Spin torque and spin-orbit effects

Universal magnetic Hall circuit based on paired spin heterostructures

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The spirit of digital electronics is to dicretise all kinds of signals, meaning that the first consideration of any proposed circuit element is if it can be digitised. Consequently, to design a spin-based electronic device, the primary concern is essentially how many 'states' the physical system has and how much it can handle these states. Usually a two-state system with distinguishable states can be used as memory, while multiplet systems should, in principle, be favoured for logic or complex memory devices. In this talk, I will demonstrate how the anomalous Hall effect in a multi-layered ferromagnetic system can be engineered to provide a read-out signal for both memory and logic circuit elements. The read-out performance, that is, the magnitude of the electrical response to a change of the magnetic state is even better than that of magnetic tunnel junctions (MTJs).

The anomalous Hall effect, or extraordinary Hall effect (EHE), is a due to the spin-orbit interaction in ferromagnetic materials, and the mechanisms are well explained theoretically [1]. What hinders the practical application of the EHE is the small amplitude in conventional ferromagnets (e.g., Fe, Co, and Ni). I will firstly demonstrate our recent work of enhancing the EHE in a common Co/Pt multilayer system by interfacial engineering from both a physics and materials point of view [2, 3, 4]. The enhanced EHE signal allows for direct incorporation of the magnetic device in electronic circuitry. Both memory and logic devices are constructed based on the core ferromagnetic layer structure. The EHE-based memory [5] embraces all advantages of a MTJ, while having a room temperature ON/OFF ratio (the counterpart of magnetoresistance for MTJs) of 47,000 %, which is much larger than that of state-of-art MTJs. Moreover, the realisation of complex logic operations [6], as well as the achievement of a three-dimensional memory architecture [7] will be presented.

This work has been supported by the Semiconductor Research Corporation (SRC) and the John Fell Fund (University of Oxford).

[1] N.Nagaosa et al. Rev. Mod. Phys. 82, 1539 (2010)
[2] S. L. Zhang et al. Appl. Phys. Lett. 82, 1539 (2010)
[3] J. Y. Zhang et al. Appl. Phys. Lett. 102, 102404 (2013)
[4] J. Y. Zhang et al. Appl. Phys. Express 6, 103007 (2013)
[5] S. L. Zhang et al. Scienti_c Reports 3, 2087 (2013)
[6] S. L. Zhang et al. SPIN 3, 1350008 (2013)
[7] S. L. Zhang et al. Scienti_c Reports 4, 6109 (2014)

Spin orbit torques in epitaxial MnSi

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Skyrmions are vortex-like spin configurations stabilised by the combined effect of the spin-orbit coupling and the broken space inversion symmetry of the magnetic crystal that hosts them [1]. Recent experiments have demonstrated that very low current densities are sufficient to set skyrmions into motion via current induced torques [2].These torques have predominantly been interpreted in terms of spin-transfer torque, where angular momentum is transferred from the carrier's spin. However, the combined presence of the spin-orbit coupling and the broken space inversion symmetry is also responsible for the spin-orbit torques observed in ferromagnetic heterostructures and strained ferromagnetic semiconductors, where angular momentum is transferred from the carrier's angular momentum, suggesting that these relativistic terms should play a role in the current induced dynamics of skyrmions.

We have quantified the spin-orbit torque in epitaxial MnSi by using current induced ferromagnetic resonance and found agreement with the theoretical prediction [3].

[1] Nature 442, 797 (2006)
[2] Science 330, 1648 (2010)
[3] PRB 89, 064426 (2014)

Magneto-optical observation of mutual phase-locking in a pair of spin-torque vortex oscillators

P S Keatley[1], S R Sani[2,3,4,5], G Hrkac[6], E Burgos[1], S M Mohseni[2,7], P Dürrenfeld[8], J Åkerman[2,3,8] and R J Hicken[1]

[1]University of Exeter, UK, [2] KTH Royal Institute of Technology, Sweden, [3]NanOsc AB, Sweden, [4]New York University, USA, [5]Uppsala University, Sweden, [6]University of Exeter, UK, [7]Shahid Beheshti University, Iran, [8] University of Gothenburg, Sweden

Microwave electrical characterisation and time-resolved scanning Kerr microscopy (TRSKM) with coherent injection locking have been used to image the magnetization dynamics excited in the vicinity of a pair of nano-contact (NC) spin-torque vortex oscillators (STVOs). Two Cu NCs with circular shape, 100 nm diameter, and 900 nm center-to-center separation were fabricated on top of a Co(6)/Cu(6)/NiFe(3.5) spin valve mesa (thickness in nm), and connected in parallel using a single top contact. Multiple auto-oscillations were observed in the power spectra with transitions in their behaviour as a function of applied DC current. A 160 MHz microwave current was used to injection-lock the different modes at different values of the DC current. At high current values, a low frequency, large amplitude, narrow linewidth mode was observed. Kerr images suggest that the mode is a collective, mutually phase-locked auto-oscillation of a pair of vortices for which both NCs generate similar dynamics. At lower current values two unstable modes indicate spatial transitions in the core trajectory from one NC to the other, or around both NCs. Kerr images support this interpretation revealing different amplitude of the dynamics at each NC. TRSKM is shown to be a powerful compliment to existing electrical characterisation techniques.

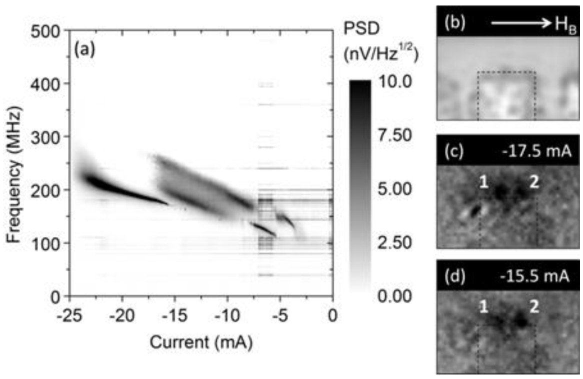

Figure 1. (a) Frequency dependence on the DC current applied to a pair of 100 nm NC-STVOs with 900 nm center-to-center separation. The greyscale represents power spectral density (PSD). (b) Reflectivity image acquired in scanning Kerr microscopy showing a single top electrical contact (dotted line) to both NCs. The surrounding uniform light grey area is the exposed NiFe free layer allowing for optical access. (c) and (d) TR Kerr images revealing regions of localized magnetization dynamics (black contrast labelled 1 and 2) associated with the gyrotropic motion of the vortex of each NC.

Asymmetry in anomalous Hall effect measurements of magnetic dots

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The anomalous Hall effect (AHE) is the phenomenon whereby a ferromagnetic material produces a transverse voltage when a current is applied. By fabricating a Hall cross of non-magnetic material, the hysteresis loop of small magnetic volumes (magnetic dots) can be obtained by fabricating them on the cross [1]. Previous AHE studies have been carried out on magnetic dots that have a single switching event where it has been shown that the magnitude of the transverse voltage produced by a dot decreases as the dot is moved away from the cross centre [2]. We have carried out AHE measurements on dots with two separated magnetic layers that have two separate switching events. Whilst dots at the cross centre have symmetric hysteresis loops, significant asymmetry is seen in hysteresis loops for dots located away from the cross centre. This asymmetry follows well defined patterns when the direction of current is reversed or applied at right angles. Possible causes for this highly unexpected behaviour will be discussed.

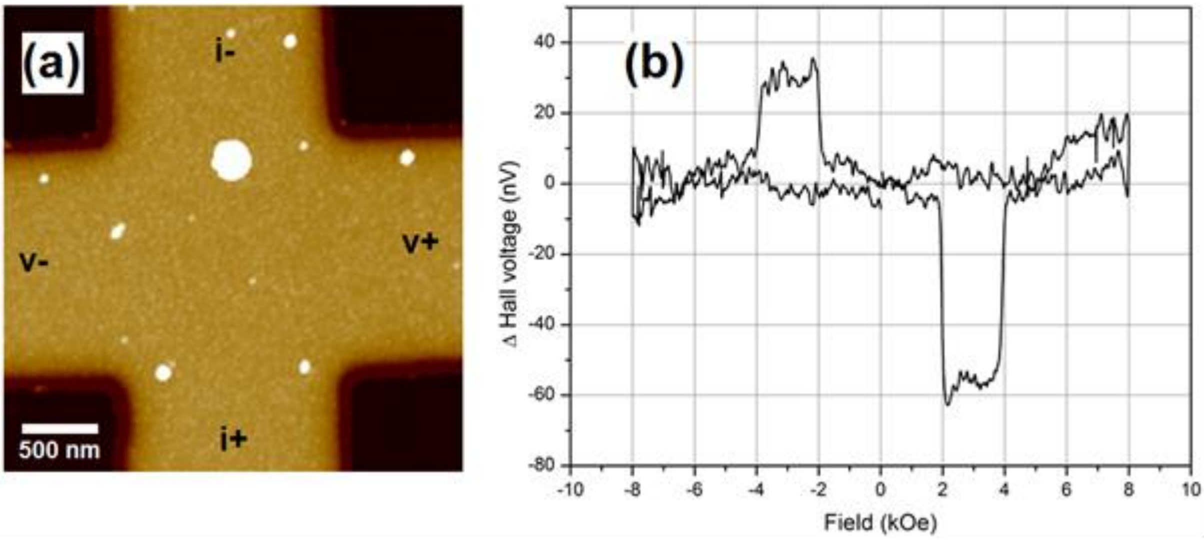

Fig. 1 (a) AFM image showing Hall measurement setup. The 250 nm diameter CoPd/Pd/CoNi dot is positioned away from the cross centre. (b) The resulting hysteresis loop shows significant asymmetry.

[1] Neumann, A. et al. (2013), Probing the Magnetic Behavior of Single Nanodots, Nanoletters, 13, 2199-2203

[2] Alexandrou, M. et al. (2010), Spatial sensitivity mapping of Hall crosses using patterned magnetic nanostructures, J. Appl. Phys., 108, 043920

Room-temperature spin-orbit torque and AMR in NiMnSb

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Spin-orbit torque (SOT) is a type of current-induced torque in materials with strong spin-orbit coupling and broken spatial inversion symmetry. NiMnSb has both properties, and is also promising for spintronic applications due to its low Gilbert damping and strong magnetic anisotropy. We measured in-plane spin-orbit-driven ferromagnetic resonance (SO-FMR), which has been previously used to study SOT in ferromagnets. Microwave-frequency current excites FMR and generates an AMR-related voltage across a NiMnSb bar, which contains information about the in-plane SOT. An effective field perpendicular to the bar was observed in bars along the easy and hard axes. It has Dresselhaus symmetry, suggesting it is due to SOT, rather than Oersted field.

Additionally, in-plane measurements of the anisotropic magnetoresistance (AMR) were performed on bars of NiMnSb on (In,Ga)As. 4 um wide bars along the easy and hard anisotropy axes showed distinct AMR, but bars perpendicular to these axes did not. To test whether this was caused by the high degree of strain in the 4 um bars, 1 um bars (with higher strain relaxation) were also measured. In these bars, AMR was detected in the perpendicular directions as well as along the easy axis.

Session 6: Superconductors

(invited) Magnetic vortices: a probe of the superconducting state

E Blackburn

University of Birmingham, UK

In Type-II superconductors, magnetic field enters the superconductor as flux lines, or magnetic vortices, each individually carrying a flux quantum. These flux lines are then packed parallel to the applied field, and form structures that can be imaged or diffracted off. I will show how neutron diffraction from these vortex lattices can give us key information on the underlying superconducting state, particularly as the vortex lattice changes structure. This will be illustrated using examples of cuprate (YBCO), iron-based ($BaFe_2(As,P)_2$), heavy fermion ($CeCoIn_5$), and BCS superconductors (BiPd).

Charge-stripe Magnetic Interactions of the checkerboard charge order state

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A breakthrough in understanding the magnetic interactions of the high hole doped high temperature cuprate superconductors was made by discovery of a near identical hourglass shaped magnetic excitation spectrum in non-superconducting charge ordered $La_{5/3}Sr_{1/3}CoO_4$ [1]. The underlying charge ordered structure of $La_{2-x}Sr_xCoO_4$ is however under debate, charge-stripes or checkerboard charge order?[2] The magnetism of an ideal checkerboard charge ordered state is spin frustrated, and we have previously shown how this spin frustration is lifted by magnetic stripe interactions in $La_{3/2}Sr_{1/2}NiO_4$[3]. In our present studies we wish to address how the magnetism of charge-stripe order develops in relation to checkerboard charge order in $La_{2-x}Sr_xNiO_4$. We will present results on the magnetic ordering from μSR, and inelastic neutron scattering on charge ordered $La_{2-x}Sr_xNiO_4$.

[1] A. T. Boothroyd, P. Babkevich, D. Prabhakaran and P. G. Freeman, Nature 471, 341 (2011)
[2] Y. Drees et al., Nature Commun. 4, 2449 (2013)
[3] P. G. Freeman et. al. Phys. Rev. B 71 (2005) 174412

Inducing magnetization at a non-magnetic interface by superconducting triplet correlations

M G Flokstra[1], S L Lee[1], G Burnell[2], S J Bending[3], S Langridge[4], M Eschrig[5], T Prokscha[6], N Satchell[2], J Kim[2], P J Curran[3], J F K Cooper[4], C J Kinane[4], A Isidori[5], N Pugach[5], H Luetkens[6] and A Suter[6]

[1]University of St. Andrews, UK, [2]University of Leeds, UK, [3]University of Bath, UK, [4]STFC - Rutherford Appleton Laboratory, UK, [5]Royal Holloway, University of London, UK, [6]Paul Scherrer Institute, Switzerland

Superconductivity and ferromagnetism are antagonistic states of matter, the interplay of which results in the conversion of conventional spin singlet superconductivity into spin triplet pair correlations. In a recent experiment on superconducting spin-valve structures we have demonstrated that this conversion can lead to an induced magnetization at a remote non-magnetic interface. This magnetization is controlled magnetically or via temperature and can easily be switched between an on and off state, providing the intriguing possibility to detect remotely the magnetic state of a device via a dissipationless superconducting conduit. Where the novel physics of these results offer great potential for spintronic applications, it is also of great theoretical interest. These results were unexpected and very different from prevailing theory models, requiring a re-evaluation of the dominant processes in the proximity effect between a superconductor and ferromagnet.

Evidence of spin triplet superconductivity in superconductor/ferromagnet heterostructures

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[1]ISIS - Science and Technology Facilities Council, UK, [2]St Andrews University, UK, [3]University of Leeds, UK, [4]University of Bath, UK, [5]Royal Holloway, University of London, UK

Superconductivity and ferromagnetism are usually antagonistic phenomenon; however, by artificially juxtaposing them into nanoscale heterostructures we novel electronic states. One such state can be created from a conventional singlet superconductor, such as niobium, and results in a spin aligned triplet Cooper pair. This "Odd Frequency Superconductivity" is not based on strong correlations and as such can be studied under the framework of the BCS theory [1].

Recent experiments have used a non-collinear magnetic interface in close proximity to a conventional superconductor to create a triplet state [2]. In our work we induce the triplet state with homogeneous magnetism; the electrons in a Cooper pair scattering from a superconductor/ferromagnet interface are able to penetrate different distances depending upon their spin direction relative to the ferromagnet [3]. This creates a phase difference between the electrons, in a manner analogous to the Goos-Hänchen shift, which gives the Cooper pair a net magnetic moment.

We have used polarised neutron reflectivity (PNR) and thin film structures which allow us to control the non-collinearity of the magnetic layers to study these effects. PNR is sensitive to interfaces and magnetism within layers, allowing the measurement of the magnetic moment of the triplet state.

With PNR we have observed a modification of the magnetic state below the transition temperature of the superconductor; this modification can be modelled and has been found to be in rough agreement with our Low Energy Muon measurements.

[1] Bergeret, F. F., Volkov, A. & Efetov, K. K. Rev. Mod. Phys.77, 1321–1373 (2005)
[2] Robinson, J. W. A., Witt, J. D. S. & Blamire, M. G. Science329, 59–61 (2010)
[3] M.G. Flokstra et al. arXiv:1404.2950v2 – Now accepted for publication in Physical Review B

Session 7: Magnetism and structure

Understanding the proximity induced magnetism in Pt using interface engineering through the addition of heavy metal interlayers

R M Rowan-Robinson[1], M Björck[2], T P Hase[3], A T Hindmarch[1] and D Atkinson[1]

[1]Durham University, UK, [2]Uppsala University, Sweden, [3]University of Warwick, UK

Measurements by S. Parkin [1] on Pt/ferromagnetic structures showed that domain wall velocities fell rapidly as Au insertion layers were added at the interface. This hinted at the importance of proximity induced magnetism for the Dzyaloshinkii-Moriya interaction.

Using X-ray resonant magnetic reflectivity (XRMR) on Pt/Co/Pt trilayer structures, we have measured the proximity induced magnetization in the Pt for different Au and Ir spacer layer thicknesses. XRMR was performed at the Pt L 3 edge and therefore only sensitive to the Pt magnetic moment. The technique has depth sensitivity, and therefore direct comparison between the top and bottom Pt moments can be made, combined with information on their respective structure.

Fits to the data show that even with no spacer, the induced moments at the Pt interfaces are asymmetric, with a larger moment on the top Pt compared to the buffer Pt interface. Top Pt moment vanished rapidly as spacer layer thickness is increased. The loss of moment is more rapid for Ir spacers, vanishing by 7Å. This coincides with the thickness at which the sign of the DMI has been observed to reverse entirely [2]. For the Au interlayers the moment persists longer, but decays on a length-scale consistent with reduced current driven domain wall velocities observed by S. Parkin [1].

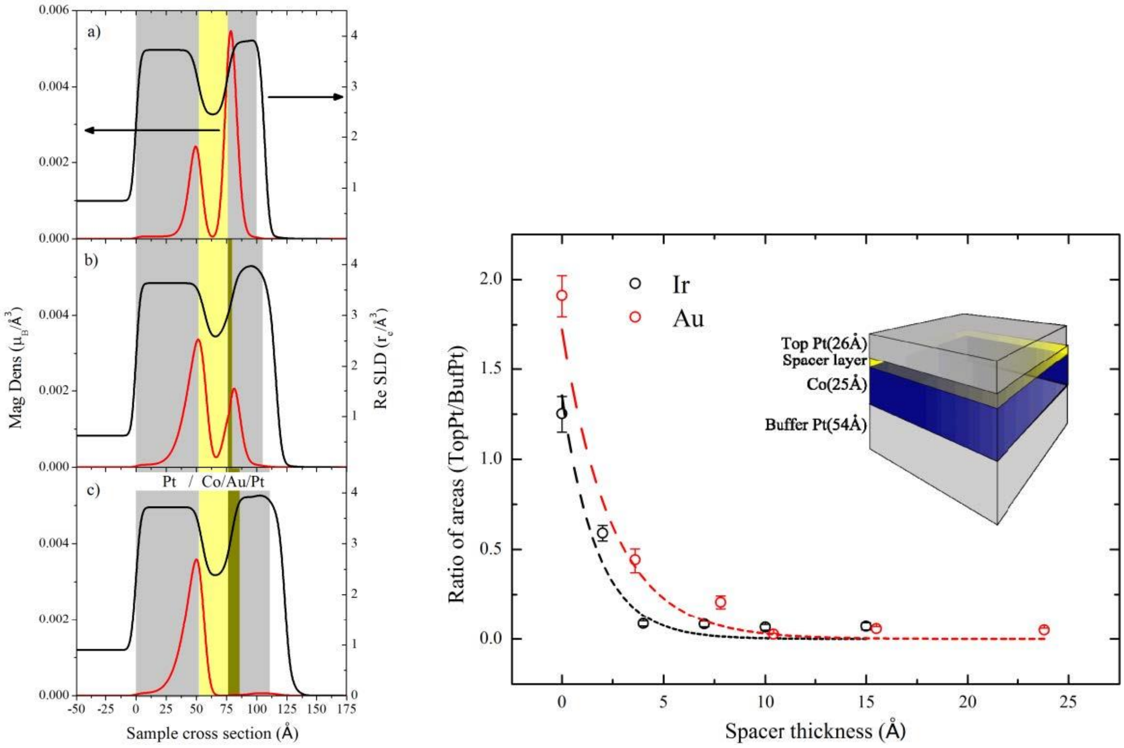

Figure 1: Left: Scattering length density (SLD) profiles showing cross sections through three sample, a) no spacer, b) Au(2.5 Å), c) Au(10 Å) spacer layers. Black lines show the chemical SLD whereas the red lines show the magnetic SLD, which is directly related to the induced moment on the Pt. Above: ratio of areas under the magnetic SLD as spacer layer thickness between the Co and top Pt layer is increased.

[1] S. P. Parkin et al. Nat. Comms., 5, 3910 (2014)
[2] A. Hrabec et al, Phys. Rev. B, 90, 020402(R) (2014)

Motion of the antiferromagneic-ferromagnetic interface in a dopant-graded FeRh thin film

T Charlton[1], C Le Graet[2], M McLaren[2], M Loving[3], S A Morley[2], C J Kinane[1], R M D Brydson[2], L H Lewis[3], S Langridge[1] and C H Marrows[2]

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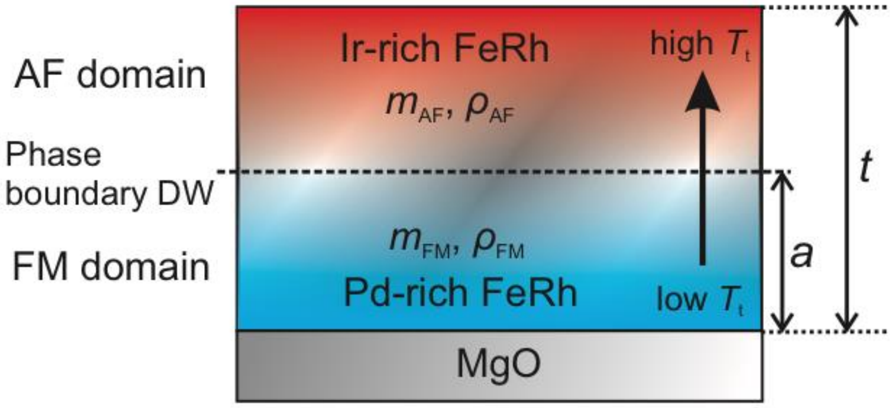
FeRh is an ordered alloy with an antiferromagnetic-ferromagnetic phase transition between 350K and 500K depending on dopant type and concentration. To gain control over the location of the phase boundary we have introduced a double wedge shaped dopant profile with a high Pd concentration of Pd at the substrate tapering to upward along the thickness of the film and an opposite Ir dopant profile yielding a Ir rich surface. As the film is heated, a smooth, horizontal antiferromagnetic-ferromagnetic phase boundary domain wall moves gradually up through the layer. The location of the phase boundary determines the magnetic thickness, which in turn directly impacts the average magnetization and resistivity of the film. We will present our observations of the temperature controlled phase boundary as seen by bulk magnetization, resistivity and polarized neutron reflectivity measurements.

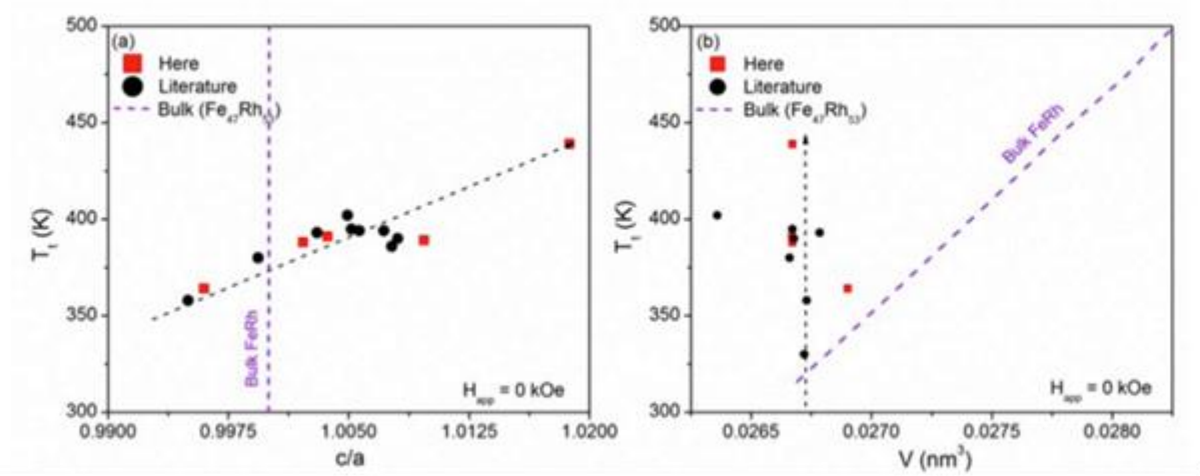


Tunable response in α'-FeRh films

L H Lewis[1], M G Loving[1], C Le Graët[2], C J Kinane[3], S Langridge[3] and C H Marrows[2]

[1]Northeastern University, USA, [2]University of Leeds, UK, [3] ISIS - Science and Technology Facilities Council, UK

Response tunability is an important consideration for sensor performance and application. Magnetostructural materials exhibit amplified functional effects in the vicinity of the first-order phase transition that are particularly well suited for sensor applications. In particular, the phase transition and accompanying amplified response of this class of materials may be controlled by magnetic and/or electric fields, thermal or strain effects, or by some combination of all these drivers, providing a multidimensional phase space for optimization. Epitaxial α´-FeRh films of nominal 50-nm thickness with out-of-plane c-axis orientation were sputter-deposited at high temperature onto (001)-MgO or (0001)-Al_2O_3 substrates and capped with Al, Au, Cr or W after in-situ annealing at 973 K to promote CsCl-type chemical order. Results derived from synchrotron-based x-ray diffraction indicate that the antiferromagnetic (AF)—ferromagnetic (FM) magnetostructural phase transformation in these films may be tuned over an ~ 90 degree range (350 K – 440 K) through variation in the c/a ratio derived from epitaxial lattice strain delivered by the capping layers. These results supply fundamental information to inform potential applications of this compound.



Acknowledgements: NSF:DMR-0908767 and UK-EPSRC:EP/G065640/1

Understanding the YIG/Pt Interface

A L Westerman, M Ali, B D G Steele and B J Hickey

University of Leeds, UK

Thin films of heavy metals (Pt) grown on top of magnetic insulators (YIG) have recently generated a lot of interest. Spin-orbit effects, including the dual action of the spin Hall effect and its inverse, lead to spin Hall magnetoresistance [1] and the spin Hall anomalous Hall effect [2] within these systems. Results have been difficult to interpret due to additional effects such as weak localisation [3] and a potential magnetic polarisation of Pt [4] causing competing magnetoresistance [2-5] as well as possible interdiffusion at the YIG/Pt interface.

We have performed a systematic study of Pt on YIG on various substrates to reveal the origins of the unconventional MR and Hall effects. Additionally, we intentionally doped thin films of Pt grown on Al_2O_3 with small amounts of Fe to simulate the effects of interdiffusion of Fe from YIG. Experiments as a function of temperature, field magnitude and orientation allow us to separate the spin-orbit determined effects from those caused by other influences. We found that many of the discrepancies between published results depend on whether interdiffusion has been a likely outcome of the growth and sample preparation method.

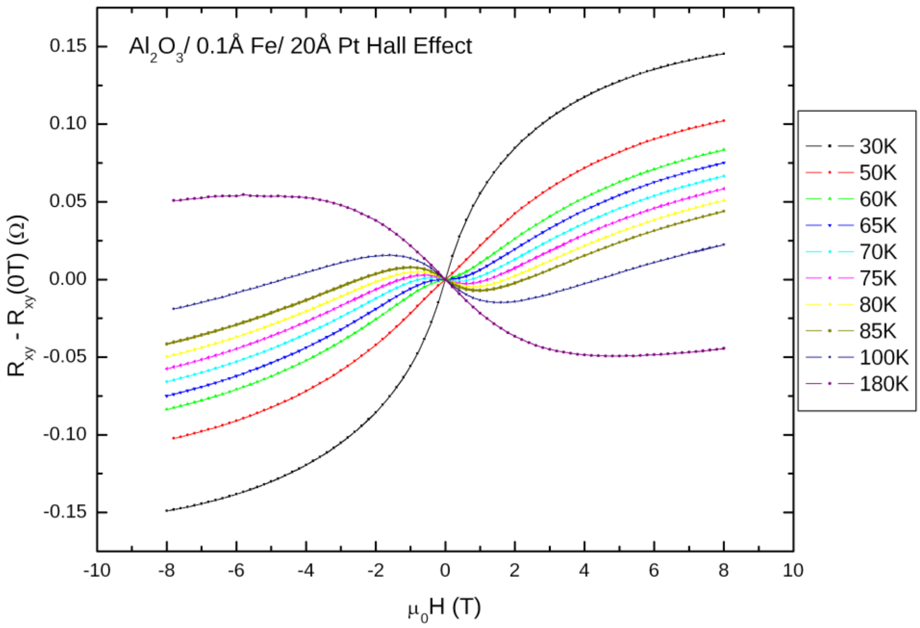


Figure 1: An example of unconventional Hall effect found for Pt doped with Fe. The curvature exhibited at high field is consistent with some results for YIG/Pt published in the literature, but is different to others. The positive sign of the Hall effect is consistent with YIG/Pt results.

[1] H. Nakayama et. al., Phys. Rev. Lett. 110, 206601 (2013)
[2] S. Meyer et. al., arXiv:1501.02574v1 [cond-mat.mtrl-sci] (2015)
[3] Y. Shiomi et. al., Appl. Phys. Lett. 104, 242406 (2014)
[4] T. Lin et. al., Phys. Rev. Lett. 113, 037203 (2014)
[5] N. Vlietstra et. al., Appl. Phys. Lett. 130, 032401 (2013)

Session 8: Skyrmions and topological effects

Helical magnetic structure in $Fe_{1-x}Co_xGe$ epilayers

C S Spencer[1], N A Porter[1], R Temple[1], C J Kinane[2], T R Charlton[2], S Langridge[2] and C H Marrows[1]

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Magnetic skyrmions are non-trivial spin textures that can form in a material that lacks inversion symmetry (e.g. chiral helimagnets, such as FeGe) and hence supports a Dzyaloshinskii-Moriya interaction (DMI) [1,2]. They are topologically stable and moveable with low current densities [1], making them promising candidates for information carriers [2].

To realise skyrmion-based devices, thin films are required. We have grown epitaxial films via MBE starting with FeGe, as it has a high magnetic ordering temperature, and moving into $Fe_{1-x}Co_xGe$.

The inner magnetic structure of $Fe_{1-x}Co_xGe$ films for x = 0, 0.3 and 0.6 were probed using polarised neutron reflectometry: data from ~70 nm nm thick epilayers, under a field of 1 mT are shown in fig 1. The fitted magnetic profile for each composition, shown in fig 1 c) x = 0, f) x = 0.3 and i) x = 0.6, were produced using a helicoid model [1] to simulate the unwinding of the magnetic helix under field. Magnetisation reversal is shown to take place by phase-shifting of the partial helicoid, rather than rotation of the entire layer moment. The wavelength of the helicoid structure was found to increase with increasing Co content.

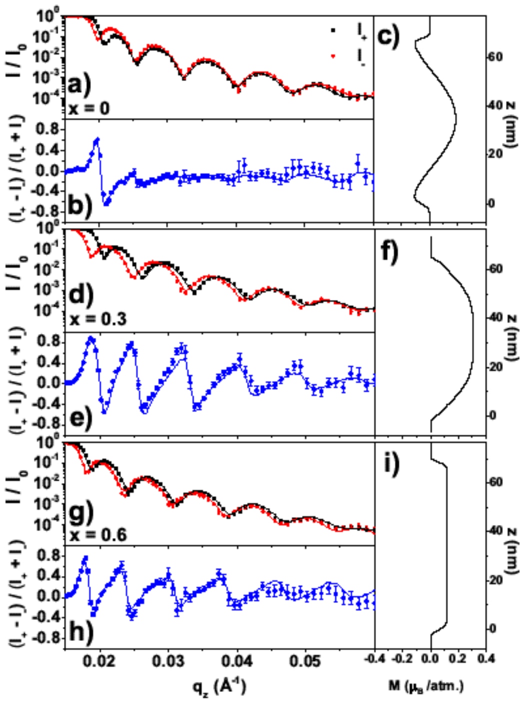

Figure 1: Polarised neutron reflectometry (PNR) scattering at 50 K with a 1 mT field applied in-plane after negative saturation for $Fe_{1-x}Co_xGe/Ge$ bilayers and extracted magnetic profiles for x = 0 (a-c), x = 0.3 (d-f) and x = 0.6 (g-i). (a, d, g) Intensity of neutron scattering for polarised neutrons (symbols) and fits (lines).(b, e, h) Spin asymmetry (symbols) and fits (line) extracted from the respective PNR profiles. (c, f, i) Resulting magnetic depth profiles of films.

[1] S. Mühlbauer et al., Skyrmion Lattice in a Chiral Magnet, Science 323, 915-919 (2009)
[2] U.Roßler, A. Bogdanov, C. Pfleiderer, Spontaneous skyrmion ground states in magnetic metals, Nature 442, 797-801 (2006)
[3] F. Jonietz et al., Spin Transfer Torques in MnSi at Ultralow Current Densities,Science 330, 1648 (2010)
[4] A. Fert, V.Cros and J. Sampaio, Skyrmions on the track, Nature Nano. 8, 152 (2013)
[5] M. Wilson et al., Discrete helicoidal states in chiral magnetic thin films, Phys. Rev. B 88, 214420 (2013)

Magnetic Cr doping of Bi_2Se_3: Evidence for divalent Cr from x-ray spectroscopy

L Collins-McIntyre[1], A Figueroa[2], G van der Laan[2], S Zhang[1], A Baker[1], S Harrison[3], P Schoenherr[1], G Cibin[2] and T Hesjedal[1]

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We report a study of the structural and magnetic properties of Cr-doped Bi_2Se_3 thin films grown by MBE. We will present a thorough exposition of the electronic character of the magnetic ground state of this material as determined by x-ray magnetic circular dichroism (XMCD) and extended x-ray absorption fine structure (EXAFS). We have previously observed the formation of a ferromagnetic ground state (via SQUID), below a measured $T_c \sim 8{:}5$ K with a saturation magnetization of $2{:}1\ \mu_B/\mathrm{Cr}$. It has been the established view that the Cr dopant is trivalent, as it substitutes for the Bi^{3+}. Divalent Cr has often be ascribed to the formation of Cr clusters within the van der Waals gap. Our XMCD and EXAFS studies indicate that, contrary to expectations, the Cr dopes into the system as Cr^{2+} due to covalency between the Cr-*d* and Se-*p* orbitals. This is evidenced by the energy positions of the *Cr K* and $L_{2;3}$ absorption edges relative to reference samples. The extended x-ray absorption fine structure at the *K* edge shows that the Cr dopants substitute on octahedral sites with the surrounding Se ions contracted by $\Delta d = 0{:}36$Å, in agreement with recent band structure calculations.

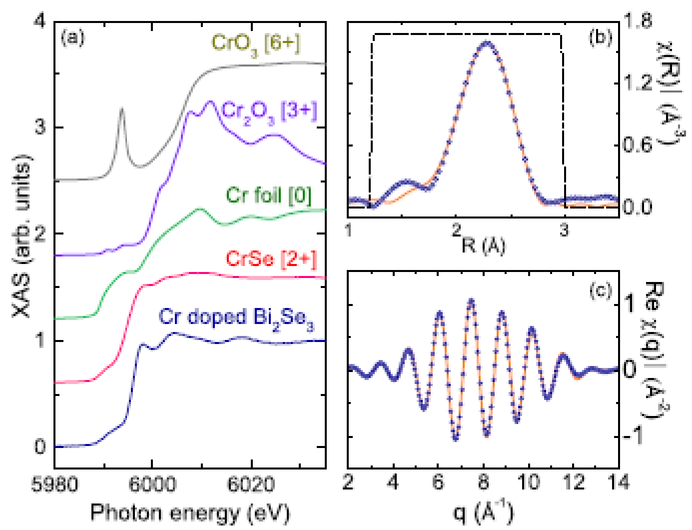

Figure 1: (a) Cr K edge XANES for Cr-doped Bi_2Se_3 thin film and comparison with CrSe, Cr_2O_3, CrO_3, and Cr foil for reference. The Cr oxidation state is indicated in the square brackets. Spectra have been shifted vertically for clarity. (b) Fourier transform of EXAFS signal at the Cr K edge on the thin film (symbols) together with the best fit to the first coordination shell (solid line). The dotted box gives the Kaiser-Bessel window function. (c) Contribution of the first coordination shell to the EXAFS signal (symbols) together with its best fit (solid line). Figure from [1].

[1] A. I. Figueroa, G. van der Laan, L. J. Collins-McIntyre, et al., Phys. Rev. B 90,134402 (2014)

Transverse field muon-spin rotation signature of the skyrmion lattice phase in Cu_2OSeO_3

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Magnetic skyrmions are arguably the topological excitations of most current interest in condensed matter physics, with wide potential for applications in spin-electronic devices. We present the results of transverse field (TF) muon-spin rotation (μSR) measurements [1] on Cu_2OSeO_3, which has a skyrmion lattice (SL) phase where skyrmions crystallize onto a hexagonal lattice [2]. By exploiting the analogy between the SL phase and the vortex lattice in a Type II superconductor, we are able to identify the SL phase in Cu_2OSeO_3 using TF μSR and distinguish it from the other magnetic phases of the material [3]. Distinctive responses in the measured local magnetic field distribution *p(B)* are visible in each of the magnetic phases [Fig. 1(a-f)] and our dipole field simulations support this interpretation. We are able to determine the phase diagram of the material from these results [Fig. 1(g)], where the SL phase is visible as a sharp feature in the spectral lineshape. Our results reveal TF μSR, which shows the SL to be static on the muon timescale, to be a promising tool for the investigation of skyrmion materials and the determination of their phase diagrams.

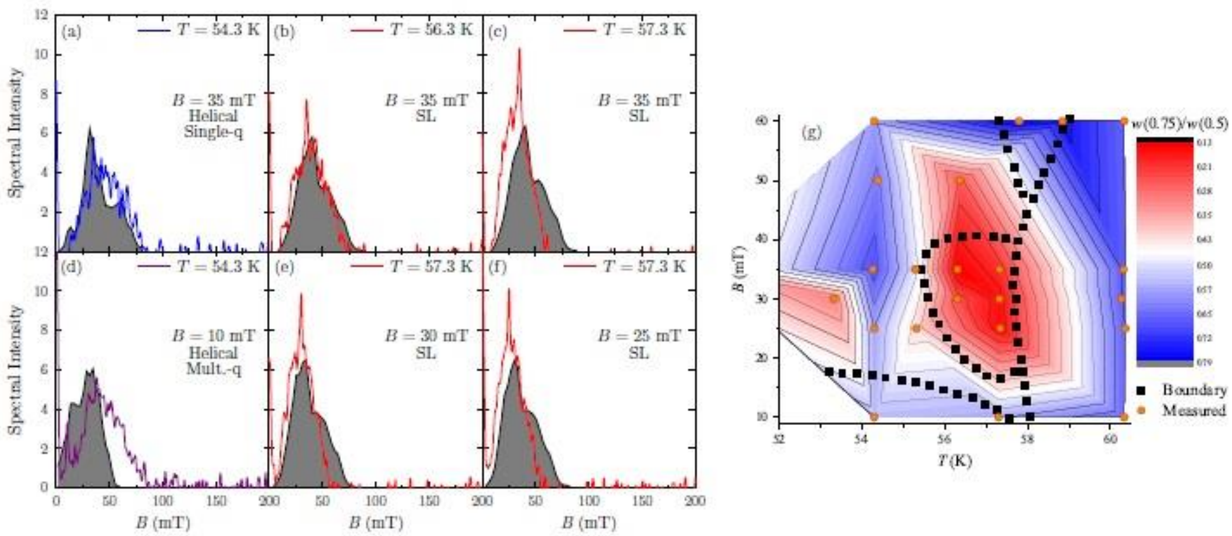

FIG. 1: (a-f) Observed magnetic field distributions p(B) (coloured line) compared with dipole simulations in each phase (grey filled area). (g) Contour plot of linewidths, capturing the SL phase.

[1] S. J. Blundell, Contemp. Phys. 40, 175 (1999)
[2] S. Seki, X. Z. Yu, S. Ishiwata and Y. Tokura, Science 336, 198 (2012)
[3] T. Lancaster et. al., arXiv:1410.4731v2 [cond-mat.str-el] (2014)

Nanometer resolution imaging of Helical and Skyrmion states in FeGe

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[1]University of Glasgow, UK, [2]Osaka Prefecture University, Japan

The behaviour of materials with B20 crystal structure is the focus of current attention due to a desire to understand the varied and complex behaviour arising from the chiral Dzyaloshinskii-Moriya interaction. In a phase diagram, depending on both temperature and magnetic field strength, ordered helical and Skyrmion states have been observed and widely reported. Materials such as FeCoSi[1], MnSi[2] and Cu_2OSeO_3[3] have received much attention but these exhibit magnetic ordering at temperatures well below 100K. FeGe exhibits a much higher magnetic ordering temperature, in the region 250-280K[4] and thus holds more potential for future application.

We have utilised the Differential Phase Contrast (DPC) mode on a JEOL ARM200FCS Scanning Transmission Electron Microscope (STEM) to study the magnetic behaviour of a <100nm thick, (110) oriented sheet of FeGe cut from a bulk crystal. Using a specimen cooling holder we have imaged magnetic behaviour in various regimes of the phase diagram, from 110-250K and by applying magnetic fields of strength 0-3kOe. Our quantitative imaging capabilities coupled with an applied spatial resolution of 3 nm have allowed us to investigate in detail the transition from helical to Skyrmion phase, the evolution of the Skyrmion structure under applied fields and interesting behaviours that arise at phase boundaries.

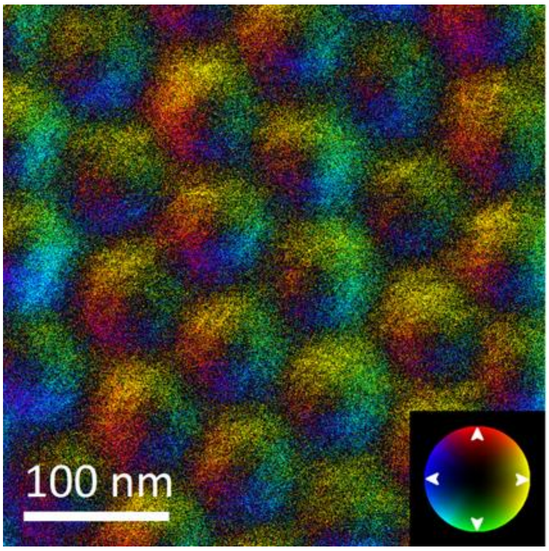

Figure 2. The Skyrmion lattice, period 74 nm, occurring at 250K stabilised by an applied field of strength 400 Oe.

[1] X. Z. Yu, et al., Nature 465, 09124 (2010)
[2] E. Karhu, et al., Physical Review B, 82, 184417 (2010)
[3] S. Seki, et al., Science 336, 198 (2012)
[4] X. Z. Yu, et al., Nature Materials 10, 106 (2011)

Session 9: Domain walls

Control of domain wall depinning fields in nanowires using induced uniaxial anisotropy

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Controlling the motion of magnetic domain walls is an important objective for studying their fundamental properties and for potential applications in devices such as Racetrack memory[1], 3-terminal MRAM[2] and logical processing architectures[3]. A key functionality for these applications is the ability to controllably pin and depin the domain wall at desired locations along a magnetic nanowire.

We have investigated the effect of a voltage-tunable strain-induced uniaxial anisotropy on the magnetic field required to depin a magnetic vortex domain wall from an artificially introduced notch in a Co nanowire. Using focused magneto-optical Kerr effect microscopy, complemented by micromagnetic calculations, we find that vortex domain walls with opposite chirality exhibit different depinning fields and an opposite dependence of the depinning field on the induced anisotropy. This behaviour is explained by the deformation of the domain wall at the notch which leads to different depinning mechanisms for the two chiralities. This functionality may find use as a chirality selective domain wall gate in schemes for information storage and processing.

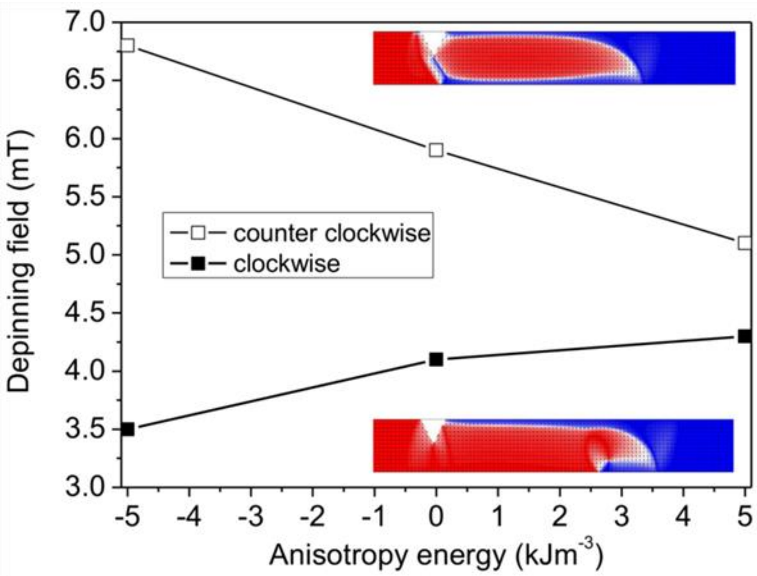


Figure 1. Dependence of depinning field of vortex domain walls of different chirality on the uniaxial anisotropy induced along a Co nanowire. The insets show examples of micromagnetic calculations of the domain wall configuration shortly after depinning.

[1] Parkin, Patent US 6834005; S.S.P. Parkin et al., Science 320, 190 (2008)
[2] Cubukcu et al., Appl. Phys. Lett. 104, 042406 (2014)
[3] D.A. Allwood et al., Science 309, 1688 (2005)

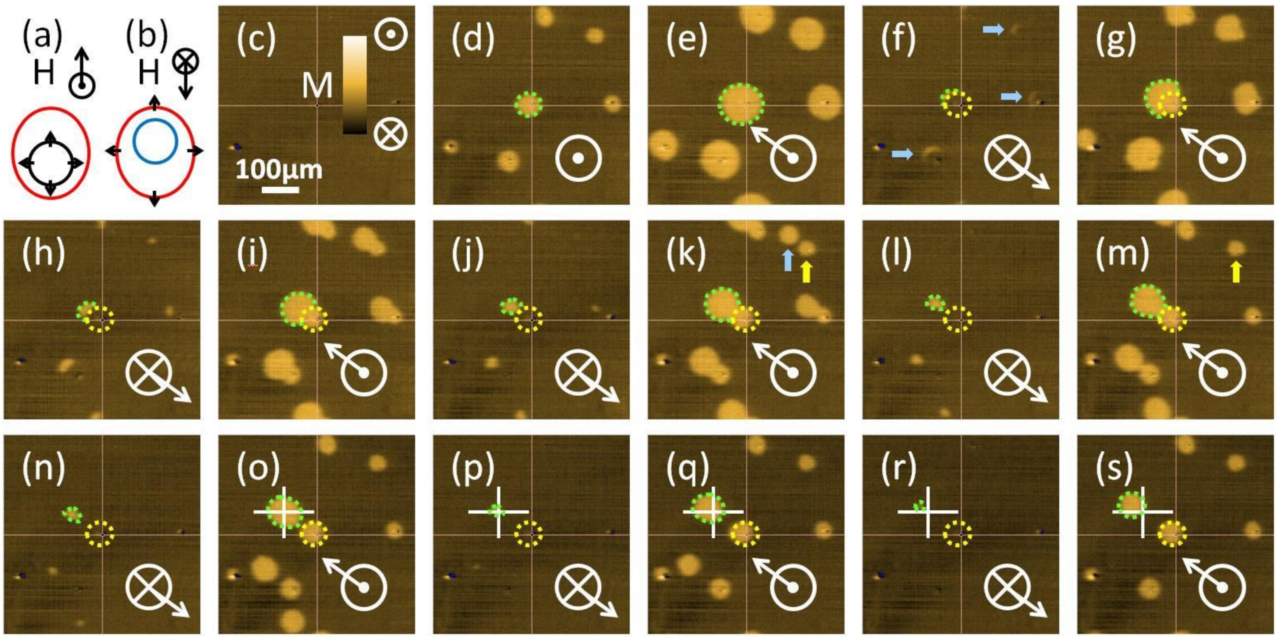
2D control of field-driven magnetic bubble movement using Dzyaloshinskii-Moriya interactions

D C M C Petit[1], P R Seem[2], M Tillette[1], R Mansell[1] and R P Cowburn[1]

[1]University of Cambridge, UK, [2]Durham Magneto Optics Ltd, UK

Recently, there have been important developments in the understanding of the role of Dzyaloshinskii-Moriya interactions (DMI) role in controlling the efficiency of domain wall (DW) motion [1] and in creating magnetic skyrmions in ultra-thin magnetic films with perpendicular anisotropy [2]. The DMI is due to the combination of strong spin-orbit interaction in an adjacent heavy metal non-magnetic layer, for instance Pt or Ir, and the broken symmetry at the interface of the magnetic material [3]. It has recently been experimentally demonstrated in such films [4] that when an in-plane field is applied in conjunction with a perpendicular field, the DMI can cause an asymmetric expansion of bubble domains. The DMI causes the spins in the DW to have a well-defined chirality in which an asymmetry is induced by the in-plane field, with the domain wall width expanding where the spins align with the applied field.

Using magneto-optical Kerr effect (MOKE) microscopy with 3D magnetic fields, we demonstrate 360-degree control of the direction of the asymmetric growth of bubbles in a Ta(4nm) / Pt(10) / Co(0.8) / Pt(3) multilayer. We then use this effect to laterally translate a bubble in an arbitrary direction [5]. The figure below shows a series of MOKE images taken as symmetric pulses of alternating magnetic field (indicated at the bottom-right corner of each image) are sequentially applied in order to grow and shrink magnetic bubbles in an asymmetric fashion. The sign of the in-plane component of the field relative to the out-of-plane component is chosen such that the top-left of the bubble moves faster than the bottom-right as the bubble grows while the bottom-right moves faster than the top-left as the bubble shrinks. The resulting movement of the bubbles is controlled by the direction of the in-plane field. This work demonstrates control of bubble movement without using patterned structures, opening up the possibility for arbitrary control of bubble domains.



[1] A. Thiaville *et al*. Europhys. Lett. 100, 57002 (2012)
[2] J. Sampaio *et al*., Nature Nano. 8, 839 (2013)
[3] A. Crépieux and C. Lacroix, J. Magn. Magn. Mat. 182, 341–349 (1998)
[4] S-G Je *et al.*, Phys. Rev. B 88, 214401 (2013)
[5] D. Petit *et al*. App. Phys. Lett. 106, 022402 (2015)

Imaging the equilibrium state and magnetisation dynamics of hard disk write heads

R A J Valkass[1], W Yu[1], L R Shelford[1], P S Keatley[1], T H J Loughran[1], R J Hicken[1], S A Cavill[2,3], G van der Laan[3], S S Dhesi[3], M A Bashir[4], M A Gubbins[4], P J Czoschke[4] and R Lopusnik[4]

[1]University of Exeter, UK, [2]University of York, UK, [3]Diamond Light Source, UK, [4]Seagate Technology, USA

Suggestions for the equilibrium domain configuration of hard disk write heads have previously been made based on simulations [1] and Kerr imaging [2, 3], but no direct observations had been made, limiting understanding of their magnetodynamic behaviour. We determined the relationship between write head geometry and micromagnetic properties for four write head designs. Images of the equilibrium state were obtained using x-ray photoemission electron microscopy (X-PEEM) with x-ray magnetic circular dichroism as the contrast mechanism. Magnetodynamics were induced by delivering a driving pulse to coils embedded beneath each write head and observed using time-resolved scanning Kerr microscopy (TRSKM). X-PEEM images show crystalline anisotropy dominates the equilibrium state domain configuration, but competition with shape anisotropy ultimately determines the stability of this equilibrium state. TRSKM images show that a longer confluence region hinders flux conduction from the yoke into the pole tip. This results from the differences in equilibrium magnetisation configuration between different shaped write heads. Minor variations in the geometric design of write heads have been shown to have a significant effect on the process of flux beaming [4]. Moreover, the viability of high-resolution X-PEEM as a technique for investigating the magnetic structure of hard disk write heads has been confirmed.

[1] D. Z. Bai, J. Zhu, P. Luo, K. Stoev, and F. Liu, IEEE Transactions on Magnetics 42, 473 (2006)

[2] P. Gangmei, P. S. Keatley, W. Yu, R. J. Hicken, M. A. Gubbins, P. J. Czoschke, and R. Lopusnik, Applied Physics Letters 99, 232503 (2011)

[3] W. Yu, P. Gangmei, P. S. Keatley, R. J. Hicken, M. A. Gubbins, P. J. Czoschke, and R. Lopusnik, Applied Physics Letters 102, 162407 (2013)

[4] M. L. Mallary, Journal of Applied Physics 57, 3952 (1985)

Strain control of domain wall creep motion in Pt/Co/Pt and Pt/Co/Ir/Pt thin films

P Shepley[1], A W Rushforth[2], G Burnell[1] and T A Moore[1]

[1]University of Leeds, UK, [2]University of Nottingham, UK

We investigate the strain control of domain wall creep motion in Pt/Co/Pt and Pt/Co/Ir/Pt films coupled to piezoelectric transducers. Domain wall creep motion has potential applications in data storage and spintronics [1], where the use of voltages rather than magnetic fields to control magnetisation reversal could reduce power consumption [2]. Materials with perpendicular magnetic anisotropy (PMA) are of particular interest due to their narrow domain walls and potential for efficient current-induced domain wall motion. Figure 1 shows the change due to piezoelectric-induced strain of field-driven domain wall velocity in sputtered Ta(4.5nm)/Pt(2.5nm)/Co(t)/Pt(1.5nm) (t=0.85-1.0nm) and Ta(4.5nm)/Pt(2.5nm)/Co(0.8nm)/Ir(0.3nm)/Pt(1.5nm) films bonded to piezoelectric transducers. Under the largest available strain (9×10^{-4} for 150V applied to the transducer) the domain wall creep velocity is doubled for Co t=1.0nm. The change in domain wall velocity with strain becomes smaller as the Co thickness of the film decreases. The inset to Figure 1 shows domain wall creep for t=1.0nm over a range of applied magnetic fields with the transducer at 0V and 150V. The creep law applies [3]; $v = v_o \exp[-(U_c/kT)(H_{dep}/H)^{1/4}]$, where v_o is a numerical prefactor, U_c is the pinning energy barrier, kT is the thermal energy, H_{dep} is the depinning field and H is the applied field. Fitting the creep law to lnv($H^{-1/4}$), we find that the pinning energy barrier to thermal energy ratio U_c/kT is unchanged under strain.

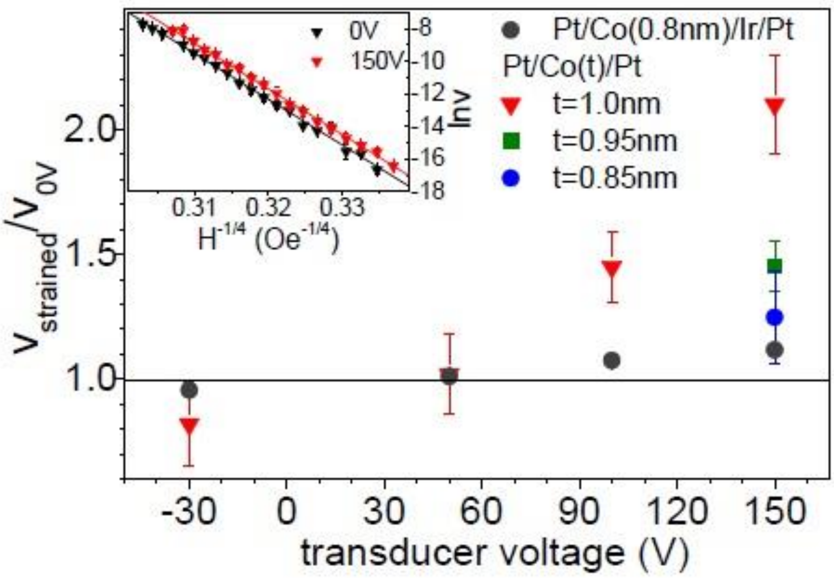


Figure 1. Change in domain wall velocity in Pt/Co capped with Pt or Ir/Pt plotted against transducer voltage. The inset is domain wall creep for Pt/Co(1.0nm)/Pt over a range of applied magnetic fields with the transducer at 0V and 150V. The lines are fits to the creep law.

[1] Schellekens, a. J., van den Brink, a., Franken, J. H., Swagten, H. J. M. & Koopmans, B. *Nature Communications* 3, 847 (2012)

[2] Wang, K. L., Alzate, J. G. & Khalili Amiri, P. *Journal of Physics D: Applied Physics* 46, 074003 (2013)

[3] Lemerle, S. *et al. Physical Review Letters* 80, 849–852 (1998)

Finding energy barriers of skyrmionic configuration in ferromagnetic nanodisks and nanotracks

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In the last decade, the study of skyrmions in ferromagnets has been highly important due to their potential as information carriers in spintronic devices. Due to the particular arrangement of the spins, they are topologically protected configurations [1] that can be easily manipulated by different methods, such as electric currents or external magnetic fields. Although there have been numerous studies about skyrmion properties, their stability is still an unknown subject, which is useful to have an idea of their reliability as information units, for example, against random thermal fluctuations. Thus, in this work we focus on computing Energy Barriers (EBs) by means of a Minimum Energy Path finding algorithm called Nudged Elastic Band Method (NEBM), that was originally developed in the context of chemistry and applied later to micromagnetic structures [2]. To have a comparison for our results, we analyse the systems published by Sampaio et al. [3] where skyrmions are stabilised by anisotropies and interfacial Dzyaloshinskii-Moriya Interactions (DMIs) in nanodisks and nanotracks (see Figure 1).

[1] A. Fert, V. Cros, and J. Sampaio. Nature Nanotechnology, 8:152-156, 2013
[2] R. Dittrich, T. Schrefl, D. Suess, W. Scholz, H. Forster, and J. Fidler. Journal of Magnetism and Magnetic Materials, 250:12-19, 2002
[3] J. Sampaio, V. Cros, S. Rohart, a. Thiaville, and A. Fert. Nature nanotechnology, 8(11):839-44, 2013

Thermally-induced stochastic domain wall dynamics in $Ni_{80}Fe_{20}$ nanowires

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The behaviour of domain walls (DWs) in soft ferromagnetic nanowires is of great interest for the development of range of nanomagnetic devices, however experimental studies have shown their pinning/depinning behaviour to be highly stochastic [1,2].

Here, we use finite temperature micromagnetic simulations to show that these stochastic behaviours are an intrinsic consequence of DW dynamics at finite temperature, and that stochastic effects would not be inhibited even in hypothetical systems where initial DW states and device operating parameters were perfectly defined. We explore dynamics in three regimes of domain wall motion: (i) the viscous regime below WB, (ii) the oscillatory regime above WB and (iii) the turbulent regime observed at high applied fields, showing that stochasticity manifests differently in each one. We then go on to examine how additional disorder, in the form of edge roughness, modifies these effects, resulting in further layers of complexity. Finally, we discuss a strategy that could be adopted to control stochastic behaviour, thus facilitating the further development of DW devices.

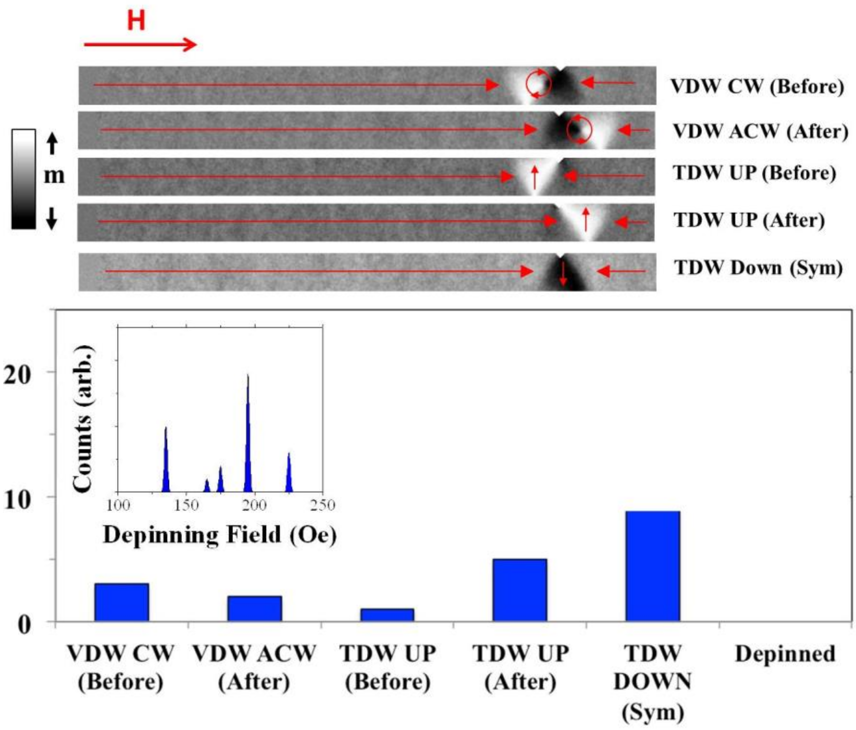

Figure 1: Distribution of pinned states observed at a notch-shaped defect when DWs are propagated to it at H = 35 Oe, T = 300 K. Micromagnetic configurations of the pinned states are shown at the top of the figure. A derived depinning field distribution is shown inset

[1] M.-Y. Im *et. al.*, Phys. Rev. Lett. 102, 147204 (2009)
[2] U.-H. Pi *et. al.,* Phys. Rev. B. 84, 024426 (2011)

Dzyaloshinskii-Moriya interaction in perpendicularly magnetized thin films

A Hrabec[1], M J Benitez[2], N A Porter[1], A Wells[1], G Burnell[1], T A Moore[1], S McVitie[2], D McGrouther[2] and C H Marrows[1]

[1]University of Leeds, UK, [2]University of Glasgow, UK

The Dzyaloshinskii-Moryia interaction (DMI) has been recently demonstrated in ferromagnet/heavy metal systems [1-3]. The classic picture of magnetism of interplay between exchange, dipolar, and anisotropy energies is perturbed by a new energy term with thoroughgoing consequences. The DMI term is expressed as **D**i;j × (**S**i × **S**j), where **D**i;j is the DMI vector, and **S**i and **S**j are spin moments sitting on neighbouring atoms. When D is sufficiently high, a non-uniform ferromagnetic state has a lower energy giving rise to exotic structures like cycloids, helicies, or skyrmions. However, for small DMI values, DWs are the first precursors indicating the presence of the DMI. Its strength is imprinted into the static DW texture via a virtual effective magnetic field preferring a Néel wall of a given chirality rather than the magnetostatically cheaper Bloch wall. The nature of the DW has extensive consequences on the DW dynamics process and its sensitivity to the torques exerted on the localized magnetic moments.

Here we show directly by Lorentz Transmission Electron Microscopy and indirectly by studying the DW dynamics and annihilation process that the films of Pt/Co/AlOx contain Néel wall indicating the presence of the DMI. The experimental data is supported with micromagnetic simulations as illustrated by Fig.1. where two Néel walls, protected by the DMI, are squeezed together by an external magnetic field. The measured DMI in Pt/Co/AlOx films is D = 0.35±0.05 mJ/m^2.

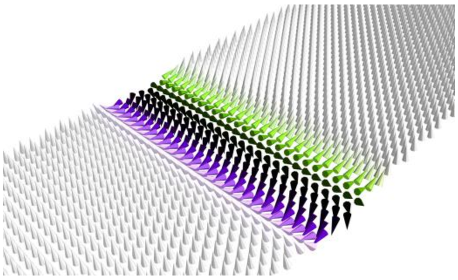

Figure 1: Simulated picture of two Neel walls squeezed together by an external magnetic field. The annihilation process of such walls is a measure of the DMI.

[1] S.-G. Je, D.-H. Kim, S.-C. Yoo, B.-C. Min, K.-J. Lee, and S.-B. Choe, Phys. Rev. B 88, 214401 (2013)

[2] G. Chen, A. T. N'Diaye, H. Kwon, C. Won, Y. Wu, A. K. Schmid, Nature Comm. 3671 (2013)

[3] A. Hrabec, N.A. Porter, A. Wells, M.-J. Romero, G. Burnell, S. McVitie, D. McGrouther, T. A. Moore, C. H. Marrows, Phys. Rev. B 90, 020402(R) (2014)

Session 10: Bio and organic magnetism

(invited) Chemical compass magnetoreception: how migratory birds might navigate

P Hore

University of Oxford, UK

Migratory birds travel spectacular distances each year, navigating and orienting by a variety of means, most of which are poorly understood. Among them is a remarkable ability to perceive the intensity and direction of the Earth's magnetic field. Biologically credible mechanisms for the sensing of such weak fields (25-65 μT) are scarce and in recent years just two proposals have emerged as frontrunners. One, essentially classical, centres on iron-containing particles. The other relies on the magnetic sensitivity of short-lived photochemical intermediates known as radical pairs. This model began to attract interest following the proposal that the necessary photochemistry could take place in the bird's retina in specialised photoactive proteins called cryptochromes. The coherent dynamics of electron and nuclear spins of pairs of radicals is conjectured to lead to changes in the yields of reaction products even though the electron Zeeman interaction with the geomagnetic field is more than six orders of magnitude smaller than the thermal energy at physiological temperatures.

I will outline the physics of the radical pair mechanism and some of the experimental evidence for the cryptochrome hypothesis, discuss the interpretation of the reported effects of nanotesla radiofrequency fields on the magnetic orientation of European robins, and comment on the extent to which cryptochromes are fit-for-purpose as magnetoreceptors.

Manipulation of the photoluminescence of C_{60} via ferromagnetic resonance

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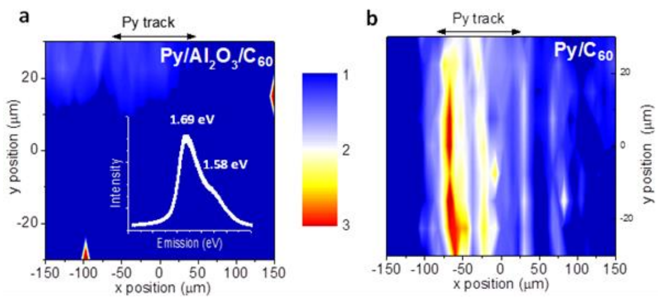
Combining spectroscopic techniques and ferromagnetic resonance (FMR) in carbon-based spintronics opens up the possibility for novel optoelectronic devices. Here, we show that a ferromagnetic electrode excited to FMR can be used to manipulate the photoluminescence (PL) of an adjacent C_{60} layer as a result of the damping mechanism of the ferromagnet. An increase in 50% of the Gilbert damping parameter of NiFe (Py) is observed when in contact with C_{60} showing that there is spin pumping from Py into C_{60}. An increase in the maximum intensity of the PL of 100±5% has been observed for C_{60} when comparing the on/off FMR state, on/off the Py track (fig. b). When adding a 3 nm insulating layer of Al_2O_3 between Py and C_{60}, this effect is reduced but still a significant change is observed of 9.7±0.5% for C_{60}/Al_2O_3/Py (fig. a). An increase in intensity cannot be attributed to spin pumping, which suggests there is an additional mechanism at play, such as phonon injection which can act to increase PL. Furthermore, a phonon replica mode of the C_{60} is excited in comparison to the zero phonon emission peak during FMR, further confirming this interpretation of phonon injection.



Ratio of maximum PL intensity change on/off FMR with position on/off a Py track for (a) Py/Al_2O_3/C_{60}/glass and (b) Py/C_{60}/glass. Inset shows typical PL spectra with the 1.69 eV zero phonon emission peak and the 1.58 eV phonon replica peak labelled.

Patterning biologically controlled magnetic nanoparticle arrays: it's a fine line

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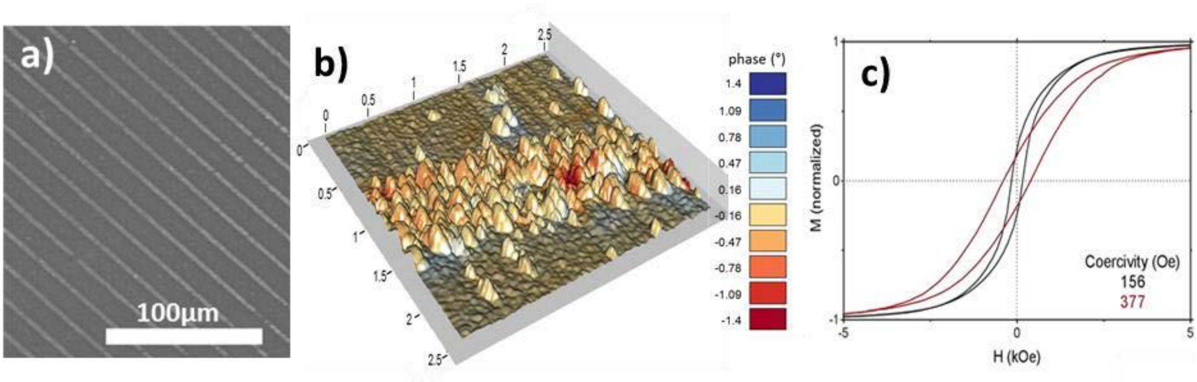
[1]University of Sheffield, UK, [2]University of Leeds, UK

Magnetic nanoparticle (MNP) patterned surfaces could be used to form bit-patterned media, potentially the next generation of high-density data storage devices. Current fabrication methods are not industrially viable and environmentally harsh. However, Arakaki *et al.*[1] found that the biomineralization protein Mms6, derived from the magnetotactic bacterium *M. magneticum* AMB-1, templated uniform MNPs of magnetite under mild aqueous reaction conditions *in vitro*. In subsequent work Galloway *et al*[2]. showed that recombinant Mms6 biotemplates consistent magnetite MNPs onto micropatterned gold surfaces, establishing a new bioinspired approach to form arrays of MNPs on surfaces.

Magnetite is magnetically soft, and not well suited to data storage applications. However, Mms6 has been shown to template MNPs of magnetically harder cobalt-doped magnetite [3]. In this presentation we demonstrate improved and simplified patterning and fabrication methods, and show how the magnetic properties of patterned biotemplated MNPs are improved with cobalt doping through characterization with techniques such as vibrating sample magnetrometry (VSM) and magnetic force microscopy (MFM). This simple and adaptable approach could be used for the production of a wide range of biotemplated nanomaterials on surfaces, and presents a significant step towards a new, greener method for the development of bit-patterned media.



a) Scanning electron microscopy (SEM) image of cobalt-doped magnetite MNP arrays on gold, biotemplated by patterned Mms6. b) Composite AFM/MFM image of the topographic features and the magnetic interactions of the biotemplated cobalt-doped MNPs recorded with a magnetised MFM tip. c) Magnetic hysteresis loops recorded using VSM at 295 K of these MNPs without (black) and with (red) the addition of 6% cobalt, showing a coercivity (magnetic hardness) increase for the cobalt-doped surface (377 Oe) over the undoped surface (156 Oe).

[1] A. Arakaki, J. Webb and T. Matsunaga, *J. Biol. Chem.*, 2003, 278, 8745-8750

[2] J. M. Galloway, J. P. Bramble, A. E. Rawlings, G. Burnell, S. D. Evans and S. S. Staniland, *Small*, 2012, 8, 204-208.; J. M. Galloway, J. P. Bramble, A. E. Rawlings, G. Burnell, S. D. Evans and S. S. Staniland, *J. Nano Res.*, 2012, 17, 127-146.

[3] J. M. Galloway, A. Arakaki, F. Masuda, T. Tanaka, T. Matsunaga and S. S. Staniland, *J. Mater. Chem.*, 2011, 21, 15244-15254.

Manipulating the magnetic properties of molecular/ non-magnetic transition metal interfaces

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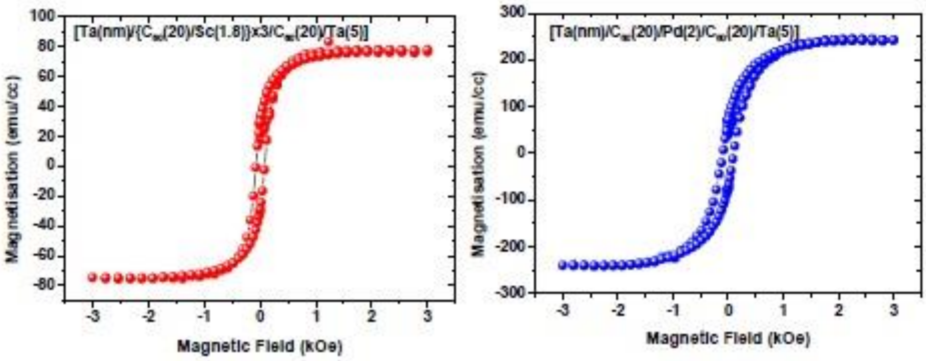
Obtaining control of the magnetic properties at well-defined hybrid interfaces is a crucial component to engineer the performance of future organic spintronic devices. Here, C_{60} molecules are used as a template to study interfacial hybridization and electron transfer between the orbitals of organic molecules and nonmagnetic metals d-band states such as Sc and Pd. This study leads to sizeable room temperature interfacial magnetic moments on the order of 240 emu/cc and 80 emu/cc for Pd/C_{60} and Sc/C_{60} multilayered systems respectively. The result is remarkable, given that all these materials are non-ferromagnetic in bulk form. Interestingly, depositing a multilayered system with a discontinuous layer of Sc leads to a formation of a superparamagnetism. However thicker layers show ferromagnetic coupling with 80 Oe coercive field and squareness ratio of about 0.4. The interaction between the molecule and the metal depends strongly on the morphology and specific molecular geometry and may lead to a change in the density of states at the Fermi energy and/or the exchange-correlation integral to fulfill the Stoner criterion for ferromagnetism. These results emphasize the importance of hybridization effects between the molecular pz orbital and the 3d metal bands in controlling the induced magnetic properties at the interfaces.



Magnetization as a function of applied magnetic measured using a SQUID magnetometer. (a) Sc/C_{60} multilayers, (b) Pd/C_{60} trilayers and (c) Sc/C_{60} trilayers, the thicknesses given in nm. The measurements were performed at room temperature and the calculations of magnetization have been performed considering the thickness of the metallic layer only even though the effect may extend further.

Unexpected antiferromagnetic exchange coupling between a Cr-porphyrin and a bare cobalt substrate

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Spin-bearing metallo-organic complexes adsorbed on magnetic substrates tend to order their spins due to the molecule-substrate exchange coupling [1, 2]. Previous studies on metallo-porphyrins and -phthalocyanines adsorbed on bare ferromagnetic films (i.e. Co and Ni) reported exclusively ferromagnetic ordering [2]. Here, we report an unexpected antiferromagnetic (AFM) coupling of CrTPP molecules to a bare cobalt substrate as revealed by X-ray Magnetic Circular Dichroism (Fig. 1) and confirmed by numerical DFT+U calculations. We assign the AFM coupling to the indirect 90 degree exchange interaction between the less-than-half-filled 3d shell of the chromium ion with the cobalt atoms in the substrate via the nitrogen atoms of the porphyrin ring [3].

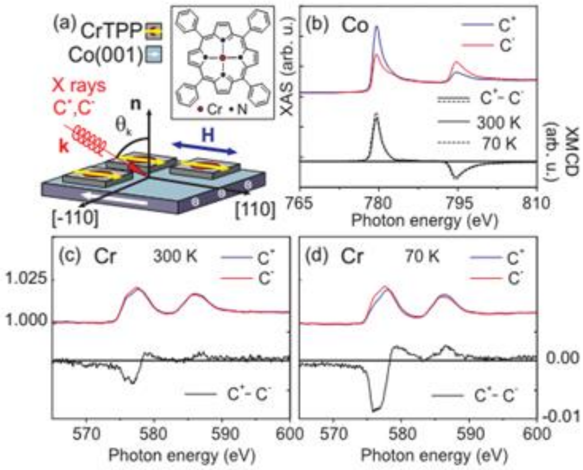

Figure 1. a) Sketch of the experimental setup. b) XMCD signal of the ferromagnetic cobalt substrate measured at Co $L_{3,2}$ edge c),d) XMCD spectra of Cr $L_{3,2}$ edge reveal an antiferromagnetic coupling of CrTPP molecules with respect to the substrate magnetization, measured at two different temperatures.

[1] A. Scheybal et al, Chem Phys Lett 411, 214 (2005)
[2] N. Ballav et al, JPCL 4, 2303 (2013)
[3] J. Girovsky et al, PRB 90, 220404(R) (2014)

Observation of antiferromagnetic coupling at organic semiconductor/ferromagnetic interfaces

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[1]University of York, UK, [2]University of Science and Technology of China, China, [3]EWHA Womans University, South Korea, [4]National Institute for Materials Science, Japan, [5]CNR-ISMN Bologna, Italy, [6]University of California, Santa Barbara, USA

Following the recent realization that organic semiconductor (OSC)/ferromagnetic (FM) interface states require a much deeper understanding in order to make progress in the field of molecular spintronics [1], much attention has been paid to the magnetic exchange coupling that exists at these 'spinterfaces' [2]. Early work has shown that stable magnetic order may be induced in the paramagnetic molecular layer although the alignment direction and origin of this effect are the topic of much current discussion [3]. Clarifying mechanisms of exchange coupling, suggested to take place either directly or indirectly across chemical bonds at the interface, is essential to be able to engineer novel organic devices. To this end, we have conducted a systematic study of a variety of OSC/FM interfaces utilising the perfect surface sensitivity associated with the technique of spin-polarized metastable (23S) helium de-excitation spectroscopy [4]. As will be shown in this talk, the results obtained reveal a general tendency towards antiferromagnetic coupling between the organic molecule and the FM substrate helping to elucidate such phenomena as spin injection into an OSC [1] and interfacial magnetoresistance [2].

[1] S. Sanvito *et al.*, Nature Phys. 6, 562 (2010)
[2] K. V. Raman *et al*., Nature 493, 509 (2013)
[3] J. Girovsky *et al*., Phys. Rev. B 90, 220404(R) (2014)
[4] A. Pratt *et al*., Phys. Rev. B 85, 180409(R) (2012); X. Sun *et al*., Phys. Chem. Chem Phys. 16, 95 (2014)

Session 11: Dynamics

(invited) Perpendicular magnetic anisotropy: from ultralow power spintronics to cancer therapy

R Cowburn (IEEE distinguished Lecturer)

University of Cambridge, UK

Most thin magnetic films have their magnetization lying in the plane of the film because of shape anisotropy. In recent years there has been a resurgence of interest in thin magnetic films which exhibit a magnetization easy axis along the surface normal due to so-called Perpendicular Magnetic Anisotropy (PMA). PMA has its origins in the symmetry breaking which occurs at surfaces and interfaces and can be strong enough to dominate the magnetic properties of some material systems. In this talk I explain the physics of such materials and show how the magnetic properties associated with PMA are often very well suited to applications. I show three different examples of real and potential applications of PMA materials: ultralow power STT-MRAM memory devices for green computing, 3-dimensional magnetic logic structures and a novel cancer therapy.

Energy efficient Thermally Induced Magnetization Switching by tailoring the electron and phonon dynamics

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The recently discovered thermally induced magnetization switching [1] (TIMS) in ferrimagnets has received a lot of attention recently as it proceeds on the time-scale of picoseconds and occurs without the need for other slower additional external sources, such as a magnetic field. Whilst the energy per bit required to reverse the magnetization is low [2], the system temperature after the application of a pulse remains rather high for a few hundreds of picoseconds. In some cases the final temperature after the pulse is near the Curie temperature of the magnetic material. Moreover, the rate of heat transfer of energy out of the system is governed by phonon processes and can be reduced by careful selection of substrate, though the rate would still be of the order of hundreds of picoseconds. Thus, lowering the fluence required to reverse the magnetic state of a material by the TIMS mechanism is a key challenge since it could allow one to (i) realize an ultra-low power magnetic bit-recording scheme and (ii) avoid long lasting elevated temperatures. In considering the optimal set of physical characteristics we must first note that TIMS, whilst is a magnetic process [3], it relies strongly on the underlying physics of the electronic and phononic systems. The focus of this work is to address, at least partially, this issue by demonstrating the properties a candidate material that would give rise to a significant reduction of the laser power required to excite TIMS.

Figure 1a shows a parametric study of the minimum fluence required to switch the magnetization after a single pulse, as a function of composition (amount of Gd). A minimum appears at a Gd concentration of around 30%, which is in agreement with our recent predictions [3]. The power required for reversing the magnetization by a (single) laser pulse is also strongly dependent on the electron-phonon coupling (Fig. 1b) and the lower end corresponds to that of Gd. A significant result of this work shows that an order of magnitude reduction of the pump fluence required can be achieved by finding materials (or materials that are part of multilayered structures [5]) with a low electron-phonon coupling, though it remains a challenge to find materials with low values of the coupling constant that undergo TIMS. As well as investigating the effect of the composition and electron-phonon coupling on the fluence required for TIMS we have also studied the effect of the coupling to the thermal bath, λ. Figure 1c shows that for low G_{ep} the minimum fluence to TIMS does not depend strongly on λ, for large values of G_{ep} the $F_{0,min}$ slightly decreases with λ. However, it is clear from Fig. 1(c) that to lower $F_{0,min}$ it is more efficient to reduce G_{ep} than to increase the magnetic damping λ. To summarize, we have extensively studied the role of relevant system parameters in the thermally induced magnetization switching process in ferrimagnetic alloys. The optimal physical parameters both magnetic as well as those governing the electronic and phononic properties are presented. Finding new materials with optimal parameters remains a huge challenge for TIMS going forward, however, the work presented here represents a recipe of what is required for low powered magnetization switching on the sub-picosecond timescale. Our findings are not only useful for magnetic data storage but has potential application for ultrafast optical interconnects [6].

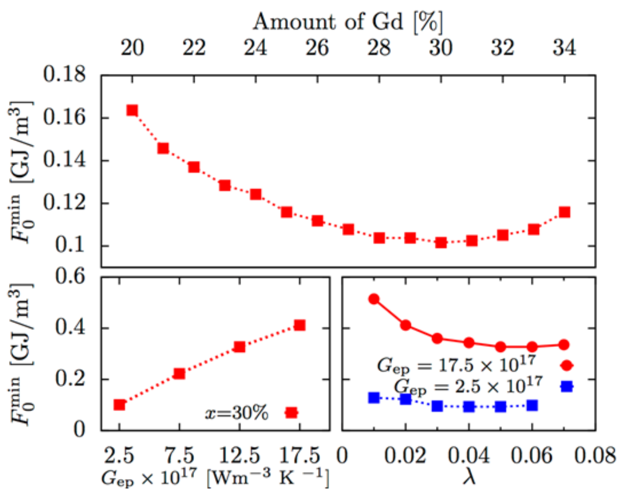

Fig 1: Minimal fluence required for magnetization switching via TIMS as a function of composition (a) and the electron-phonon coupling (b). Around x=30% the threshold fluence is minimum for an electron-phonon coupling

G_{ep}=2.5 ×10^{17} $Wm^{-3}K^{-1}$. (b) For x=30% the minimum fluence required increases with increasing G_{ep}. (c) Fluence threshold to TIMS as a function of the coupling to the bath parameter, λ, for two limiting values of G_{ep}.

[1] T. A. Ostler *et al*., “Ultrafast Heating as a Sufficient Stimulus for Magnetization Reversal”, *Nature Communications*, 3, 666 (2012)

[2] M. Savoini *et al*., “Highly Efficient All-Optical Switching of Magnetization in GdFeCo Microstructures by Interference-Enhanced Absorption of Light”, *Physical Review B*, 86, 140404(R) (2012)

[3] J. Barker *et al.,* “Two-magnon Bound State Causes the Ultrafast Thermally Induced Magnetization Switching”, *Nature Scientific Reports,* 3, 3262 (2013)

[4] J. Chen *et al.,* “A Semi-classical Model for Ultrafast Laser Heating”, *International Journal of Heat and Mass Transfer*, 49, 307-316 (2006)

[5] R. F. L. Evans *et al.*, “Ultrafast Thermally Induced Magnetization Swithing in Synthetic Ferrimagnets”, *Applied Physics Letters*, 104, 082410 (2014)

[6] Z. Azim *et al.,* “Laser Induced Magnetization Reversal for Detection in Optical Interconnects”, *IEEE Electron Device Letters*, 35, Issue 12, 1317-1319 (2014)

Electrical manipulation of a ferromagnet by an antiferromagnet

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Antiferromagnets (AFM) have for decades played a passive role in conventional spin-valve structures where they provide pinning of the reference ferromagnetic (FM) layer. This implies that on one hand, incorporation of some AFM materials, including IrMn, in common spintronic structures is well established. On the other hand, limiting their utility to a passive pinning role leaves a broad range of spintronic phenomena and functionalities based on AFMs virtually unexplored. Here we demonstrate that an AFM can be employed for the highly efficient electrical manipulation of a FM. In our study we use electrically detected ferromagnetic resonance which is also electrically excited by an in-plane alternating current in a NiFe/IrMn structure (Fig. 1). At room temperature, we observe an antidamping-like spin torque acting on the NiFe FM, generated by the in-plane current driven through the IrMn AFM. A large enhancement of the torque, characterized by an effective spin Hall angle exceeding most heavy transition metals, correlates with the presence of the exchange-bias field at the NiFe/IrMn interface. This highlights that, apart from strong spin-orbit coupling, the AFM order in IrMn governs the observed phenomenon.

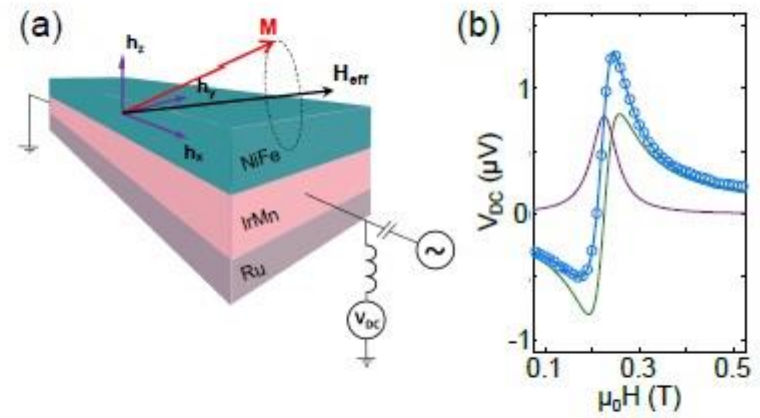

Figure 1: (a) Schematic representation of the measurement technique. MW current-induced effective field h(h_x; hy; h_z) drives magnetization precession around the total field He_{eff} . Precessing magnetization results in oscillating resistance due to AMR. This mixes with oscillating current of the same frequency resulting in a measurable DC voltage. (b) Resonance curve decomposed into symmetric and antisymmetric components measured in a bar with 2 nm IrMn at frequency of 17.9 GHz.

Enhancing the magneto-optical Kerr effect with a near field plasmonic antenna

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Time resolved scanning Kerr microscopy (TRSKM) is a powerful technique for imaging magnetisation dynamics [1], however the technique has limited spatial resolution due to the diffraction limit of light. Plasmonic effects can localise optical fields within a sub-wavelength region [2, 3], and could be exploited to increase the spatial resolution of TRSKM. We present simulations of plasmonic antenna structures and describe progress towards their experimental realisation.

Simulations performed on plane magnetic films showed a MOKE response consistent with analytical expressions found in [4]. Arrays of antenna structures were introduced into these simulations, and a frequency dependent enhancement of the MOKE was observed.

In order to experimentally realise these effects, structures were fabricated by focused ion beam (FIB) milling of the gold surface of Pt(3nm)/4x[Co(0.5nm)/Pt(3nm)]/Ta_2O_5(various)/Au(100nm) stacks. However, the MOKE signal through these devices was reduced due to Ga implantation, which can alter the properties of magnetic materials [5]. To avoid this we adopted a lift-off approach [6], allowing us to recover the full MOKE signal. Further refinement of these devices will lead to enhancement of the magneto-optical signal beyond the diffraction limit.

[1] W. Yu , P. Gangmei, P.S. Keatley, R. J. Hicken, M.A. Gubbins,P. J. Czoschke ,R. Lopusnik. “Time resolved scanning Kerr microscopy of hard disk writer structures with a multilayered yoke”, Appl. Phys. Lett. 102,(2013)

[2] A. Degiron and T. Ebbesen "Analysis of the transmission process through single apertures surrounded by periodic corrugations", Opt. Express 12, (2004)

[3] Dmitri K. Gramotnev & Sergey I. Bozhevolnyi, “Plasmonics beyond the diffraction limit”, Nature Photonics 4, (2010)

[4] J. Wu, J.R. Moore, R.J. Hicken “Optical pump-probe studies of the rise and damping of ferromagnetic resonance oscillations in a thin Fe film” J. Mag. Mag. Mat. 222 (2000)

[5] J. Gierak , et al “Exploration of the ultimate patterning potential achievable with focused ion beams” Microelectron. Eng. 78–79, (2005)

[6] Fu Min Huang, Jatin K. Sinha, Nicholas Gibbons, Philip N. Bartlett, Jeremy J. Baumberg “Direct assembly of three-dimensional mesh plasmonic rolls” Appl. Phys. Lett. 100, (2012)

Thermally induced magnetization switching in Gd/Fe multilayers

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The observation of thermally induced magnetisation switching (TIMS) [1] in amorphous ferrimagnetic GdFeCo has received wide attention due to its potential application in magnetic recording and optical interconnects[2]. An obvious barrier towards technological applications is the use of large amorphous structures as the key magnetic properties are not scalable to high density. To address this issue, the use of multilayered systems has been posed as one solution for it allows for greater control of the structure [3]. In this study, a theoretical model of Gd/Fe multilayers based on the atomistic spin dynamics formalism has been constructed to investigate both the static and dynamic magnetic properties for a range of layer thicknesses and number of repeats of the layers.

The temperature dependent magnetisation curves show a decreasing Curie temperature with decreasing thickness of the layers due to the reduced Fe-Fe exchange. Besides, the pump fluence dependent magnetisation dynamics show that the minimum fluence required for switching is strongly dependent on the structural properties (thickness/repeats), even though the samples' composition remains constant. Finally, the result of spin wave dispersion reveals a discretisation of the band structure due to the periodicity of the multilayer structure. That the bands become “flat” indicates standing spin waves which have an unusually long lifetime, and the frequency of the spin waves can be tuned between 0.5THz and 4THz by varying the structure of the multilayers.

[1] Ostler *et al.,* Nature Communications, 3, 666 (2012)
[2] Azim *et al.,* IEEE Electron Device Letters, 35, Issue 12, pages 1317-1319 (2014)
[3] Evans *et al.,* Applied Physics Letters, 104, 082410 (2014)

Element- and site-resolved magnetization dynamics in a YIG/Cu/Co trilayer measured by x-ray detected ferromagnetic resonance

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[1]University of Exeter, UK, [2]Diamond Light Source, UK, [3]University of York, UK, [4]University of Leeds, UK

X-ray detected ferromagnetic resonance (XFMR) is a powerful tool for the investigation of spin transfer torque (STT) effects in magnetic multilayers [1]. In the present work, XFMR has been used to study element and site specific magnetization dynamics in a GGG / yttrium iron garnet (YIG) (60 nm) / Cu (5 nm) / Co (6 nm) / Mg (3 nm) multilayer. The very low ferromagnetic resonance linewidth of YIG is expected to lead to efficient generation of spin current by spin pumping [2]. Clear dynamic coupling of the Co to the YIG at resonance is observed. Fitting the phase of the Co precession suggests that the spin mixing conductance is of comparable magnitude to that within a metallic spin-valve [1]. However, the interpretation is complicated by the presence of multiple unresolved resonance modes within the YIG.

Multiplet structure in the x-ray magnetic circular dichroism (XMCD) spectra of Fe in YIG allows for separation of the two antiferromagnetically-coupled Fe sublattices. At resonance the Fe moments at the two sublattices precess in antiphase. However, static and dynamic XMCD spectra (Fig. 1(b)) show strongly different lines shapes, suggesting that the amplitude of precession may be different for the two Fe sites.

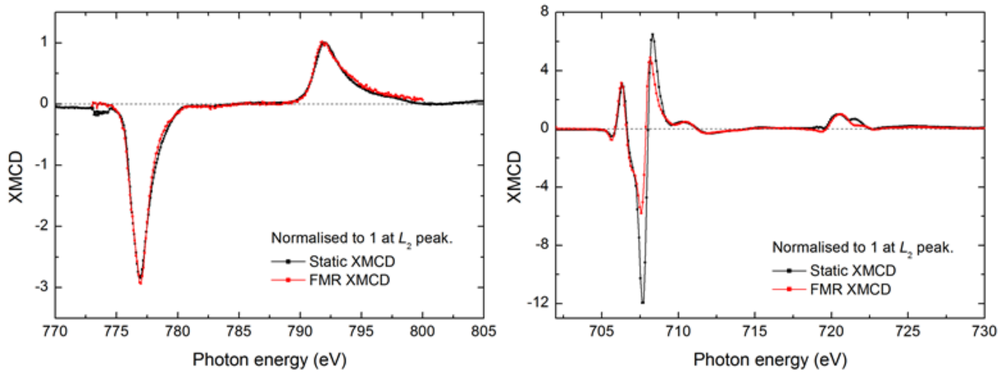

Figure 3 – Comparison of XMCD spectra of static magnetisation (black) and magnetisation at resonance (red), for Co (left) and Fe in YIG (right). The strongly modified multiplet structure of Fe at resonance suggests different amplitude precession of the two Fe sublattices.

[1] M. Marcham *et al.*, Phys. Rev. B 87, 180403 (2013)
[2] Y. Kajiwara *et al.*, Nature 464, 262 (2010)

Session 12: Artificial spin ice

Thermal behaviour study of an artificial magnetic quasi-crystal

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Quasi-crystals, due to their unique structure and resulting interesting physicals properties have been intensively studied for decades [1,-2,-3]. However, due to the limitations of probing techniques, the nature of thermally-driven dynamic behaviour of quasi-crystals is still not fully understood. Here, we have nanofabricated artificial magnetic quasi-crystals, consisting of magnetic nanoelements arranged in Penrose tiling patterns that possesses similar geometrical frustration to "real" systems.

Thermal annealing has been proved to be most successful method in looking for ground state of artificial nanostructures in other patterns [4]. In this manner, the constituent material of nanostructures is heated above its Curie temperature and then cooled down to room temperature. We have applied this protocol to our artificial quasi-crystals, yielding magnetic configurations that are significantly closer to ground state compared to the states arising from other protocols.

The ground state of Penrose tiling divides the pattern into two groups of elements: one has 2-fold degeneracy: "skeleton part", the other has multi-degeneracy: "flippable"part. After being heated, the "skeleton" part of the pattern clearly forms 2 types of domains which correspondent to 2 fold degeneracy ground state. These domains are observed from MFM image after mapping with ground state by 2 different colours (Fig.1), which tend to coarsen as lattice constant (the distance between the centres of one vertex to another) decreases. This process is indicated by total length of boundary between domains. However, this trend is truncated because the lattice constant is hard to further decrease due to limitation of fabrication.

Nevertheless, statistical results of different structural vertex types (which have different energy level) imply that the thermal dynamics during the cooling process shows spin-glass-like freezing: different vertices build up correlations at different temperature, which causes frustration when the whole system cools down. This frustration leads to some vertices energy distributions that have a shift which is revealed by the energy distribution statistics (Fig.2).

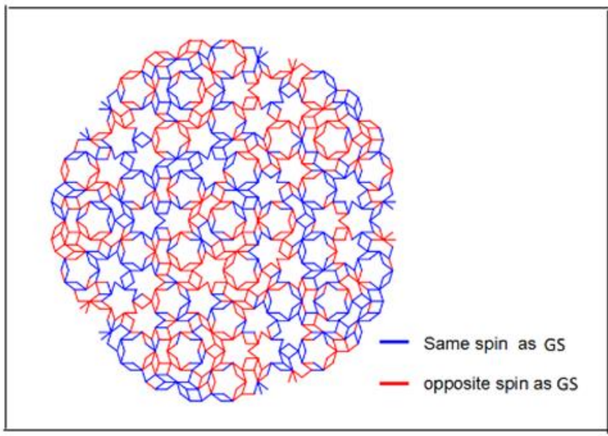

Fig.1 2-colour mode mapping of MFM image after thermal annealing

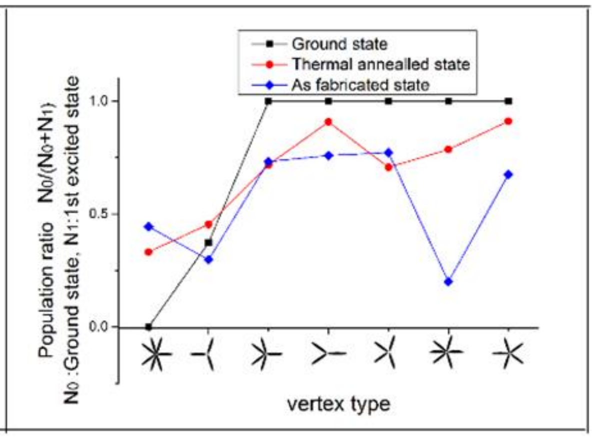

Fig.2 Energy distribution fraction of each vertex

The propagation of magnetic domain walls in interconnected artificial spin ice structures

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Geometrically patterned magnetic nanostructures supporting individual magnetic domain walls (DWs) have been extensively studied due to the potential impact from the development of novel technological devices. Our current understanding has led to the development of magnetic meta-material systems such as artificial spin ice. Here, the collective behaviour originates from the DWs as they interact with the vertices between many interconnected nanowire structures [1,2].

In this work, spatially resolved magnetisation reversal behaviour in a kagome structure is investigated through focussed MOKE magnetometry. With a combination of spatially uniform quasi-static fields and localised pulsed fields, the role of DWs in the reversal process has been investigated [3]. Localisation of the DW injection field allows the DW propagation behaviour to be probed at fields below the intrinsic nucleation field in the system. This behaviour can be differentiated from that associated with the boundary effects resulting from the edges of the structure. Furthermore, varying the applied field direction around particular symmetry can bias the DW propagation and vertex interactions giving further insight into the interactions taking place in these structures.

This research builds on our understanding of complex interconnected magnetic systems and opens pathways to further explore the manipulation of magnetic charges [4] and potential technological applications.

We acknowledge Leverhulme Trust grant RPG_2012-692 and UK EPSRC grant EP/G004765/1 for funding.

[1] D. Burn *et.al. Phys. Rev. B* 90, 144414 (2014)
[2] K. Zeissler *et.al. Sci. Rep.* 3, 1252 (2013)
[3] D. Burn *et.al. Phys. Rev. B* 88, 104422 (2013)
[4] E. Mengotti *et.al. Nat. Phys.* 7, 68 (2010)

Lorentz transmission electron microscopy study of three dimensional artificial spin ice

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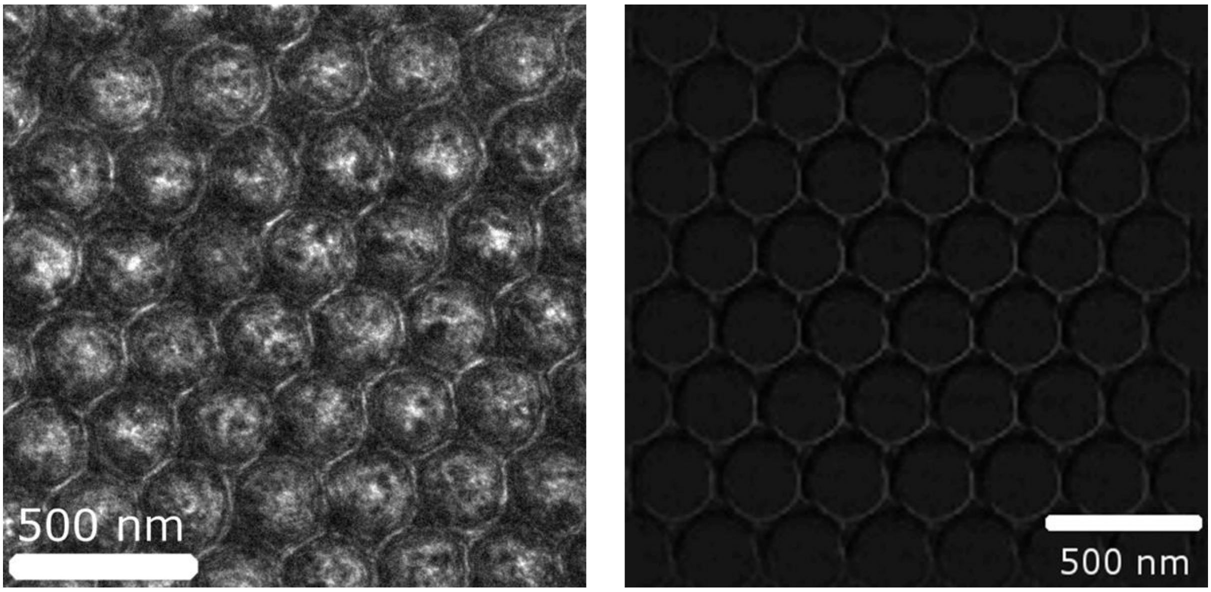
Frustration, i.e. the inability to simultaneous satisfy all interactions, occurs in a wide range of systems including neural networks and water ice[1]. Systems where the frustrated properties can be measured are therefore of fundamental scientific interest. One such model system is 'spin ice'[2], where geometrical constraints cause frustration in the orientation of the magnetic moments; this was originally found in pyrochlore crystals at very low temperatures. In two-dimensional artificial-spin-ices the atomic moments are replaced with single-domain ferromagnetic islands[3]. A number of interesting properties of canonical spin ices, such as emergent magnetic monopoles[4], can be reproduced. However, going from three to two dimensions leads to a change in either symmetry or connectivity at each vertex, changing some aspects of the frustrated system. Here we show that three-dimensional inverse opal nanostructures of ferromagnetic permalloy produce Ising spin states with the same symmetry and connectivity as the pyrochlore lattice. Using Lorentz transmission electron microscopy we directly image the micromagnetic state, observing spin-ice behaviour.



[1] L. J. Pauling, *J. Am. Chem. Soc.*, 57, 2680 (1935)
[2] M. J. Harris, et al., *Phys. Rev. Lett.*, 79, 2554 (1997)
[3] R. F. Wang, et al., *Nature,* 439, 303 (2006)
[4] S. Ladak, et al., *Nature Phys.*, 6, 359 (2010)

Speckle dynamics in artificial spin ice

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We report on the dynamics of artificial spin ice formed from magnetic nanoelements whose lateral size is much smaller than those which can be imaged with current magnetic microscopy techniques. The sizes of the NiFe islands in this study are ≈ 30 nm x 75 nm and 8 nm thick. We use resonant magnetic soft x-ray photon correlation spectroscopy (XPCS) to observe the time-time correlations of the thermal fluctuations in the system. In XPCS, a small part of the sample is illuminated coherently. The resulting Bragg spots have speckle that can be imaged on a CCD camera. As the sample's magnetic configuration varies with time, so do the details of the speckle pattern. We have determined the form of these correlations both as a function of temperature and of lattice constant. The correlation is found to be of stretched exponential form. There is a strong dependence of relaxation time with temperature. At 180 K the sample is frozen but displays increasing dynamics up to 250 K, whereas at 295 K the fluctuations are too fast to measure. We measure a stretching exponent close to one for weak interaction, describing diffusive-like behaviour, and an exponent different from unity for strongly interacting arrays, indicating more coupled/jammed dynamics due to the designed-in frustration.

Low temperature behaviour of honeycomb artificial spin ice

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Artificial spin ice is a model system which has seen a lot of activity in the last year as it allows investigation of equilibrium and field driven magnetic processes. The magnetic structures consist of arrays of ferromagnetic nanowires that are single domain with anisotropy along the long axis, arranged on a square or honeycomb lattice. Here we present electrical transport data between 2 K and 290 K of an electrically continuous permalloy honeycomb artificial spin ice. The influence of the bar geometry, i.e. the width and length, on the field driven magnetic reversal is studied. In particular the low temperature transport anomaly, previously reported in cobalt artificial spin ice [1] and the dependence of its onset temperature on the geometry is explored. The onset temperature was found to be rather sensitive to the length of the nanowires.

WB acknowledge Leverhulme Trust grant RPG_2012-692 and UK EPSRC grant EP/G004765/1 for funding. KZ thanks EPSRC Doctoral Prize Fellowship for support grant EP/L504786/1.

[1] Branford WR, Ladak S, Read DE, Zeissler K, Cohen LF. Emerging Chirality in Artificial Spin Ice. Science. 2012;335(6076):1597-600

Micromagnetic studies of nanostructure gadolinium

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The study of frustration and the collective behaviour stemming from it has been a growing topic in magnetism over the past decade. The pioneering works in artificially frustrated magnetic systems used ferromagnetic islands, made of room-temperature ferromagnets, on a geometrically frustrated lattice[1,2]. The competition between the exchange and anisotropic energies led to a frustrated system.

Gadolinium is an often overlooked material. The thin film form has a ferromagnetic phase below 293 K when grown hcp; paramagnetic when the conditions favour fcc growth [3]. The low T_C along with the rapid oxidation it experiences are evident obstacles to the study of the magnetic properties of nanostrucutred gadolinium. However, a T_C around room temperature would allow thermal effects to play a role in frustrated magnetic systems, motivating this study.

By use of micromagnetic modelling, the magnetic moment and reduced energy density of gadolinium nano-islands were studied and the results inform and act as a comparison for the experimental creation of gadolinium islands to be used in a geometrically frustrated lattice.

[1] Wang et al (2006), *Nature*, 439, 303–6
[2] Tanaka et al (2006), *Phys. Rev. B* 73, 052411
[3] Schuenert et al (2012), *Appl. Phys. Lett.* 101, 142407

Session 13: Magnonics

Coupling of magnetisation dynamics and heat currents

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Applying temperature gradients to magnetic samples is a state-of-the-art method to generate magnetisation dynamics [1,2]. The usual setup utilises uniform temperature gradients which means that the gradient of the scalar temperature field is a constant. In this presentation we address the effect of nonuniform temperature gradients instead of uniform ones. In particular, we study low-lying energy excitations in ferromagnets subject to externally applied temperature profiles characterised by a spatially varying gradient.

Building on our previous work [3], we discuss possible coupling terms within a Lagrangian approach. The corresponding energy functional is proposed and the relevant equations of motion for both magnetisation and temperature are derived. This results in a system of partial differential equations (pde) for the magnetothermally coupled system. Neglecting higher-order coupling terms the spatial and temporal variation of the temperature is described by the conventional heat equation, whereas the equation of motion for the magnetisation is coupled to the temperature gradient which plays the role of an effective magnetic field. Solving the system of pde's we observe the formation of magnetic excitations which follows the spatial structure of the temperature distribution, see Fig.1.

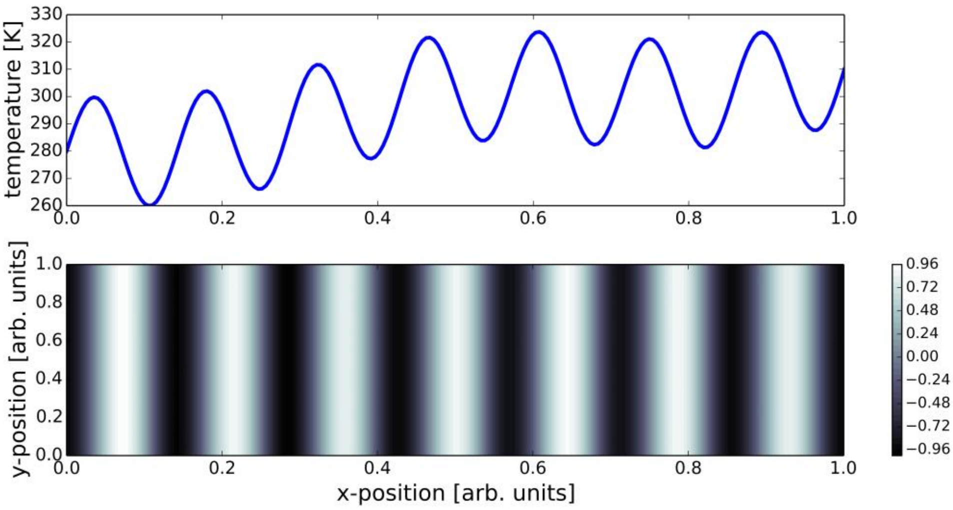

Figure 1: Spatial variation of transverse magnetisation (lower panel) in a magnetic film caused by oscillating temperature profile (upper panel).

[1] K. Uchida, S. Takahashi, K. Harii, J. Ieda, W. Koshibae, K. Ando, S. Maekawa and E. Saitoh, *Nature*, 455, 778 (2008)

[2] G.E.W. Bauer, E. Saitoh and B.J. van Wees, *Nat. Mater.*, 11, 391 (2012)

[3] T. Bose and S. Trimper, *Phys. Lett. A*, 376, 3386 (2012)

Ferromagnetic resonance of patterned chromium dioxide thin films grown by selective area chemical vapour deposition

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A selective area chemical vapour deposition technique has been used to fabricate continuous and patterned epitaxial CrO_2 thin films on (100)-oriented TiO_2 substrates. Precessional magnetization dynamics were stimulated both electrically and optically, and probed by means of time-resolved Kerr microscopy and vector network analyser ferromagnetic resonance techniques. The dependence of the precession frequency and the effective damping parameter upon the static applied magnetic field were investigated. All films exhibited a large in-plane uniaxial anisotropy. The effective damping parameter was found to exhibit strong field dependence in the vicinity of the hard axis saturation field. However, continuous and patterned films were found to possess generally similar dynamic properties, confirming the suitability of the deposition technique for fabrication of future spintronic devices.

Long-range coupling between magnets using magnon quantum electrodynamics

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Spins can be coupled together via the direct exchange interaction if they are close neighbours, or at longer distances by, for example, double exchange or the RKKY interaction. These interactions all operate over length scales of order nanometres, but pseudospins (such as qubits), have been coupled at much longer distances using the techniques of circuit quantum electrodynamics (cQED). In this approach, the two level system is embedded in a transmission line cavity and the interaction between matter and light correspondingly enhanced. Here we use the toolkit of cQED to couple and measure the magnetostatic modes of two yttrium iron garnet (YIG) spheres (Fig. 1). YIG is a ferrimagnetic insulator with low magnetic losses and a high moment density, which attracts sustained scientific interest.

We present dispersive measurements of the longitudinal magnetisation of YIG, and use this technique to probe the photon-mediated coupling of the spheres. We measure the size of the coupling as a function of detuning from the cavity modes and understand our results in the context of the cQED formalism. This room temperature approach to magnetic coupling will enable the straightforward measurement of more complicated cavity coupled systems, leading to the exploration of coherent magnetic metamaterials.

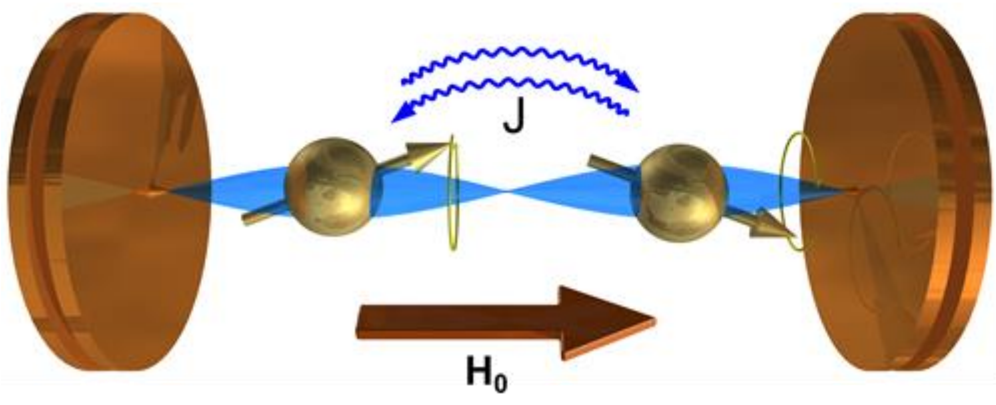

Fig. 1. Schematic of our magnet coupling scheme. Two macrospins are embedded in a transmission line cavity, and a coaxial magnetic field, $\mathbf{H_0}$, is applied. The precession of the spins around $\mathbf{H_0}$ is coupled by the exchange of virtual photons in the cavity.

Exploring spin-wave systems at the single magnon level

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The fields of spin-wave dynamics and magnonics (the study of spin-wave and magnon dynamics in magnetic films and nanostructures) have made extensive contributions to our understanding of basic magnetic physics, and are increasingly widely acknowledged to be regions of condensed matter physics with real technological potential. To date however, the majority of experimental effort in these areas has been directed toward the study and possible application of room-temperature systems operating within classical limits. Here, we report a series of experiments in which we demonstrate the excitation and detection of propagating spin waves at the single magnon level. Our results, which have been obtained at cryogenic temperatures in an yttrium iron garnet spin-wave waveguide, serve as evidence that the experimental tools now exist to permit us to create microwave (i.e. GHz frequency) quantum circuits incorporating dispersive magnon systems. This allows us to anticipate the possibility both of exploring quantum aspects of magnon physics with new clarity, and of examining how this physics – in particular, the magnon's highly tunable dispersion, its readily accessible nonlinearity, and its capacity to couple to optical excitations and electron-based spintronic systems – might have a role to play in new microwave quantum technologies.

Towards graded-index magnonics: Steering spin waves in magnonic networks

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The dispersion and propagation of spin waves is highly anisotropic[1]. We have used time-resolved scanning Kerr microscopy[2] and micromagnetic simulations to study the propagation of spin waves across 5 μm wide Permalloy waveguides, arranged to form a T-junction structure and biased asymmetrically. We demonstrate that the non-uniformity of the internal magnetic field and magnetization inherent to patterned magnetic structures (Fig.1(a)) creates a medium of graded refractive index for propagating magnetostatic waves and can be used to steer their propagation in magnonic architectures (Fig.1(b)-(c)). The character of the non-uniformity can be tuned and potentially programmed using the applied magnetic field. Thus, our findings suggest a possibility of a novel reconfigurable computing technology based on the principles of the graded-index magnonics.

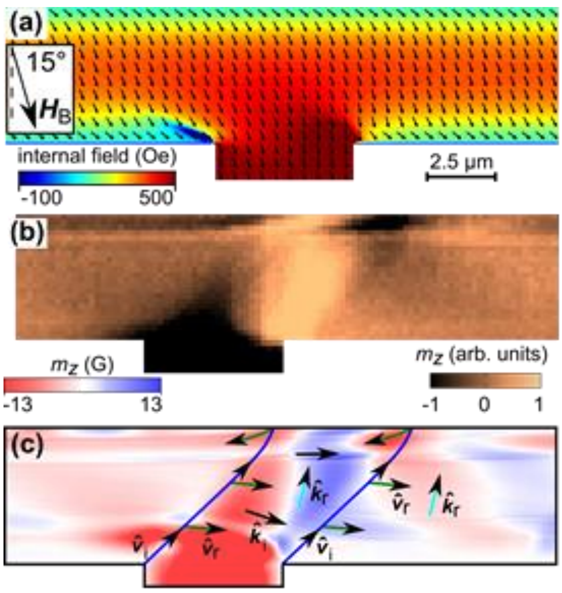

Fig. 1 (a) The calculated distribution of the static magnetization (arrows) and the projection of the internal field on to the magnetization (colour) in a 5μm wide T-junction structure. The global bias field H_B=500 Oe is applied at 15° to the "leg" of the T-junction. **(b)** An experimental snapshot of spin wave propagation. **(c)** The calculated variation of the initial/reflected magnonic group velocity ($\boldsymbol{v}_i$)/($\boldsymbol{v}_r$) and wave vector ($\boldsymbol{k}_i$)/($\boldsymbol{k}_r$) overlaid on a snapshot of similar spin wave propagation obtained from micromagnetic simulation.

[1] A. G. Gurevich and G. A. Melkov, "*Magnetization oscillations and waves*" (Chemical Rubber Corp., New York, 1996)

[2] Y. Au, T. Davison, E. Ahmad, P. S. Keatley, R. J. Hicken, and V. V. Kruglyak, Appl. Phys. Lett. 98, 122506 (2011)

Curved magnonic waveguides based on domain walls

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Spin waves offer possible alternatives for energy efficient computing. In constrast to optical based computing, practical methods for controlling the flow of spin waves through a system is an important challenge within magnonics. An attractive option would be the equivalent to an optical fibre for spin waves, thereby allowing propagating spin waves to travel along curved paths for circuit design and wave processing schemes. In this work we suggest a means of achieving this for spin wave propagation by using curved magnetic domain walls in a system with chiral interactions.

We demonstrate channeling of spin waves with domain walls in ultrathin ferromagnetic films theoretically and with micromagnetics simulations. It is shown that propagating excitations localized to the wall, which appear in the frequency gap of bulk spin wave modes, can be guided effectively in curved geometries and can propagate in close proximity to other channels with no perceptible scattering or loss in coherence. For Nèel-type walls arising from an interfacial Dzyaloshinskii-Moriya interaction, the channeling is strongly nonreciprocal and group velocities can exceed 1 km/s in the long wavelength limit for certain propagation directions.

[1] A. Khitun, M. Bao, and K. L. Wang, J. Phys. D: Appl. Phys. 43, 264005 2010)

[2] V. V. Kruglyak, S. O. Demokritov, and D. Grundler, J.Phys. D: Appl. Phys. 43, 264001 (2010)

[3] R. Hertel, W. Wulfhekel, and J. Kirschner, Phys. Rev. Lett. 93, 257202 (2004)

Session 14: Magnetic structure and properties

(invited) The dynamics of a quantum spin liquid

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Spin liquids have been viewed as a possible phase of matter since P. W. Anderson's work on resonating valence bonds some forty years ago. There has been enormous progress in the intervening years, and we now have good candidate materials, in the form of both organic molecular magnets and insulating transition metal compounds, as well as a greatly improved theoretical understanding of spin liquids states. I will give a brief overview of the status of this field and will also outline recent theoretical results on the dynamics of a remarkably simple, exactly solvable model (the Kitaev honeycomb model) that has a spin liquid ground state. In this system, magnetic moments are "dissolved" by quantum fluctuations and reform as new degrees of freedom: mobile fermions and flux lines of an emergent gauge field. I will discuss the implications of this reorganisation, known as quantum number fractionalisation, for measurements of dynamics such as the inelastic neutron scattering response.

[1] J. Knolle, D. L. Kovrizhin, J. T. Chalker, and R. Moessner, Phys. Rev. Lett. 112, 207203 (2014)

Designed magnetic systems based on the 2D-XY ferromagnet

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The underlying physics of phase transitions is often studied via the intuitive picture provided by magnetic systems. Theoretical models typically specify the symmetry and degrees-of-freedom of the spin-system, along with the dimensionality of the exchange interactions. For magnetism in two-dimensional systems, where two 'universality classes' exist, particularly interesting phenomena emerge. In addition to the 2D-Ising model, where spins are confined to lie along a single axis, the 2D-XY model leads to the concept of an exotic infinite order 'Berezinskii-Kosterlitz-Thouless' (BKT) phase transition [1]. This transition is predicted to involve topological defects - in this case magnetisation vortices - which bind in order to allow thermodynamically-forbidden ordering. Variants on the 2D-XY Hamiltonian have been studied theoretically and via simulation; including additions of random on-site anisotropies, and uniaxial, cubic and higher order anisotropies. These additions to the Hamiltonian act to modify the critical behaviour, transition temperature, and may suppress the BKT transition, or create a novel half-order BKT transition [2].

We have deposited thin-films of a prototype material, amorphous CoFeTaB alloy with Curie temperature controlled by Ta doping, which demonstrates 2D-XY magnetism similar to [3]. We find critical exponents characteristic of 2D-XY magnetism for amorphous CoFeTaB films of thickness up to around 3nm, changing to conventional 3D-Heisenberg magnetism as thickness further increases. By adjusting the Curie temperature relative to the growth temperature we induce random local magnetic anisotropy into the films and find, by XMCD-PEEM imaging, features similar to those predicted; related to trapping of topological magnetization vortices in anisotropy energy minima, and formation of 2π domain-walls by a magnetic field. Depositing our films onto a III-V(001) surface induces a uniaxial magnetic anisotropy [4] and results in a novel 2D-XY-h2 ferromagnet; analogous to the more commonly observed 2D-XY-h4 system with inbuilt four-fold in-plane anisotropy [5].This novel class of magnet has the anticipated non-universal magnetization critical exponent in the range bounded by the 2D-Ising and 2D-XY values, and is a candidate system for observing a half-integer BKT transition.

[1] V. L. Berezinskii, Sov. Phys. JETP (1972); J.M. Kosterlitz and D. J. Thouless, J. Phys. C (1973)
[2] D.H. Lee and G. Grinstein, Phys. Rev. Lett. (1985)
[3] M. Ahlberg, G. Andersson, and B. Hjörvarsson, Phys. Rev. B (2011)
[4] A. T. Hindmarch et al., Phys. Rev. Lett. (2008)
[5] A. Taroni, S. T. Bramwell, and P.C.W. Holdsworth, J. Phys.: Condens. Matter (2008)

α-CoV_2O_6 a prototype Ising antiferromagnet on a zigzag ladder

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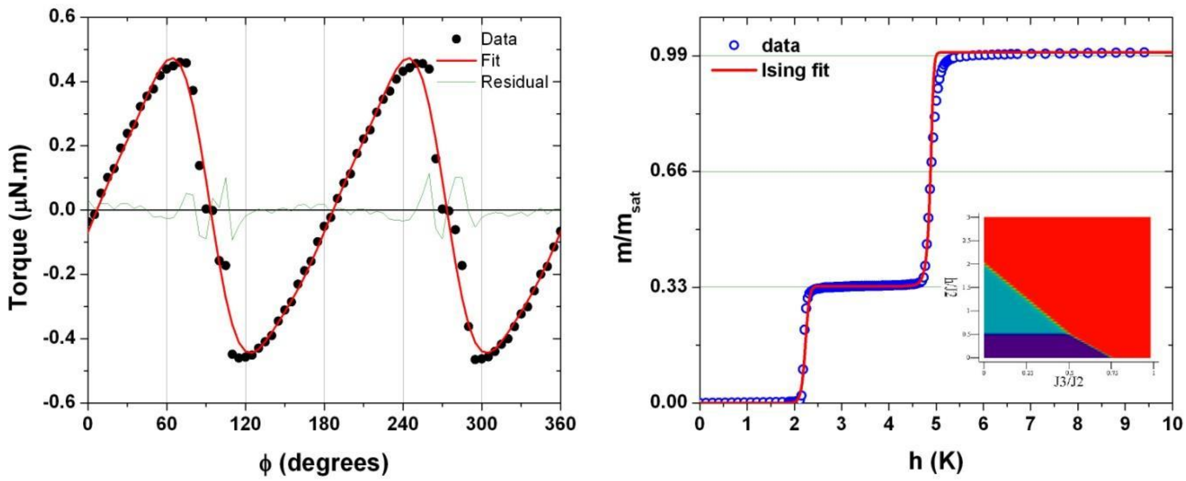
The bulk magnetic properties and magnetic structure of α-CoV_2O_6 have recently been reported showing m=1/3 magnetization plateau at critic al field a signature of low dimensionality and frustration in the magnetic lattice. In this study the complete magnetic phase diagram is determined using magnetic torque measurement on a single crystal. Series of angular dependence of the torque at fixed magnetic field and temperature were measured in order to determine the magnetic anisotropy of the system using cosine series up to the 4th order and additional feature of the magnetic frustration was observed in the angular dependence of the torque near the hard axis where the torque goes to zero instead of a sharp change of sign (Left figure). Magnetic field dependence of the torque at fixed magnetic field direction was used to extract the evolution of the critical field as function of magnetic field direction. The low dimensional behaviour of the magnetization is mapped using a zigzag ladder model, and transfer matrix method is used to model the magnetization data and exchange coupling parameters are extracted for this system (Right figure).



Left: Measured angular dependence of the torque (black dot) measured at 5 K and 14 T together with a fit using a cosine series up to the 4th order (red line). Right: Normalised magnetisation as a function of applied magnetic field along the easy axis (blue circles) together with a fit (red line) using an Ising antiferromagnet model on a zigzag ladder. The inset shows a calculated magnetic phase diagram showing the variation of the critical fields for different exchange energies (purple m=0, cyan m=1/3 and red m=1).

Core/shell magnetism in NiO nanoparticles

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Recently, magnetic nanoparticles (MNPs) have become a subject of intense research in a myriad of different fields, from catalysis and pattern formation to MRI contrast agents and for diagnoses in magnetic biosensors [1,2]. A feature common to both superparamagnetic and ferromagnetic MNPs is the addition of correction factors, which must be included when calculating their magnetisation compared to the expected bulk value. These factors are predominantly explained as accounting for finite size effects; however, the nature of these effects is as yet, unresolved [3].

The anomalous appearance of a ferromagnetic moment in nominally antiferromagnetic nanoparticles has been known about since Néel, but never well understood. We present proof of the core/shell model of magnetism in antiferromagnetic NiO nanoparticles (NP) using neutron diffraction (Fig.1). Nickel oxide nanoparticles were produced in a large quantity by a novel continuous hydrothermal flow synthesis method. The antiferromagnetic nature of the nanoparticles allowed the structural and the magnetic diffraction peaks to be completely separated. Using both the microstructure option in "Fullprof" microstructure fitting suite and convolution techniques, we determined the NP consisted of an ordered antiferromagnetic core 5.2(2) nm in diameter surrounded by a disordered shell 0.7(2) nm thick.

Further magnetic measurements showed that this disordered shell possess a significant polarisable magnetisation, up to a fifth that of pure nickel. They also indicate that two magnetic transitions occur between 400 and 10 K; around 350 K, there is a broad transition from paramagnetic to a form of superparamagnetism, then near 30 K there is a transition to a higher anisotropy state. Differences in field cooled and zero field cooled hysteresis loops were found, though with no evidence of exchange bias effects.

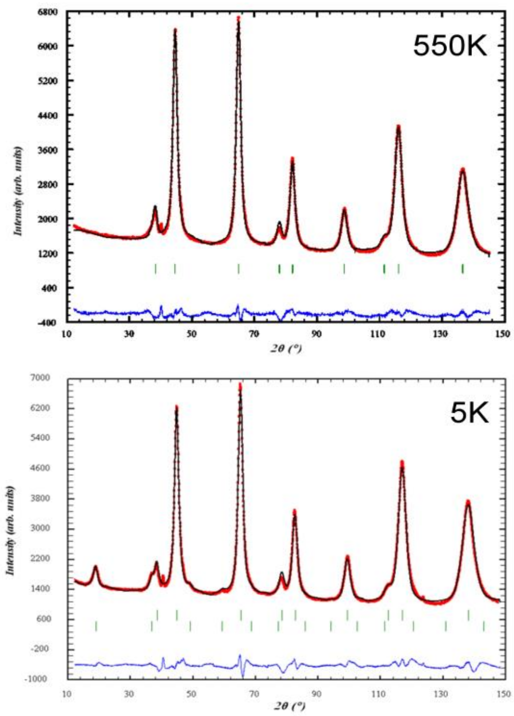

Figure 1: Neutron powder diffraction (red) and fit (black) for the NiO NP at 550 K (top) and 5 K (bottom). At low temperatures, below the Néel temperature of TN = 523 K, an additional peak arises due to the antiferromagnetic ordering of the NiO, clearly visible near 13°.

[1] J. Llandro, J.J. Palfreyman, A. Ionescu, and C.H.W. Barnes, Med. Biol. Eng. Comput. 48, 977 (2010).
[2] N.T.K. Thanh, "Magnetic Nanoparticles: From Fabrication to Clinical Applications", Taylor and Francis (2012).
[3] J.F.K. Cooper, A. Ionescu, R.M. Langford *et al.*, Journal of Applied Physics 114, 083906 (2013)

Disentangling the spin and orbital moments in the heavy fermion system $CeRu_2Al_{10}$ using polarised x-rays

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We present the first ever observation of non-resonant magnetic scattering at soft x-ray energies. The scattered x-ray polarisation from a magnetic Bragg reflection is highly sensitive to the direction of the magnetic moment [1], allowing us to determine the magnetic structure of these systems [2].

Non-resonant magnetic scattering can distinguish the spin and orbital components of the magnetic moment [4]. A more common technique is resonant x-ray scattering, in which the energy of the incident x-rays are tuned to an electronic transition of the magnetic atoms, resulting in a resonantly enhanced scattered intensity [5]. This has the advantage of allowing the observation of otherwise very weak (non-resonant) scattered signals at the cost of sensitivity to the spin and orbital moments separately.

$CeRu_2Al_{10}$ is a Kondo semiconductor heavy fermion system, which displays similar properties in its phase transitions to those of the hidden order transition in the heavy fermion superconductor URu_2Si_2 [6][7]. From the Ce-Ce separation the magnetic transition temperature, as predicted by the RKKY interaction, is expected to be around 2 K, whereas it is observed close to 30 K [8]. We have separately undertaken both resonant (at the cerium M_{IV} edge, 902.4 eV) and non-resonant studies of the (0,1,0) magnetic reflection in $CeRu_2Al_{10}$ using single-crystal soft x-ray diffraction.

This technique is potentially capable of providing new information about the detailed magnetic and orbital structure of a wide variety of materials. The currently accepted magnetic structure is shown in figure 1.

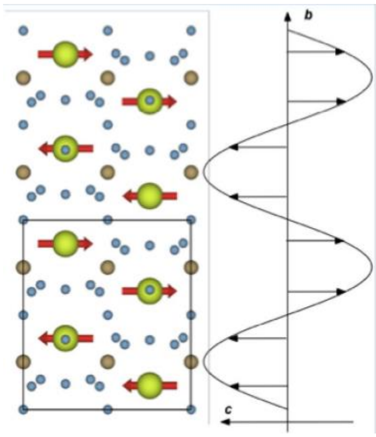

Fig. 1. The magnetic structure of $CeRu_2Al_{10}$ as determined by neutron scattering. Cerium atoms shown in green, ruthenium atoms in brown and aluminium in blue [3].

[1] M.Blume and Doon Gibbs. Phys.Rev.B, 37:1779, 1988
[2] C. Detlefs, M. Sanchez del Rio, and C. Mazzoli. Eur. Phys. J. Special Topics, 208:359, 2012
[3] Y. Muro, J. Kajino, T. Onimaru, and T. Takabatake. J. Phys. Soc. Jpn., 80:SA021, 2010
[4] J.P. Hill and D.F. McMorrow. Acta. Cryst., A52:236, 1996
[5] J.P. Hannon, G.T. Trammell, M. Blume, and Doon Gibbs. Phys. Rev. Lett., 61:1245, 1988
[6] E.D. Isaacs and D.B. McWhan et al. Phys. Rev. Lett., 65:3185, 1990
[7] C.S. Lue and H.F. Lui et al. Phys. Rev. B, 85:245116, 2012
[8] T. Nishioka and Y. Kawamura et al. J. Phys. Soc. Jpn., 78:123705, 2009

Poster abstracts

Ab initio

P.01 Non-Fermi-liquid behavior and anomalous suppression of Landau damping in layered metals close to ferromagnetism

S Ridgway and C Hooley

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We analyse the low-energy physics of nearly ferromagnetic metals in two spatial dimensions using the functional renormalization group technique. We find a new class of low-energy fixed point, at which the fermionic (electron-like) excitations are non-Fermiliquid (z_f = 7=6) and the magnetic uctuations exhibit an anomalous Landau damping whose rate vanishes as $\Gamma_{\mathrm{q}} \sim |\mathbf{q}|^{1/3}$ in the low-$|\mathbf{q}|$ limit. We discuss the physical nature of this fixed point, and highlight its possible applicability to experiments on UGe_2 and related compounds.

P.02 *Ab initio* study of magnetoelastic and elastocaloric effects in Mn-antiperovskites

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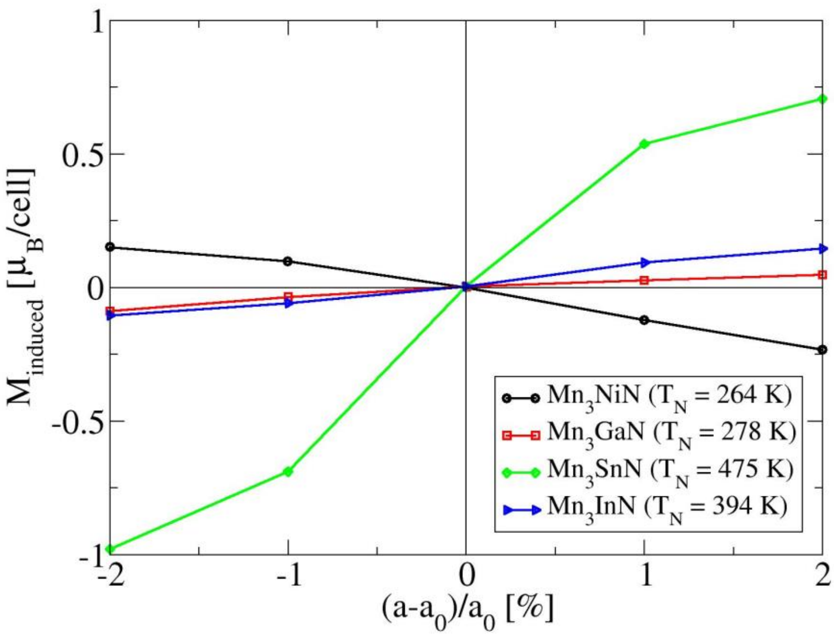
We perform a comparative study of the piezomagnetic effect in four closely related Mn_3XN (X = Ga, In, Ni, Sn) antiperovskites using the framework of projector augmented-wave (PAW) method as implemented in VASP code [1]. Subsequently, we calculate the electronic entropy as a function of temperature and applied strain using the *ab anitio* densities of states. Our focus on the perovskite structure is motivated by recent measurements of a giant barocaloric effect in Mn_3GaN [2] and a prediction of an elastocaloric (piezocaloric) effect in strained $BaTiO_3$ thin film [3].

All four studied compounds are metallic and have a fully compensated non-collinear antiferromagnetic ground state [4,5] which is confirmed by our calculations. We predict canting and change of magnitude of the Mn local magnetic moments as a function of applied biaxial strain. The induced net magnetization is linearly dependent on small biaxial lattice strains and reaches values of 0.1 μ_B/Mn per 1% of strain.

The research has received funding from the European Community's 7th Framework Programme under Grant agreement 310748 "DRREAM".



[1] G. Kresse and D. Joubert, Phys. Rev. B 59, 1758 (1999)
[2] D. Matsunami et al., Nat. Mater. 14, 73–78 (2015)
[3] Yang Liu et al., Adv. Mater., 26: 6132–6137 (2014)
[4] D. Fruchart and E.F. Bertaut, J. Phys. Soc. Jpn. 44 781 (1978)
[5] Landolt-Bornstein, New Series, Group III/19c, p. 249, Springer-Verlag, Berlin (1981)

P.03 **Towards a simple description of magnetism in heavy rare earths: application to magnetic refrigeration**

E Mendive-Tapia and J Staunton

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Magnetic refrigerants are much more efficient than conventional fridges based on compression/ expansion technology and are promising candidates for environmentally friendly refrigerants. Therefore, the development of simple theoretical models for their study has an important value in order to provide qualitative insights into otherwise an incredibly complex research field. Here we employ an ab-initio Disordered Local Moment Theory (DLM)[1,2] to investigate the magnetic phase diagram of heavy rare earths. We focus on the study of magnetic phase transitions that are characteristic of the common valence electronic structure among the heavy rare earths. Thus, Gd is used in order to mimic other heavy rare earths due to their chemical similitude[3]. As a preliminary main result, we observe that FAN, distorted AFM, and CONE magnetic phases[4] can be obtained by changing the temperature and/or the strength of an applied magnetic field without including crystal field contributions nor relativistic effects. In the long term, we seek to model the magnetism of the heavy rare earths and nanostructure potential materials exhibiting large caloric responses by scaling the exchange interaction with the Gennes factor and by including anisotropy effects as additional phenomenological terms[4].

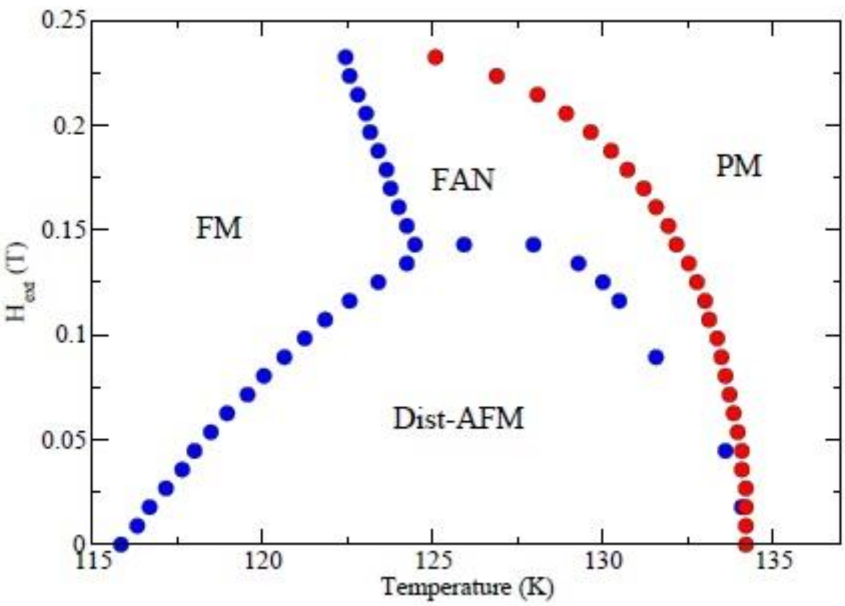

Fig 1: Magnetic phase diagram of Dy[5] using Gd as a basis of DLM calculations. Second (red) and first (blue) order transitions between ferromagnetic (FM), antiferromagnetic (AFM), distorted antiferromagnetic (Dist-AFM), and fan (FAN) magnetic phases have been obtained by changing the temperature and/or the strength of the applied magnetic field H_{ext} along an easy axis direction.

[1] B. L. Gyorffy, A. J. Pindor, J. Staunton, G. M. Stocks, and H. Winter, J. Phys. F 15, 1337 (1985)

[2] J. B. Staunton, L. Szunyogh, A. Buruzs, B. L. Gyorffy, S. Ostanin, and L. Udvardi, Phys. Rev. B 74, 144411 (2006)

[3] I. D. Hughes, M. Däne, A. Ernst, W. Hergert, M. Lüders, J. Poulter, J. B. Staunton, A. Svane, Z. Szotek, and W. M. Temmerman, Nature 446, 650 (2007)

[5] J. Jensen and A. R. Mackintosh, Rare Earth Magnetism, Structures and Excitations (Clarendon, Oxford, 1991)

[6] A. S. Chernyshov, A. O. Tsokol, A. M. Tishin, K. A. Gschneidner, and V. K. Pecharsky, Phys. Rev. B 71, 184410 (2005)

Bio and organic magnetism

P.04 Magnetoresistance and doping effects in conjugated polymer-based organic light emitting diodes

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Magnetoresistance (MR) and doping effects have been investigated in poly(3-hexylthiophene-2,5-diyl) (P3HT) based organic light emitting diodes. In single device of fixed composition (Au/P3HT/Al as spun and processed in air), the measured MR strongly depends on the drive conditions. The magnetoconductance (MC) varies from negative to positive ($-0.4\% \leq MC \leq 0.4\%$) with increasing current density, depending on which microscopic mechanism dominates. We attribute the negative MC to bipolaron based interactions and the positive MC to triplet-polaron based interactions (as confirmed by light emission). Oxygen doping is prevalent in P3HT devices processed in air and we investigate the effect of de-doping (by annealing above the glass transition temperature) on the MC of an Au/P3HT/Al diode. De-doping reduces the current through the device under forward bias by ~3 orders of magnitude, but increases the negative (low current) MC from a maximum of -0.5% pre-annealing to -3% post-annealing. This increased negative MC is consistent with bipolaron theory predictions based on Fermi level shifts and density of states (DoS) changes due to de-doping. The decrease in current density is explained by increased injection barriers at both electrodes also resulting from de-doping. Deliberate chemical doping of the P3HT is carried out using pentacene as a hole trap centre. The trapping effect of pentacene is confirmed by reproducible and significant hole mobility-pentacene concentration behaviour, as measured by dark injection (DI) transient measurements. The enhanced carrier injection resulting from the pentacene doping also leads to increased electroluminescence (EL). The resultant MC in pentacene doped devices is strongly dependant on carrier injection and can be significantly enhanced by doping, for example from -0.2% to -0.6% depending on device and drive conditions. Throughout this thesis Lorentzian and non-Lorentzian function fitting is carried out on the measured MC, although the underlying microscopic mechanisms cannot always be discerned.

[1] Hang Gu, Shankui Chang, David Halford, Tingting Zhang, Haizhou Lu, Theo Kreouzis*, William Gillin. "Annealing and doping-dependent magnetoresistance in a single layer poly(3-hexyl-thiophene) organic semiconductor device" *Organic electronics*, 17, no.19 (2015):51

[2] Hang Gu, Theo Kreouzis*, William Gillin. "The transition from bipolaron to triplet-polaron magnetoresistance in single layer organic semiconductor devices" *Organic electronics* 4, no. 36 (2014):1711

P.05 **Hydrazinium metal-formate frameworks of $[NH_2NH_3][M(HCOO)_3]$ (M = Fe^{2+} and Co^{2+}): framework polymorphism, structural phase transitions, and dielectric and magnetic properties**

S Chen, R Shang, Z Wang and S Gao

Peking University, China

The assembly of three simple building blocks, hydrazinium $NH_2NH_3^+$, formate $HCOO^-$ and M^{2+}, resulted in two polymorphs of $[NH_2NH_3][M(HCOO)_3]$ for M = Fe^{2+} and Co^{2+}, **Fe1** and **Co1**, **Fe2** and **Co2**. The perovskite **Fe1** and **Co1** possess anionic NaCl-frameworks of $4^{12}\cdot 6^3$ topology with cubic cavities occupied by the $NH_2NH_3^+$ cations while **Fe2** and **Co2** have chiral metal-formate frameworks of $4^9\cdot 6^6$ topology, with chiral hexagonal channels containing $NH_2NH_3^+$ cations. They all show structural phase transitions above room temperature. The two perovskite members undergo phase transitions around 350 K. The structures change from low temperature (LT) polar phases in space group $P\,na2_1$ to high temperature (HT) non-polar phases in space group $P\,nma$, due to the thermally activated librational movement of the NH_2 end of the $NH_2NH_3^+$ pendulum in the cavity and the significant framework regulation. **Fe2** and **Co2** show phase transitions at 338 K and 380 K, respectively, and the structures change from LT non-polar phases in space group $P\,2_12_12_1$ to polar HT phases in space group $P\,6_3$, triggered by the order-disorder transition of the cations from one unique orientation in LT to three of trigonally-disorder state in HT. The phase transitions are ferro- to para-electric for the perovskite **Fe1** and **Co1**, but antiferro- to ferro-electric for the chiral **Fe2** and **Co2**. The middle size of $NH_2NH_3^+$ and its characteristics in forming H-bonds led to these interesting polymorphs and the phase transitions. The four materials all show long-range-ordering of spin-canted antiferromagnetism, with the Néel temperatures of 19.7 K, 11.7 K, 15.5 K, and 13.9 K for **Fe1**, **Fe2**, **Co1** and **Co2**, respectively. They are possible multiferroics.

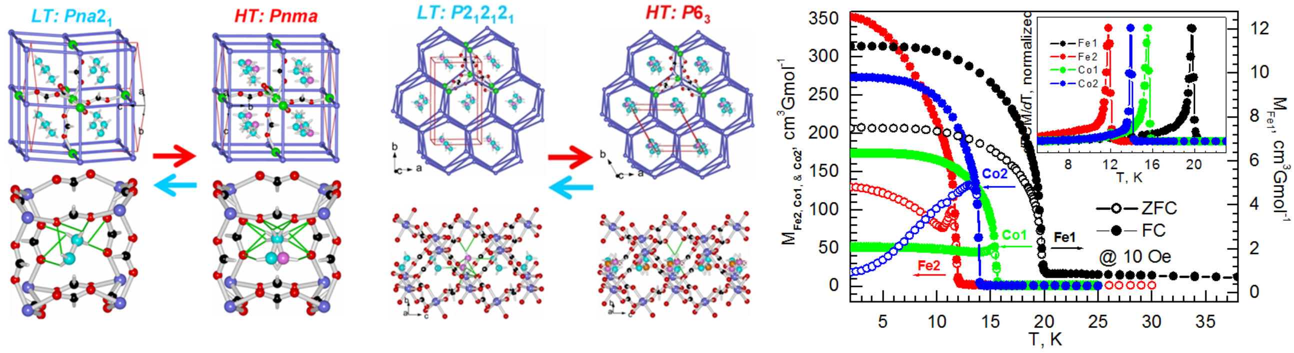

Figure 1. The structures and the phase transitions of **Fe1** and **Co1** (left), and **Fe2** and **Co2** (middle), and the ZFC/FC plots of the four compounds (right).

This work was supported by the NSFC and the National Basic Research Program of China.

[1] Wang, Z.-M.; Hu, K.-L.; Gao, S; Kobayashi, H. *Adv. Mater.* 2010, 1526

[2] Chen, S.; Shang, R.; Hu, K.-L.; Wang, Z.-M.; Gao, S. *Inorg. Chem. Front.* 2014, 83

P.06 **Erbium organometallic single-ion magnets with half-sandwich structure**

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Single-ion magnets (SIMs), which contain only one spin carrier, can exhibit slow magnetic relaxation and/or hysteresis below blocking temperature (T_B). This fascinating property origins from one isolated metal ion and has sparked the developments in studying the magneto-structural correlation and potential application in spintronics. Compared with Dy^{III}, which has half-integer spin ground state (Kramers ion) and large spin-orbit coupling, Er^{III} should also have large possibilities exhibiting SMMs property. However, the examples based on Er are rather scarce. The first organometallic SIM [(COT)Er(Cp*)] exhibiting excellent SIM behavior is reported by Gao et al. encouraged by this work, by controlling the local coordinating environment basically unchanged, we regulate the substituents and coordinated atoms to study their effects on magnetism. Using different substituted tri-(R-pyrazol-1-yl)hydroborates (**1** and **2**), (cyclopentadienyl)tris(dimethyl-phosphito) cobaltate (**3**) and cyclooctatetraene dianion, we successfully obtained three half-sandwich type Erbium complexes. Magnetic study revealed that they are all SIMs. Despite the deviation from C_{3v} point group, **2** shows higher effective energy barrier and blocking temperature, which reminds us that there might not be a simple rule between the structural symmetry and their magnetism.

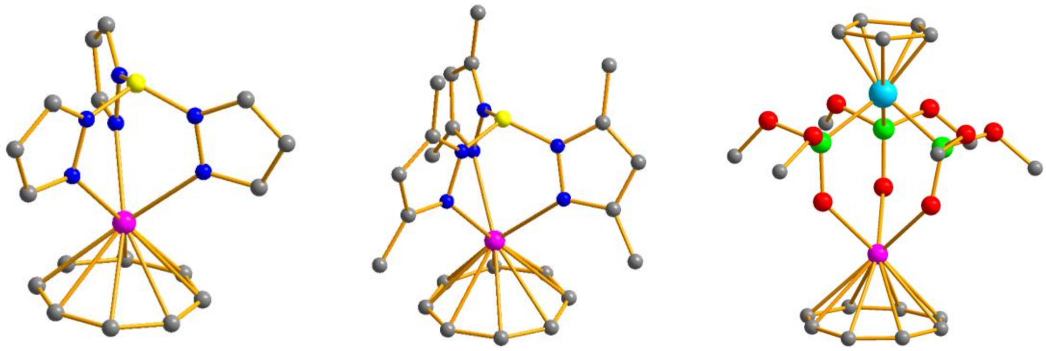

Fig. 1 From left to right, each structure represent $[HB(C_3N_2)_3Er(C_8H_8)]$, $[HB(C_5H_7N_2)_3Er(C_8H_8)]$ and $[(C_5H_5)Co(OP(CH_3)_2)_3Er(C_8H_8)]$.Color code: blue, N; grey, C; yellow, B; pink, Er; red, O; green, P; light blue, Co.

Acknowledgements: We are grateful to the NSFC, the National Basic Research Program of China for financial support.

[1] Jiang, S.-D.; Wang, B.-W.; Sun, H.-L.; Wang, Z.-M.; Gao, S. *J Am Chem Soc* 2011, *133*, 4730

[2] Jeletic, M.; Lin, P.-H.; Le Roy, J. J.; Korobkov, I.; Gorelsky, S. I.; Murugesu, M. *J Am Chem Soc* 2011, *133*, 19286

P.07 **Quantifying long-time thermal relaxation decay in clusters of magnetic particles**

O Laslett[1], S Ruta[2], J Barker[3], G Friedman[4] and O Hovorka[1]

[1]University of Southampton, UK , [2]University of York, UK, [3]Tohoku University, Japan, [4]Drexel University, USA

In this talk we discuss our recent study of the effects of dipolar interactions on the long-time thermal activation in clusters of magnetic nanoparticles. Our work is motivated by the need to understand the properties of inverse problems for developing enhanced magnetic particle detection for applications in biomedicine [1]. Applying the Néel-Arrhenius transition state theory (Figure 1), formulated in terms of coupled many-body master equations, reveals a breakdown of the conventional energy barrier picture depending on the geometrical symmetry of clusters [2], rendering the method inapplicable for sensitive detection. Instead, the resulting magnetization decay is shown to follow the stretched exponential behaviour, with parameters dependent on the geometrical symmetries of clusters. Moreover, the relaxation rates depend considerably on the history of the applied field used to initialize the relaxation process. Combining this symmetry and initialization dependent behaviour could serve for improving the ability to distinguish between particle cluster types, thus enhancing the degree of resolution in magnetic particle detection beyond the standard use of non-interacting particle systems.

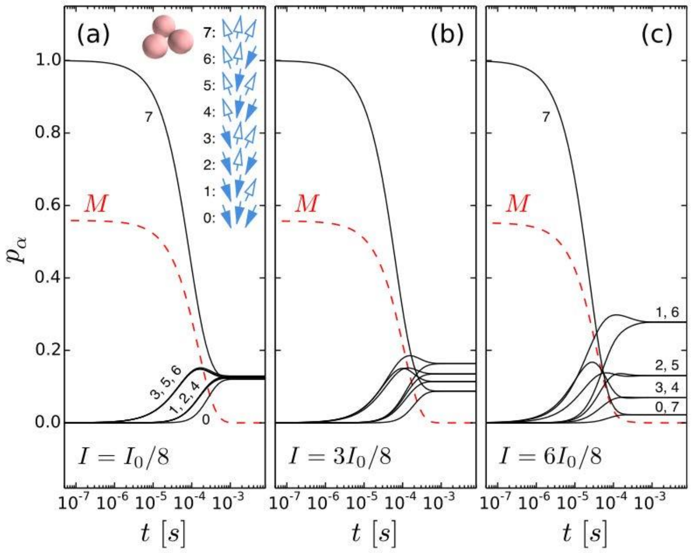

Figure 1: Néel-Arrhenius transition state theory: probability of discrete state configurations over long-time thermal activation

[1] Frank Wiekhorst, Uwe Steinhoff, Dietmar Eberbeck, and Lutz Trahms. Magnetorelaxometry assisting biomedical applications of magnetic nanoparticles. Pharmaceutical Research, 29(5):1189{1202, 2012. ISSN 0724-8741. doi: 10.1007/s11095-011-0630-3. URL http://dx.doi.org/10.1007/s11095-011-0630-3

[2] O. Laslett, S. Ruta, J. Barker, R. W. Chantrell, G. Friedman, and O. Hovorka. Interaction effects enhancing magnetic particle detection based on magneto-relaxometry. Applied Physics Letters, 106(1):012407, 2015. doi: http://dx.doi.org/10.1063/1.4905339. URL http://scitation.aip.org/content/aip/journal/apl/106/1/10.1063/1.4905339

P.08 **SQUID magnetometry measurements of magnetic polynuclear metal clusters synthesised in acetate ionic liquids**

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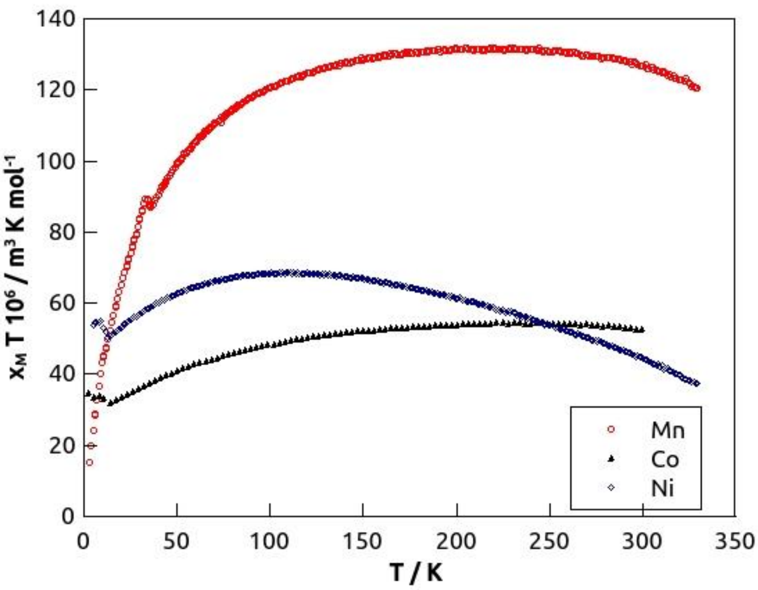
The use of ionic liquids in place of conventional fabrication processes has contributed greatly to the fields of crystal engineering and material chemistry[1,2]. By a simple methodology using dissolutions of transition metal acetates in imidazolium acetate ionic liquids three new polynuclear metal, Ni(II), Co(II) and Mn(II), complexes have been synthesised. In contrast to previous examples for synthesising polynuclear complexes this methodology requires no additional ligands or solvothermal conditions using autoclaves.

Investigation of the formation process of the Ni(II) complex was carried out using UV-Vis spectroscopy and variable temperature ^1H NMR suggesting it to be both temperature and concentration dependent.

The magnetic properties of the three compounds were investigated using SQUID magnetometry. DC susceptibility data were collected on powdered microcrystalline samples of the compounds over the range 2-330K, revealing both ferro- and antiferromagnetic interactions. Using the PHI software package[3] to fit the magnetic data, values for S and g were obtained for the Ni(II) and Co(II) compounds.

This synthetic pathway hence opens up a promising strategy to obtain assemblies with spin-cooperative topologies.



[1] Taubert et al, *Dalton Trans*. 2007, 723-727
[2] Freudenmann et al, *Angewandte Chemie-International Edition*. 2011, *50*, 11050-11060
[3] Chilton et al, *Journal of Computational Chemistry*. 2013, *34*, 1164-1175

P.09 **Organic spintronic field effect transistors**

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The general purpose of a field effect transistor is that a voltage applied to a gate terminal controls the current flowing between two other terminals, the source and drain. The gate voltage should be more effective than the drain voltage in controlling the drain current. In the field of organic spintronics, there has been one report of an attempted organic magnetic FET by Alborghetti et al. [1] but the dimensions used preclude the transistor operation. The characteristics are similar to 'short channel' transistors e.g. the 70 nm channel length devices in Austin et al. [2]. The 'short channel' effect happens in FETs when the channel length (L) is comparable to or less than the gate insulator thickness (D =210nm for SiO_2 insulator and L=80 nm channel length in Alborghetti et al). Consequently, the lateral electric- field (source- drain field) will be larger than the gate field (source-gate field) and thus the characteristics will be similar to those of a diode rather than a FET.

In this work, we demonstrate and present full characteristics of organic spintronic field effect transistor (OS-FET) operated by an electrolyte- gating as shown in Figure 1. The formation of what is so-called the electric double layer (EDL) [3] which is of the order of molecular sizes or few nanometres helps to overcome the short-channel effect in [1].

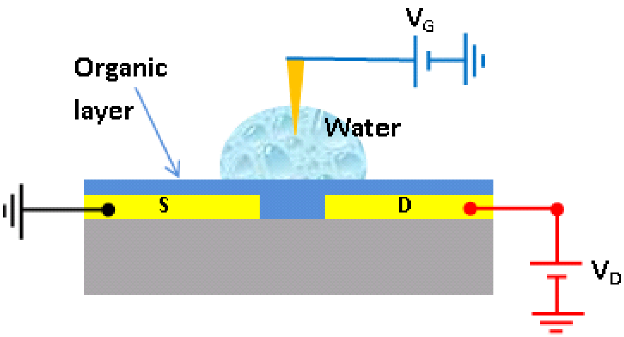

Figure 1: a Schematic of the electrolyte-gated in-plane organic spintronic FET.

[1] Alborghetti, S., J.M.D. Coey, and P. Stamenov, *Electron and spin transport studies of gated lateral organic devices.* Journal of Applied Physics, 2012. 112(12): p. 124510

[2] Austin, M.D. and S.Y. Chou, *Fabrication of 70 nm channel length polymer organic thin-film transistors using nanoimprint lithography.* Applied Physics Letters, 2002. 81(23): p. 4431-4433

[3] Kergoat, L., et al., *A Water-Gate Organic Field-Effect Transistor.* Advanced Materials, 2010. 22(23): p. 2565-2569

P.10 **A dysprosium(III) SMM based on naphthyridine-like ligand**

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Following the prior work focusing on the β-diketone based lanthanide SMMs[1],we synthesized a dysprosium(III) compound{KDy(8-mCND)$_4$(CH_3OH)}$_2$(CH_3OH)$_8$(1)with 8mCND as the N-, O-, chelate ligand(Fig.1, inset). There are two centrosymmetric Dy(III)ions located in the same coordination environment of {O_4N_4} shaping a similar dodechedron. The distance between two closest Dy(III)ions is 10.94 Å.The **1** shows the slow magnetic relaxation at zero dc field(Fig.1). Furthermore, the characterization of the static magnetic property is undergoing.

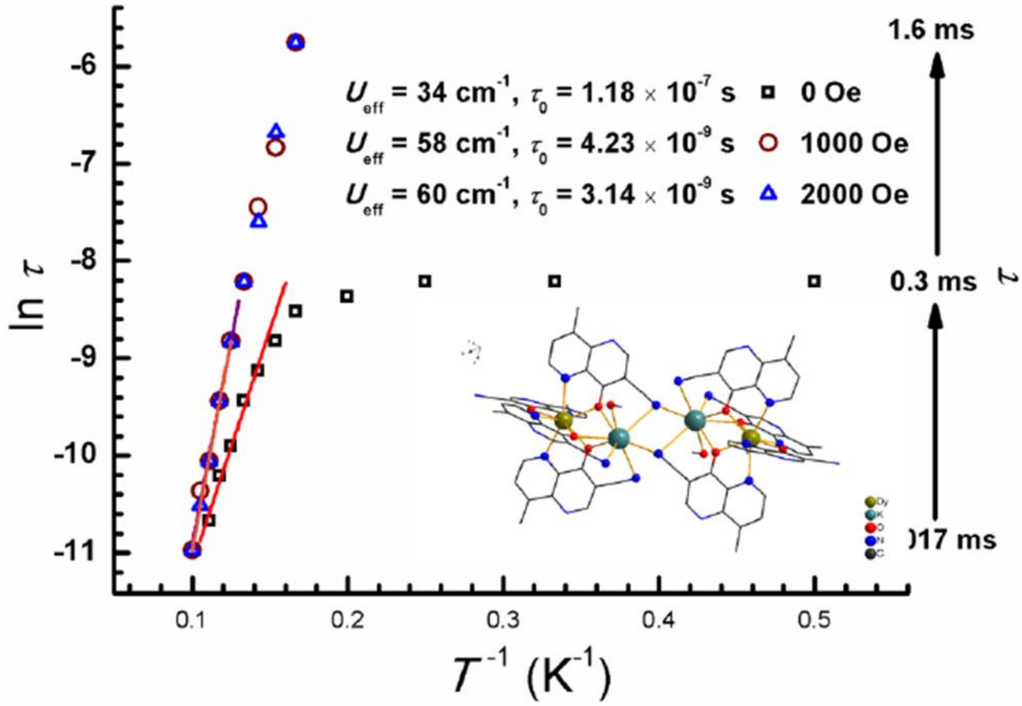

Fig.1 The plots of ln τ *vs*. 1 / *T* are derived and then the *U*eff values were obtained. Inset: The structure of compound 1.Solvent molecules in lattice were omitted.

This work was supported by the NSFC and the National Basic Research Program of China

[1] Jiang, S.;Wang, B.; Su, G.;Wang, Z.; Gao, S. *Angew. Chem., Int. Ed.,* 2010, 49, 7448

P.11 **Novel spin injection into graphene**

J L Warren, G Auton, R Griffiths, E W Hill and T Thomson

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When assessing the suitability of a material for spintronic applications its spin lifetime and diffusion length are important considerations, as they directly impact the performance and efficiency of spintronic devices. Theory predicts exceptional spin-transport in graphene, with expected values of spin lifetime and diffusion length far exceeding those observed in conventional metals. As a result, there has been significant interest in the development of graphene as a spintronic material [1]. Despite observations of record breaking spin transport [2], experimental results are often orders of magnitude below those predicted by theory. A potential cause for the discrepancy is the dwelling of spins underneath contacts. In order to explore this problem, we propose an investigation of spin injection into graphene, specifically the utilisation of a novel method of electrically contacting graphene [3], with the aim of minimising dwell time. A device has been prepared with contacts arranged in a non-local geometry. The room-temperature mobility of this device is about 34,000 $cm^2 V^{-1} s^{-1}$. Initial measurements indicate the successful injection of spin and the detection of spin signals over distances greater than 3 microns.

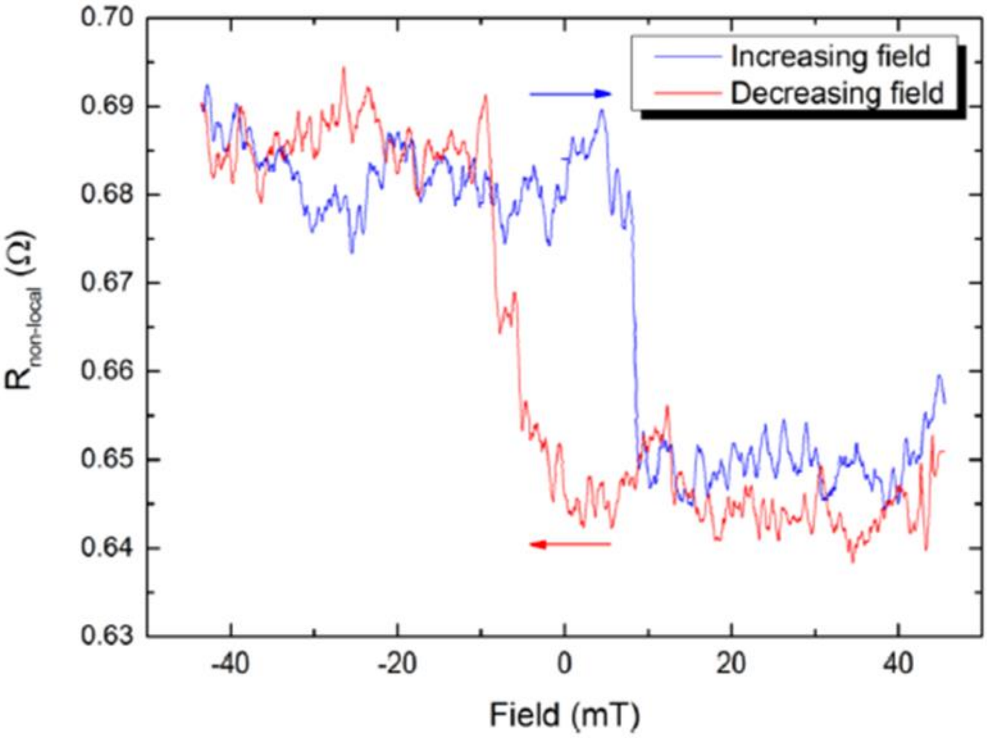


Fig. 1: Non-local spin valve signal for a novel graphene spintronic device. The arrows and line colours indicate the sweep direction of the externally applied magnetic field.

[1] E. W. Hill *et al.* "Graphene Spin Valve Devices" *IEEE Trans. Magn.* 42, 2694 (2006)

[2] N. Tombros *et al.* "Electronic spin transport and spin precession in single graphene layers at room temperature" *Nature* 448, 571 (2007)

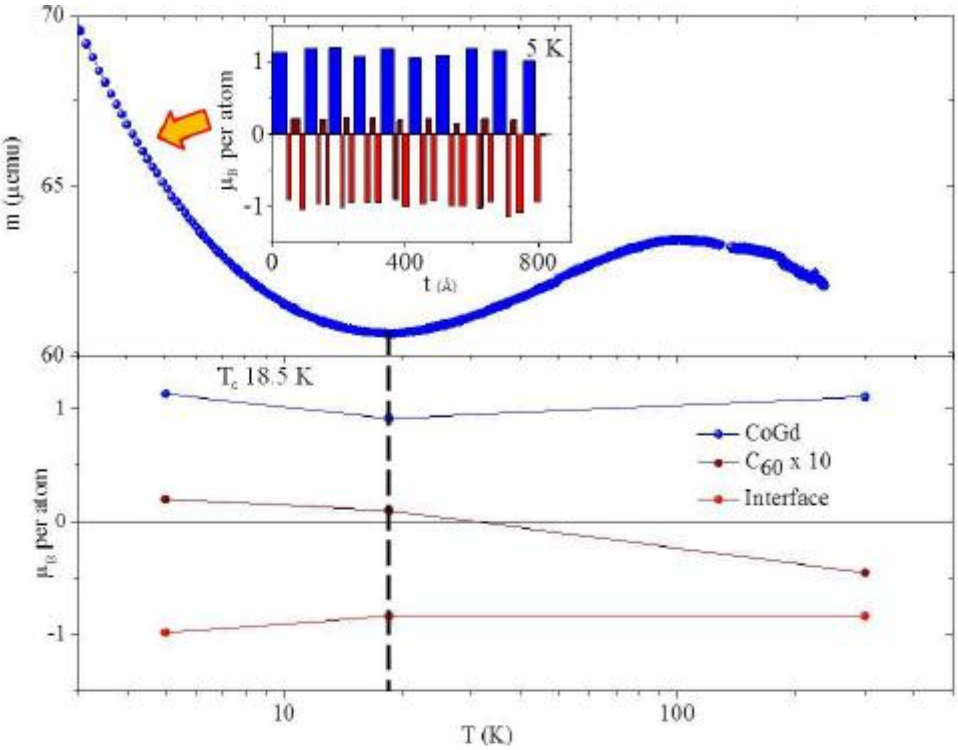
[3] L. Wang *et al.* "One-Dimensional Electrical Contact to a Two-Dimensional Material" *Science* 342, 614 (2013)

P.12 **Spin doping and induced molecular magnetism studied via a ferrimagnetic spin donor**

T Moorsom[1], M Wheeler[1], T M Khan[1], F A Ma'Mari[1], C Kinane[2], S Langridge[2], D Ciudad[3], L Hueso[3], G Teobaldi[4], G Burnell[1], B Hickey[1] and O Cespedes[1]

[1]University of Leeds, UK, [2]ISIS - STFC, UK, [3]CIC NanoGUNE, Spain, [4]University of Liverpool, UK

The behaviour of molecular/metal interfaces is a key consideration for molecular spintronic devices. An important step toward viable molecular spintronic devices is understanding the density, polarization and diffusion length of transferred electrons in these hybrid systems. We present a study into the use of ferrimagnetic spin donors to observe spin doping in C_{60}. The ferrimagnetic alloy CoGd contains both transition metal and lanthanide ferromagnets, antiferromagnetically coupled through RKKY coupling. This alloy can be put into a net zero magnetization, non-zero net polarization state: known as a compensation point. The localization of the 4f shell responsible for ferromagnetism in Gd eliminates the possibility of $4f/p_z$ hybridization such that the C_{60} couples only to the transition metal ferromagnet and can be observed in an environment with net zero background magnetization. Through polarized neutron reflectivity and SQUID magnetometry, we have been able to observe long range magnetic order in C_{60} with a moment per atom on the order 0.01 μ_B as a result of interfacial hybridization which reverses its polarization as the alloy passes through its compensation point. This is indicative of long range coupling mechanisms in molecular solids which go beyond current interfacial models of spin doping in molecules.



Average moment per atom in a superlattice of: [CoGd(5 nm)/C_{60}(5 nm)]x10; probed using polarized neutron reflectivity. Our fitting model comprises bulk CoGd, an interfacial region in which hybridization occurs and a region of bulk molecular solid (inset). The polarization of the bulk molecular region is reversed as the CoGd alloy passes through its compensation point (blue line).

P.13 **Investigation of the magnetic exchange coupling between spin-bearing molecules and ferromagnetic substrates by X-ray photo-emission electron microscopy**

J Girovsky[1], M Buzzi[1], C Waeckerlin[1], D Siewert[1], J Nowakowski[1], M Baljozovic[1], PM Oppeneer[2], F Nolting[1], T A Jung[1], A Kleibert[1] and N Ballav[3]

[1]Paul Scherrer Institute, Switzerland, [2]Uppsala University, Sweden, [3]IISER Pune, India

Adsorption of spin bearing metallo-porphyrins and -phthalocyanines on ferromagnetic substrates leads to an induced magnetic moment in the metal ions of the molecules due to exchange coupling [1]. Such magnetic interaction across the magneto-organic interface can be further modified by introducing a spacer layer [2-4]. In this contribution we demonstrate the possibility to use X-ray photo-emission electron microscopy to study the magnetic exchange coupling between spin-bearing molecules (e.g. Mn-porphyrin) and magnetic substrates. Furthermore, such spectro-microscopy correlation enables not only to study the local magnetic coupling of the molecules, but also their chemical state and the spatial distribution of the respective elements on the sample [5].

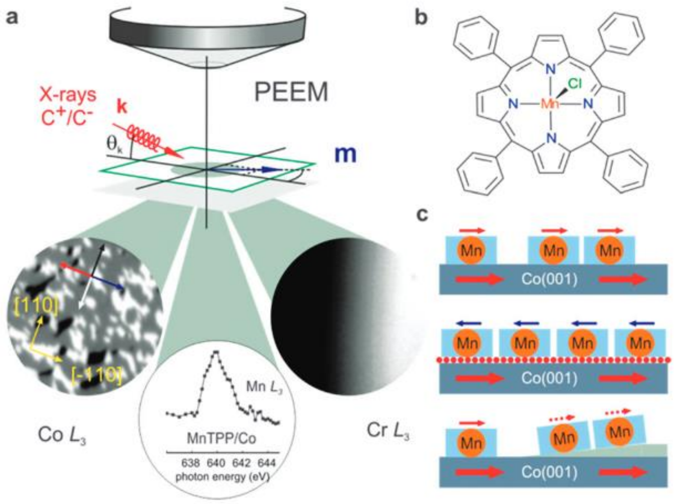


Figure 1. a) Sketch of the experimental setup allowing to gain microscopic (left) spectroscopic (middle) and elemental (right) information. b) Chemical structure of MnTPPCl. c) Graphical representation of the three studied systems.

[1] A. Scheybal et al., Chem. Phys. Lett. 411, 214 (2005)
[2] D. Chylarecka et al., J. Phys. Chem. Lett. 1, 1408 (2010)
[3] M. Bernien et al., Phys. Rev. Lett. 102, 047202 (2009)
[4] C. F. Hermanns et al., Adv. Mater. 25, 3473 (2013)
[5] J. Girovsky et al., Chem. Commun. 50, 5190 (2014)

P.14 **A scanning TMR microscope for magnetic elements in biosensor applications**

K N Vyas[1], D M Love[1], A Ionescu[1], J Llandro[1], P Kollu[1], T Mitrelias[1,2], S Holmes[1,3] and C H W Barnes[1]

[1]University of Cambridge, UK, [2]Cambridge Biomagnetics Ltd., UK, [3]Toshiba Research Europe Ltd., UK

We present a novel tunnel magnetoresistance (TMR) scanning microscope set-up capable of quantitatively imaging the magnetic stray field patterns of micron-sized elements in 3D [1]. The modular design incorporates a commercial TMR sensor, previously used to detect a single magnetotactic bacterium [2], with an optical microscope and piezoelectric stages with nm resolution for XYZ scanning. By employing an Anderson loop [3] for impedance matching before a lock-in amplifier in the measurement circuit, we are able to detect sensor magnetoresistance changes of as little as 0.006% per Oe by measuring the amplitude and the phase of the sensor's impedance. We demonstrate domain imaging of our magnetic barcode structures [4-6] by rastering the TMR sensor in 2D at fixed sample-sensor separation, enabling their complex ferromagnetic domain structures to be revealed (Figure 1).

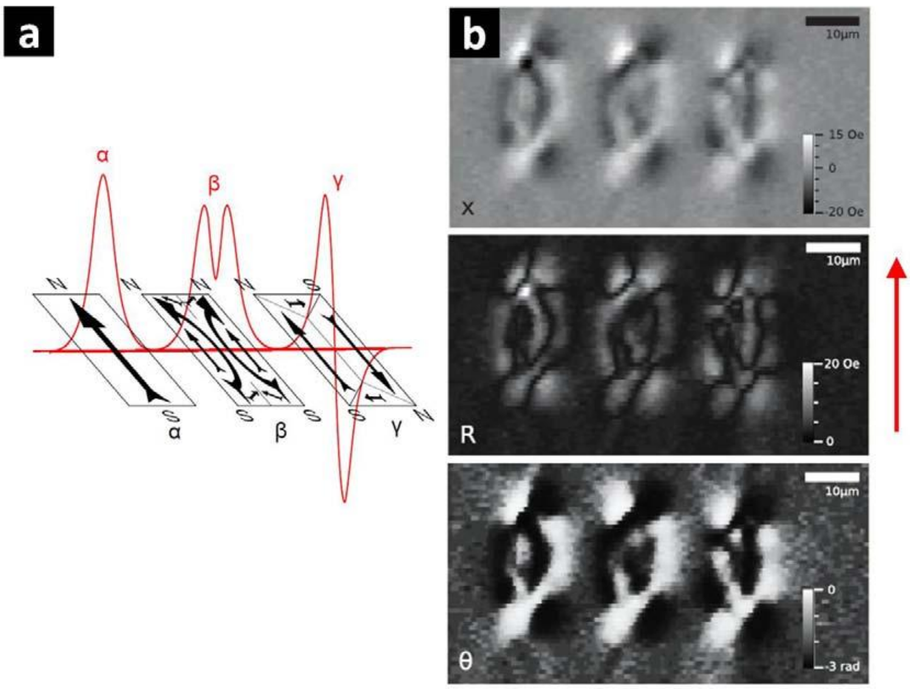


Figure 1: (a) Schematic of three characteristic signal shapes, labelled α, β and γ. The corresponding distribution of edge North (N) and South (S) poles are shown along with the possible domain configurations. (b) Stray field images obtained from the in-phase component (X), the amplitude (R) and the phase (θ) of the signal from a TMR sensor scanned in 2D a few microns below a 3-bit barcode. The sensor detects the stray fields in the direction of the arrow.

The capability of the instrument to produce quantitative measurements of both the amplitude and direction of magnetic stray fields and map them in 3D (by varying the sample-sensor distance) provides significant advantages over other commonly used scanning magnetometry techniques. Furthermore, the ability to incorporate different sensor heads renders the TMR microscope a versatile platform for studying and imaging complex magnetic domain structures of micron-sized entities.

[1] K.N. Vyas, D.M. Love, A. Ionescu, J. Llandro, T. Mitrelias, S.N. Holmes, P. Kollu, C.H.W. Barnes, *Biosensors*, in press (2015)
[2] A. Ionescu, N.J. Darton, K.N. Vyas & J. Llandro, *Phil. Trans. Roy. Soc. A* 368, 4371 (2008)
[3] K.F. Anderson, *IEEE Instrumentation & Measurement Magazine* 1, 5 (1998)
[4] J. R. Jeong, J. Llandro, B. Hong, T.J. Hayward, T. Mitrelias, K.P. Kopper, T. Trypiniotis, S.J. Steinmuller, G.K. Simpson & J. A. C. Bland, *Lab Chip* 8, 1883 (2008)
[5] K.N. Vyas, B. Hong, J.F.K. Cooper, J.J. Palfreyman & C.H.W. Barnes, *IEEE Trans. Magn*. 47, 1571 (2011)
[6] K.N. Vyas, J.J. Palfreyman, D.M. Love, T. Mitrelias & C.H.W. Barnes, *Lab Chip* 12, 5272 (2012)

P.15 **The photoexcited μSR technique probes of electronic state of excited molecules**

K Yokoyama[1], A Drew[1], J Lord[2], P Murahari[1], K Wang[1], P Heathcote[1], M Willis[3] and I Schultz[3]

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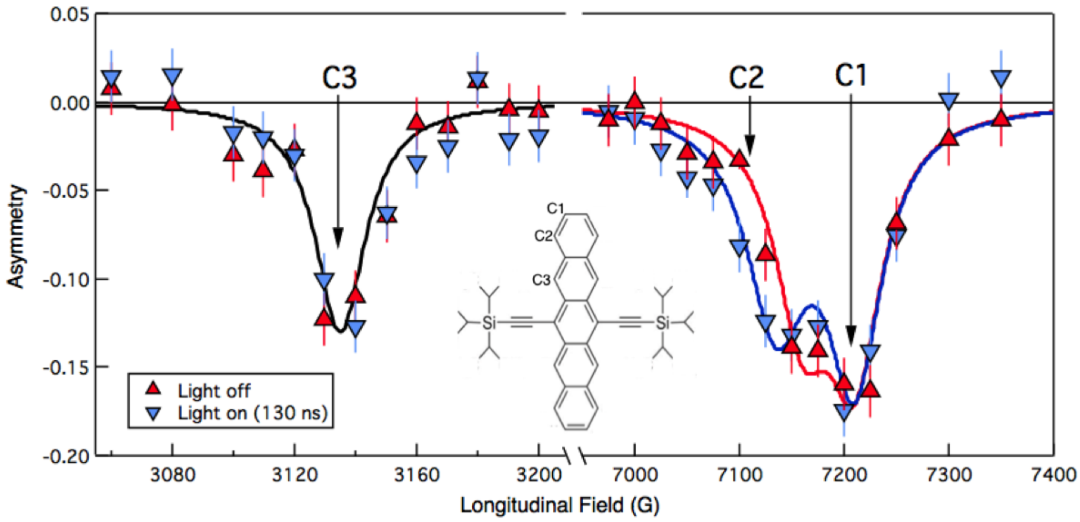
The photo-μSR technique combines the standard muon spin relaxation spectrometer with a high-intensity laser to photoexcite samples to investigate their dynamics. We have developed such a laser system on the HiFi muon spectrometer in ISIS, UK to explore the photoexcited materials using the avoided level crossing (ALC) method, which is an extremely sensitive probe of spin dynamics of organic molecules. Recently we have performed an experiment on TIPS-pentacene, with the motivation of studying exciton dynamics with spatial and temporal resolution. As can be seen from Figure 1, we have observed a significant light-induced change in amplitude of one of the ALC resonances, corresponding to the muonium (Mu) adding to the C2 atom on the backbone (see inset to Figure 1). The timescale of this light-induced change is found to correspond to two known transient species, a transient dimer with a timescale of a little less than 1 μs and a triplet exciton with a 6.5 μs lifetime. We note that the timescales measured with muons agree well with those extracted by transient photo-absorption spectroscopy. Based on the light-induced changes, we have interpreted the ~1 μs timescale signal as a photochemical modification of the chemical reactivity of the molecule and muonium, a hydrogen-like species.



C60 / graphite

P.16 **Phase diagram of a semimetal in the magnetic ultra-quantum limit**

A Isidori[1], F Arnold[1], E Kampert[2], B Yager[1], M Eschrig[1] and J Saunders[1]

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Semimetals like graphite have recently received compelling interest as they not only are able to host topologically non-trivial phases but also can be driven into the ultra-quantum limit by magnetic fields now achievable in modern-day laboratories. Thus, they provide insight into quantum-Hall physics and the physics of massless Dirac fermions in three dimensions. They also represent ideal model systems for studying magnetic-field driven density wave instabilities, as the onset field for such collective excitations is suppressed in semimetals. Using pulsed high-magnetic fields up to 60 T applied to a single crystal of natural Tanzanian graphite, we find a series of field-induced phase transitions into collinear charge-density wave states resulting from enhanced interactions between the lowest four Landau levels. By analysing magneto-transport data and calculating the renormalized Landau level structure at high fields, we establish the phase diagram of graphite in its ultra-quantum limit. Our results imply the existence of a topologically-protected chiral edge state at high fields supporting both charge and spin currents.

Domain walls

P.17 **Injection of 360 degree domain walls in magnetic nanostructures via MFM tip**

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Imperial College London, UK

Domain walls (DWs) in magnetic nanostructures have long been a subject of much interest[1]. The majority of work so far has focused on 90° and 180° DWs. However, recently the field has seen promising developments in 360° DWs, stable topological defects consisting of two strongly-coupled 180° DWs of opposite chirality[2].

360° DWs have several unique properties. They are stationary under applied magnetic fields[3], interact interestingly with spin-waves4 and have a small stray field, desirable for systems such as racetrack memory[4].

Current methods for generating 360° DWs rely on fabricating injection structures and applying rotating fields[5] or current pulses[6]. These techniques have several drawbacks including additional nanofabrication steps and the application of global magnetic fields.

We present a novel method for injecting 360° DWs into nanowires via MFM tip. Experimental evidence is presented from MFM images and supported by micromagnetic simulations (example below). The method avoids fabricating injection structures and global field/current application. Additional benefits include localised injection via precise tip positioning and chirality selection of injected DWs.

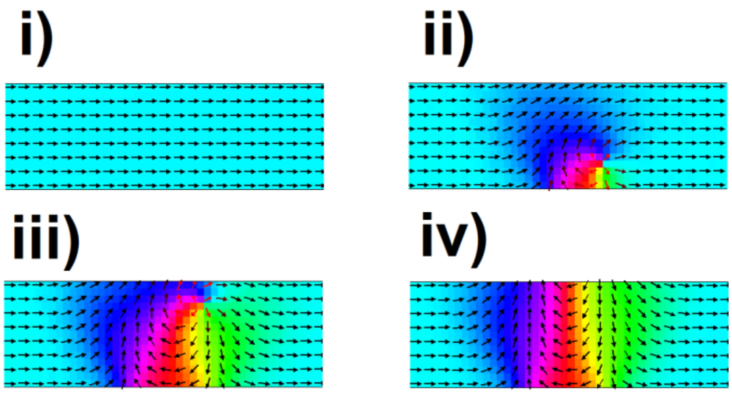


Figure 1: Micromagnetic simulation showing 360° DW injection process. An initially homogenous nanowire i) has an MFM tip scanned over it ii)-iii) resulting in a stable 360° DW after the tip has passed iv)

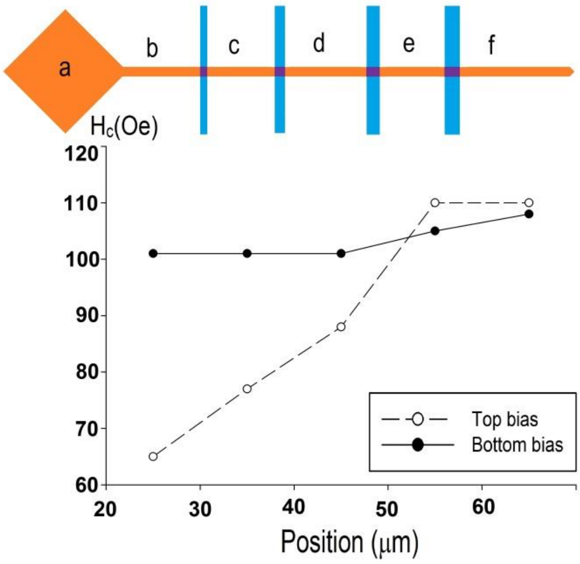
[1] Kläui, M. – JOP: Cond. Matt. 20(31), 2008
[2] McMichael, R.D. and Donahue, M.J - IEEE Trans. Mag. 33(5), 1997
[3] Mascaro, M. D. and Ross, C. A. – PRB 82(21), 2010
[4] Roy, P.E., Trypiniotis, T. and Barnes, C. H. W. – PRB 82(13), 2010
[5] Diegel, M. Mattheis, R. and Halder, E. – IEEE Trans. Mag. 40(4), 2004
[6] Oyarce, A. L., Llandro, J. and Barnes, C.H.W. – APL 103(22), 2013

P.18 **Racetrack memory using exchange bias**

I Polenciuc[1], A J Vick[1], D A Allwood[2], T J Hayward[2], G Vallejo-Fernandez[1], A Hirohata[1] and K O'Grady[1]

[1]University of York, UK, [2]University of Sheffield, UK

The pinning of domain walls in ferromagnetic (F) wires is one possible technique for the creation of a solid state magnetic memory [1]. Such a system has been under consideration for some time but one of the main limitations is the control and non-uniformity of the domain wall pinning. Techniques such as the lithographic definition of notches and steps in the substrate have had some success in creating local pins but have the disadvantage of being expensive to fabricate and the reproducibility of the domain wall pinning strength is limited. In this work we report on an alternative strategy to create pins of reproducible strength using crossed ferromagnetic and antiferromagnetic (AF) wires such that exchange bias can be introduced at the crossing points. Such a system has the advantage of ease of fabrication and creating domain wall pins of controlled strength by varying the width of the AF wire. We have achieved domain wall pinning field strengths of up to 37 Oe in a system where the AF wire is deposited above the F wire which is comparable to the values achieved using notches.



[1] S.S.P. Parkin, M. Hayashi, L. Thomas, Science 320, 190 (2008)

P.19 **Micromagnetic simulations of DW states and dynamics in rare earth doped NiFe nanowires**

T J Broomhall, D A Allwood and T J Hayward

University of Sheffield, UK

Many proposed devices are dependent on the propagation of Domain Walls (DW) through soft-ferromagnetic nanowires. However, at higher velocities DWs become unstable and undergo Walker-Breakdown (WB), causing oscillations of their internal magnetisation structure and a decrease in velocity. These effects give rise to stochastic pinning behaviours[1], thus reducing the efficiency and effectiveness of devices.

Here we employ micromagnetic simulations to explore how DW behaviour changes when nanowires are doped with rare-earth elements. We use values of the Gilbert damping factor (α) and MS found for holmium[2], with the aim of stabilising propagation dynamics. We investigate how the stabilities of both transverse and vortex DWs are affected by changing α. We then go on to probe how changing α affects the stability of the magnetisation structure of a propagating DW.

We find that with an increasing α, the WB critical field is greatly increased thereby suppressing the stochasticity associated with the WB regime. We also show that as a result of this, the upper speed limit of the linear regime, Figure 1, can be greatly enhanced by rare earth (RE) doping. Also that DW Pinning can be supressed from a multi-modal process to a singular mode by RE inclusions.

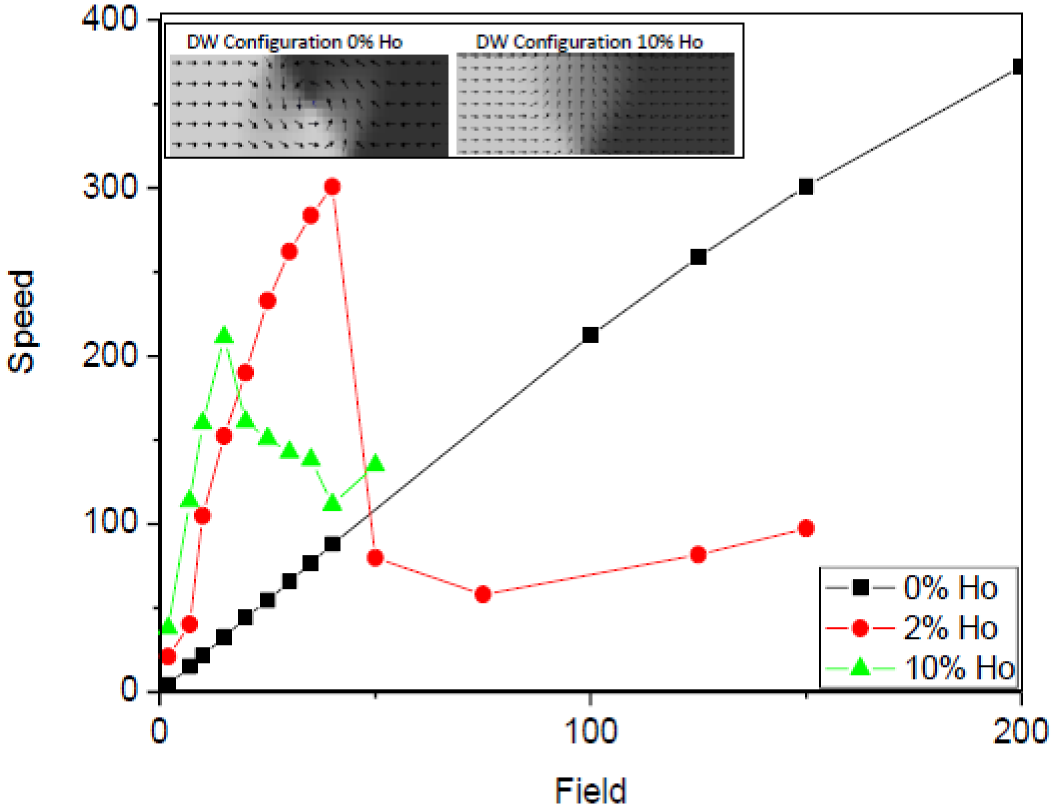


Figure 1. Plot showing average speed of DW in a permalloy nanowire with a series of damping values. Inset shows most stable ground stable for 0% Ho and 10% Ho.

[1] *Phys. Rev. B* 84, 024426 (2011)
[2] *Phys. Rev. B* 82, 094445 (2010)

P.20 **Measuring Dzyaloshinskii-Moriya interaction (DMI) in Ta/CoFeB/MgO thin films**

R A Khan, C H Marrows and T A Moore

University of Leeds, UK

Ta/CoFeB/MgO is an interesting system in which to study magnetic domain wall motion [1] and is technologically relevant as it is used as an electrode in tunnel junctions [2]. The goal of this study is to measure Dzyaloshinskii-Moriya interaction (DMI) in perpendicularly magnetized Ta/CoFeB/MgO using a field-driven domain wall creep method [3]. Using field alone avoids the possibility of mixing with current-related effects. We also wish to understand the effect of annealing temperature on the DMI.

The SiO_2/Ta(5nm)/$Co_{20}Fe_{60}B_{20}$(0.8nm)/MgO(2nm)/Ta(5nm) as-grown film has “line” domains (Figure 1(a)) that annihilate at a field of about 15 Oe.

The same film annealed at 250 °C for 2 hours has “bubble” domains (Figure 1(b)) whose expansion in an in-plane field (and small out-of-plane field) depends on the directions of the in-plane field, the DMI, and the in-plane easy axis induced during annealing.

Plots of domain wall velocity as a function of θ, where θ is the angle between the velocity vector and the in-plane field, are well fitted by an expression with terms representing the DMI and induced anisotropy (Figure 1(c)). This enables the DMI to be evaluated, even in such soft amorphous films.

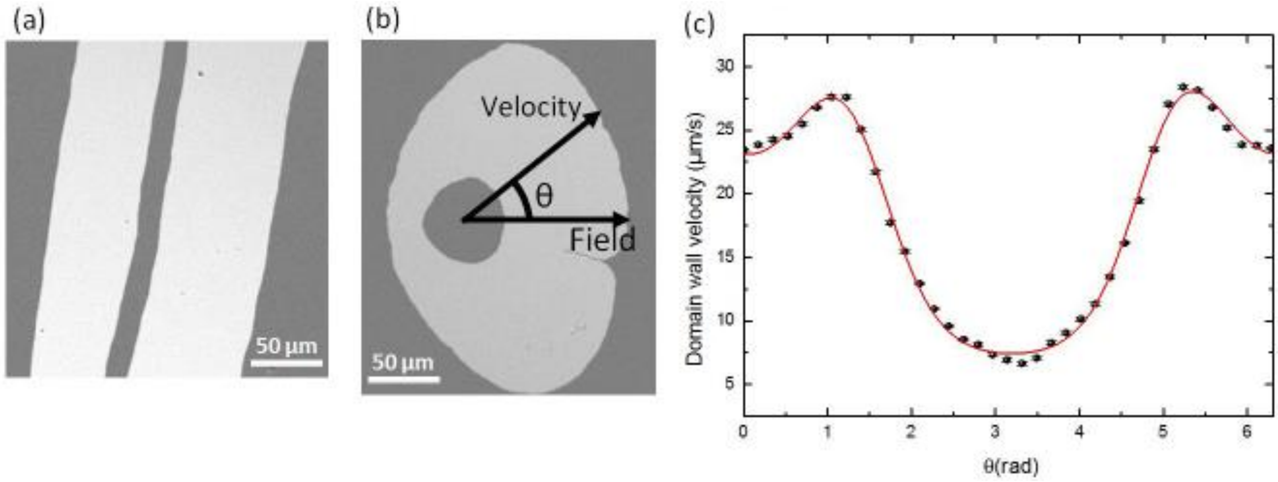


Figure 1: Kerr microscope difference images of (a) “line” domains in as-grown, and (b) “bubble” domains in 250 °C annealed films of Ta/CoFeB/MgO. (c) Domain wall velocity vs θ plot corresponding to image (b). Here, θ is the angle between the velocity vector and the in-plane field. The solid line corresponds to the fit expression.

The work was funded by Marie Curie ITN WALL.

[1] Lo Conte R *et al* 2014 *Appl. Phys. Lett.* 105 122404; Lo Conte R *et al Phys. Rev. B* (in press)

[2] Zhao W S, Devolder T, Lakys Y, Klein J O, Chappert C and Mazoyer P 2011 *Microelectronics Reliability* 51 1454

[3] Hrabec A, Porter N A, Wells A, Romero M J, Burnell G, McVitie S, McGrouther D, Moore T A and Marrows C H 2014 *Phys. Rev. B* 90 020402(R)

P.21 **Effects of deposition temperature on the creep velocity of epitaxial Co/Pt**

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University of Leeds, UK

Co/Pt is of great interest for the study of the physics of domain walls and spin torque[1,2]. In our investigation, we turn to epitaxial samples of $\mathrm{Pt(30Å)/Co(7Å)/Pt(10Å)}$ in order to study the effects of structure on magnetic properties[3]. Here, we demonstrate control of the crystallographic order through variation of the temperature of bilayer deposition and its effects on the magnetic properties. Using X-ray reflectometry, we find that as deposition temperature is increased, within the range of 100°C to 300°C, the intermixing between layers increases by 50% whilst the roughness diminishes by a factor of 2. These structural changes have the effect of increasing the coercivity of the samples by up to 20mT whilst decreasing their anisotropy by 200mT, as found through magneto-resistance measurements. The net result is that samples grown at 300°C, whilst having the lowest creep velocity, experience the largest velocity change with a change in field.

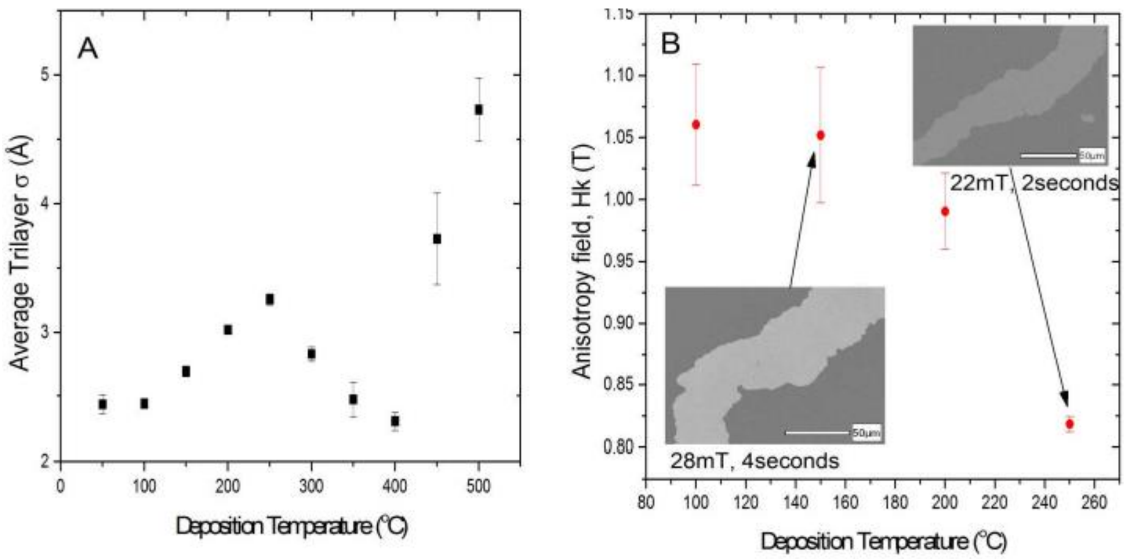

Figure 1: A) The effect of varying the temperature during top Co/Pt layer deposition on the roughness-intermixing, σ, averaged over the Pt/Co/Pt trilayer interfaces (A) and the anisotropy field (B). Kerr microscopy images used to measure creep velocity have been included in B alongside their propagation field pulse strength and duration.

[1] I. Miron et al., Nature Mat. 10, 419 (2011)

[2] L. Liu et al., Phys. Rev. Lett. 109, 096602 (2012)

[3] A. Mihai et al., App. Phys. Lett. 103, 262401 (2013)

P.22 Lorentz imaging of Domain wall motion in fabricated nanowires

R Lamb

University of Glasgow, UK

A driven gravitational pendulum is a well known example of a simple resonant system. An analogous situation can be realised for a domain wall in a curved magnetic nano-wire where a magnetic field, oriented normal to the curvature, provides the restoring force and an alternating electric current is used to drive the wall displacement [1].

Such a system provides an ideal opportunity to investigate the efficient current induced motion of domain walls and aspects of their dynamics during propagation. It has been reported that when driving at resonance there is a significant increase in linear momentum transfer to the domain wall, which dominates over the more usually considered terms of the spin transfer torque. Currently we are performing micromagnetic simulations to model such a system and to guide our experimental investigations. Direct imaging of DW motion in fabricated nanowires will be performed using the Lorentz modes of Transmission Electron Microscopy (TEM). Initially, time averaged imaging will provide measurement of the amplitude of domain wall displacement and insight into aspects of the motion dynamics. Long term our ambition is to develop and apply time-resolved Lorentz imaging in order to uncover the full dynamics of such a system.

[1] Nature 432, 203-206 (11 November 2004)

Dynamics

P.23 **Ferromagnetic resonance measurements of multilayer films using a Vector Network Analyser**

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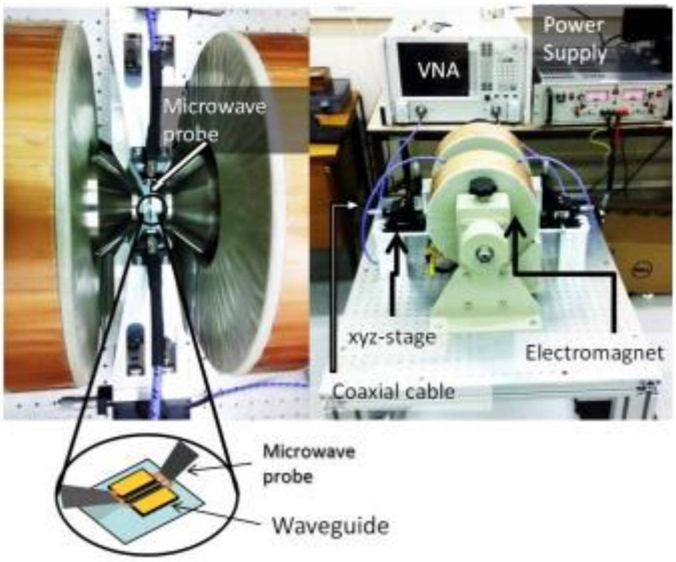
University of Manchester, UK

Ferromagnetic resonance (FMR) is a spectroscopic measurement technique in which the precessional motion of magnetisation is excited and measured. The availability of Vector Network Analyser (VNA's) allows this technique to be applied to magnetic thin films and nanostructures using co-planar waveguides. In this poster, I will describe the construction and characterisation of a VNA based FMR system. The measurements of short-timescale behaviour from this system will be useful in understanding intergranular exchange coupling and dynamic processes such as domain formation.

Initial tests on thin Co films have been performed and will be presented. The next step is to use the instrument to study two sets of thin magnetic structures. These are (i) exchange spring CoCrPt-SiOx films for perpendicular recording media and (ii) hybrid anisotropy Co/Pd-NiFe films which have recently been shown to have considerable potential as vortex oscillators when patterned to micron sized elements[1].

FMR measurements will provide new insight into the magnetic properties of the system both in terms of anisotropy, and importantly for spintronics applications, how the engineered systems affect the damping parameter.



[1] G. Heldt, M. T. Bryan, G. Hrkac, S. E. Stevenson, R. V. Chopdekar, J. Raabe, T. Thomson, and L. J. Heyderman, "Topologically confined vortex oscillations in hybrid [Co/Pd]8-Permalloy structures," *Appl. Phys. Lett.*, vol. 104, no. 18, p. 182401, May 2014

P.24 **Magnetisation dynamics of confined magnetic nanostructures controlled by voltage-induced mechanical strain**

S Bowe[1], R Beardsley[1], D Parkes[1], A W Rushforth[1] and S A Cavill[2,3]

[1]University of Nottingham, UK, [2]Diamond Light Source, UK, [3]University of York, UK

Magnetic nanostructures containing flux closure and vortex domain configurations have potential applications including information storage technologies and spin torque oscillators. The magnetisation dynamics of confined magnetic structures can be complex and consist of standing wave modes in regions with uniform magnetisation, oscillations of the domain wall structure[1] and gyration of the vortex core[2].

In our recent work we demonstrated how voltage induced strain can be used to significantly modify the configuration of magnetic flux closure domains in structures fabricated using $Fe_{81}Ga_{19}$[2]. Here we present investigations of the effects of a strain-induced uniaxial magnetic anisotropy on the magnetisation dynamics of $Fe_{81}Ga_{19}$ square structures in the flux closure configuration. Using time-resolved XMCD PEEM and micromagnetic simulations we find that the induced anisotropy modifies the precession frequency of the uniform magnetic regions, the oscillations of the domain wall structure, and the gyration of the vortex core (Figure 1).

Our investigations show that inverse magnetostriction provides a promising route for tuning significantly the complex magnetisation dynamics of magnetic nanostructures.

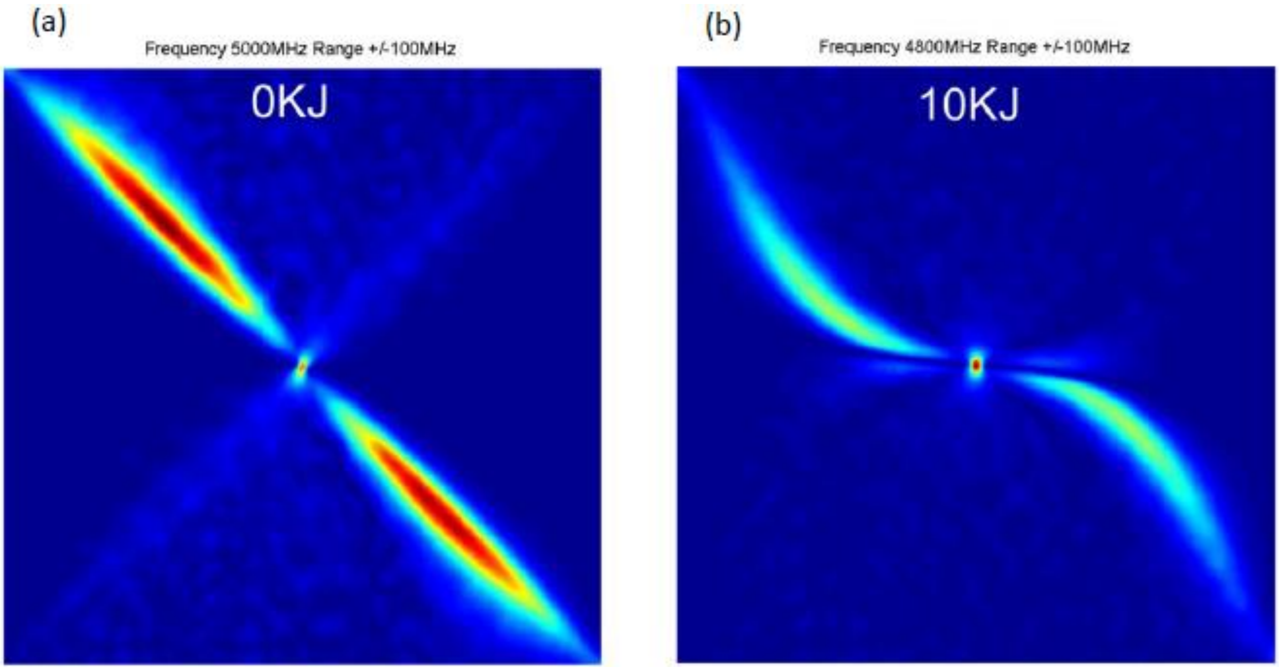


Figure 1. Spatial character of the approx.. 5GHz mode of the x component of magnetisation in a 500nm square with uniaxial anisotropy a (a) 0kJm^{-3} and (b) 10kJm^{-3} along x.

[1] Bailleul et al., Phys. Rev. B 76, 224401 (2007)
[2] Parkes et al., Appl. Phys. Lett. 105, 062405 (2014)

P.25 **Dispersive read-out of ferromagnetic resonance in strongly coupled magnon-microwave photon system**

J A Haigh[1], N J Lambert[2], A C Doherty[3] and A J Ferguson[2]

[1]Hitachi Cambridge Labs, UK, [2]University of Cambridge, UK, [3]University of Sydney, Australia

We demonstrate the dispersive measurement of ferromagnetic resonance in an yttrium iron garnet sphere embedded within a microwave cavity. Conventional ferromagnetic resonance (FMR) measures how the complex susceptibility tensor depends on frequency and magnetic field. By contrast, and enabled by a strong magnon-photon coupling, here we demonstrate off-resonant dispersive detection of FMR. Rather than measuring directly the susceptibility, we measure the change in longitudinal magnetization under resonant driving via a cavity frequency shift. Our measurement is inspired by circuit QED, where a related dispersive measurement has been central to the measurement of superconducting qubits [1], but in the context of recent work on this coupled magnet-cavity system [2-3]. Figure 1 shows an example of this dispersive measurement, a probe tone phase shift as a function of drive tone frequency with the two modes significantly detuned. We present results on the dispersive readout as a function of detuning between cavity and FMR mode frequencies and of drive and probe tone power.

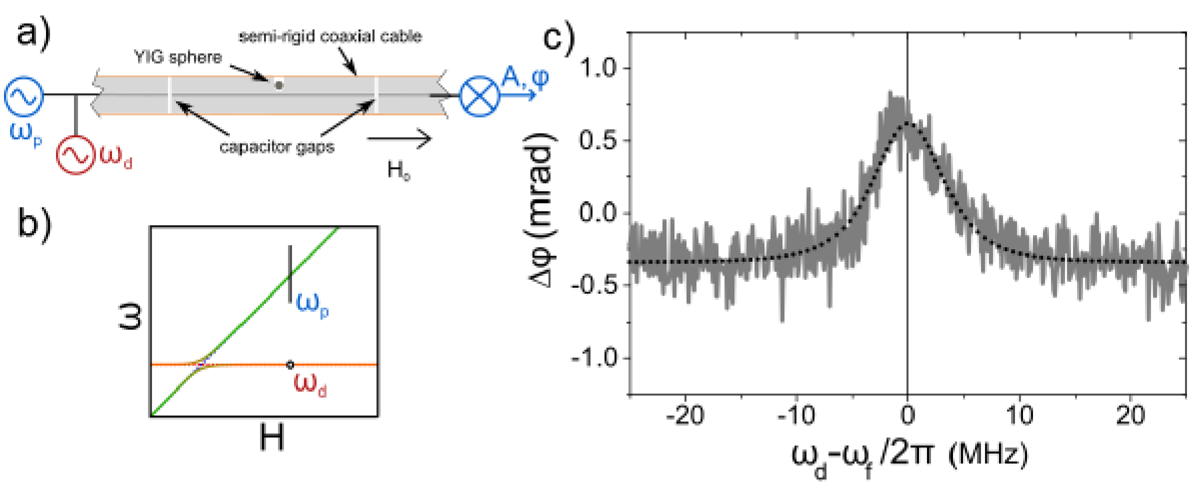


Figure 1: a) Schematic of the semi-rigid coaxial resonator with YIG sphere inside. Probe tone ωp and mixing are provided by a vector network analyzer (blue) while FMR drive tone ωd is from a separate microwave source (red). b) Reference map of the measurement region over the modes (FMR: green, cavity: orange) of the system c) Probe phase shift as a function of and drive frequency. Probe frequency is fixed at resonance frequency of the cavity, ≈3.55 GHz, as indicated in b).

[1] Majer, J. *et al.* Coupling superconducting qubits via a cavity bus. *Nature* 449, 443–447 (2007)

[2] Zhang, X *et al*. Strongly Coupled Magnons and Cavity Microwave Photons. *Phys. Rev. Lett.* 113, 156401 (2014)

[3] Tabuchi, Y. *et al.* Hybridizing Ferromagnetic Magnons and Microwave Photons in the Quantum Limit. *Phys. Rev. Lett.* 113, 083603 (2014)

P.26 **Understanding the thickness dependence of Gilbert damping in ferromagnetic thin films with non-magnetic capping layers**

S Azzawi[1], A Ganguly[2], J A King[1], J Sinha[2], A T Hindmarch[2], A Barman[2] and D Atkinson[2]

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Magnetisation dynamics in thin-film magnetic multilayers may be significantly influenced by interfaces with non-magnetic (NM) metal layers via effects such as spin-pumping or strong spin-orbit coupling effects. Understanding these influences is of vital importance in realising low-energy spintronic and magnonic devices utilising magnetisation precession and ultra-fast switching processes [1, 2].

Bilayer thin-films of Co/Pt, Co/Au, NiFe/Pt and NiFe/Au with varying thicknesses of the NM capping layer were fabricated by magnetron sputtering. Magnetisation precession was studied using time resolved magneto-optical Kerr effect (TR-MOKE) magnetomtery to detect ultra-fast magnetization processes in the time-domain. Experimental results were fitted and interpreted within the framework of the Landau-Lifshitz-Gilbert equation to extract the phenomenological Gilbert damping constant, α. The dependence of the damping parameter on NM layer thicknesses was determined for layer thicknesses ranging from 2 Å up to 20 Å. The figures show examples of the background corrected TR-MOKE signals for a series of Co/Pt bilayers, and the NM thickness dependence of damping parameter for a Pt capping layer. The xomplex non-monotonic thickness dependence of the damping parameter observed is in good qualitative agreement with very recent theoretical predictions [3].

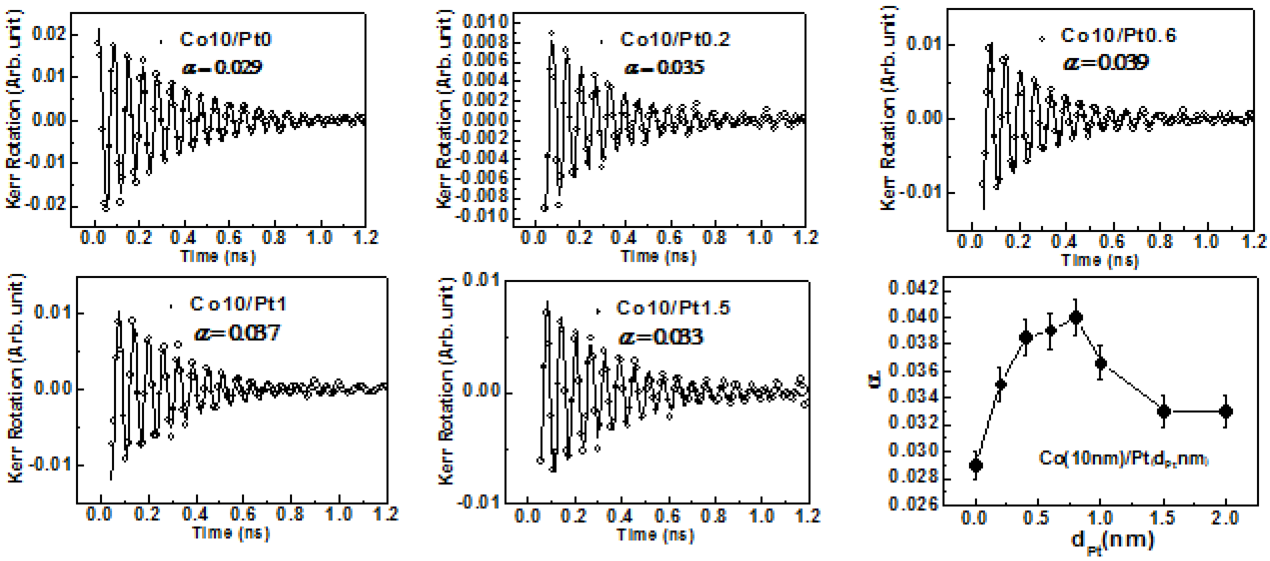

Figure (1): Damping parameter α as a function of capping layer thickness for Co(10 nm)/Pt (t_{Pt}) bilayers, with precession frequency ~16 GHz.

[1] Hillebrands, B. (2003). *Spin dynamics in confined magnetic structures II*. Springer

[2] Iihama, S., Mizukami, S., Naganuma, H., Oogane, M., Ando, Y., & Miyazaki, T. (2014). Gilbert damping constants of Ta/CoFeB/MgO (Ta) thin films measured by optical detection of precessional magnetization dynamics.*Physical Review B*, *89*(17), 174416

[3] Barati, E., Cinal, M., Edwards, D. M., & Umerski, A. (2014). Gilbert damping in magnetic layered systems. *Physical Review B*, *90*(1), 014420

P.27 Thickness, crystallinity and single interface contribution to ferromagnetic resonance of polycrystalline co thin-films

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[1]Durham University, UK, [2]Universidade do Porto, Portugal, [3]University of Perpignan Via Domitia, France

The magnetization dynamics of thin ferromagnetic films have attracted much interest in the field of magnetic memory devices. In the ferromagnetic layer, a precession of the magnetization causes a spin current which propagates through the interface into the nonmagnetic Cu seed and into the caping layer [1]. This spin pumping increases the relaxation of the magnetization in the ferromagnetic layer, thus enabling faster switching processes [2].

We present room temperature magnetization dynamics of sputtered polycrystalline Co thin films in a wide range of thicknesses capped with either nonmagnetic Cu or Ir. The magnetic behaviour was measured using broadband ferromagnetic resonance (FMR). The resonance field and linewidth were measured as a function of the Co layer thickness. The Gilbert damping was observed to increases with decreasing Co film thickness for both series of films. Mizukami et al. [3] showed that the ferromagnetic resonance linewidth of NiFe sandwiched between metallic non-magnetic layers depends on the material of these cladding layers. Materials with strong spin-orbit coupling, such as Ir, which results in a higher spin flip scattering causes a broadening of the linewidth. This is explained by spin injection into the adjacent normal metal by a ferromagnetic layer with moving magnetization. This spin current which is pumped by the precessing magnetization is subject to spin-flip scattering in the normal metal, adding to the damping.

The ferromagnetic linewidth of thin films is related to the damping and can be described as a sum of two terms; intrinsic contribution due to Gilbert damping and extrinsic contribution due to two magnon scattering. Both of these contributions exhibit similar thickness dependence; characterized by a large increase for cobalt layers thinner than 10 nm. Above 10 nm, the behavior of both intrinsic and extrinsic contributions to the damping are constant. As the cobalt thickness is reduced, particularly below 10nm, the ratio between surface to volume increases and the extrinsic contribution (two-magnon scattering) is more significant and plays a dominant role in determining to the linewidth.

[1] Y. Tserkovnyak, A. Brataas, G.E.W. Bauer, Phys. Rev. Lett. 88 (2002) 117601; B. Heinrich, R. Urban, G. Woltersdorf, IEEE Trans. Magn. 38 (2002) 2496

[2] M. Charilaou, K.Lenz, W.Kuch, JMMM 322 (2010) 2065 – 2070

[3] Mizukami et al. JMMM 226-230 (2001) 1640 – 1642

P.28 Time-resolved holographic imaging of magnetic vortex dynamics

N Bukin[1], F Ogrin[1], G van der Laan[2], E Burgos Parra[1], C McKeever[1], R Hickin[1], P Keatley[1], G Beutier[3], M Dupraz[4] and S Cavill[5]

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X-ray Holography with extended reference by autocorrelation linear differential operation (HERALDO) holds great promise for imaging magnetic materials at the nano-scale [1]. In particular it has been demonstrated recently that in-plane magnetised thin films can be imaged with much greater ease and stability than similar techniques such as Fourier Transform Holography (FTH). Here we report our first experiments on using the HERALDO to obtain time-resolved measurements. As an object of study we used magnetic vortex structures formed in 2μm x 2μm permalloy magnetic elements. Experiments were performed at ESRF using 16 bunch mode x-ray filling pattern. The aim of the experiments was to excite the vortex core gyration with a magnetic pulse and image different phases of gyration in a stroboscopic regime. The RF excitation of the vortex core was achieved with a CPW antennae integrated directly on top of the magnetic elements. By using different delay times between the pump and the probe allowed us to image the dynamics of the core within the sample at different stages of time from the point of excitation. We aim to further develop this technique to be used on other, more exotic dynamic magnetic structures.

[1] T. A. Duckworth, Feodor Y. Ogrin, Guillaume Beutier, Sarnjeet S. Dhesi, Stuart A. Cavill, Sean Langridge, Amy Whiteside, Thomas Moore, Maxime Dupraz, Flora Yakhou and Gerrit van der Laan, “Holographic imaging interlayer coupling in Co/Pt/NiFe”, New Journal of Physics 15 (2013) 023045

P.29 Controlling ferromagnetic resonance using three dimensional exchange biased antidot lattice stacks

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[1]University of Glasgow, UK, [2]Queen's University Belfast, UK, [3]Universite de Perpignam Via Domitia, France

Patterning of ferromagnetic films with periodic arrays of holes is an effective method for producing structures with interesting microwave frequency properties [1]. The magnetic fields produced by uncompensated poles in these antidot arrays give rise to a distribution of internal fields that strongly affect frequencies and mode profiles of spin waves and resonances [2]. In this way, patterning can be used to manipulate the microwave properties of ferromagnetic films. Additional control of resonance frequencies can be achieved by introducing anisotropies through exchange bias at a film interface. Antidot patterning of an exchange biased sample also strongly affects magnetisation processes and the corresponding hysteretic properties of the structure [3]. We present results for a novel structure in which three films, each exchange biased, are stacked upon one another and patterned with an antidot geometry. The bias fields acting on each film are different, thereby allowing for pinning of magnetisation in one film while another reverses. This results in a highly configurable three dimensional magnetic structure. We show that a complex ferromagnetic resonance mode structure results, and demonstrate how this can be understood in terms of the inhomogeneous fields produced by the stacked structure. The exchange biased tri-layer consists of [NiFe(10nm)/FeMn(15nm)]x3 as a stack of thin continuous films. The FMR results show three resonance lines which are associated with the three NiFe layers. A large antidot array (1.5mmx1.5mm) is patterned with hole diameters of 240nm and edge to edge separation of 160nm. Broadband frequency behaviour is measured at different external applied fields, producing multiple resonances. At low fields there can be partial flux closure, strongly modifying the distribution of internal fields produced by magnetic charges at the hole edges.

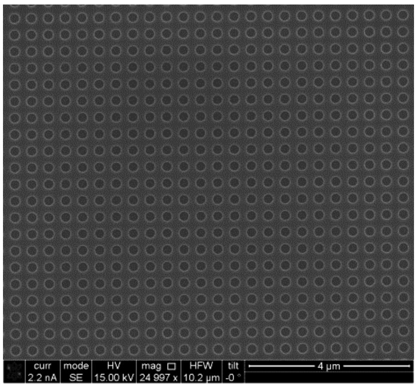


Figure 4-Top view of the antidot lattice. Reactive ion etching was performed on the sample protected by Ta layer and SiN hardmask.

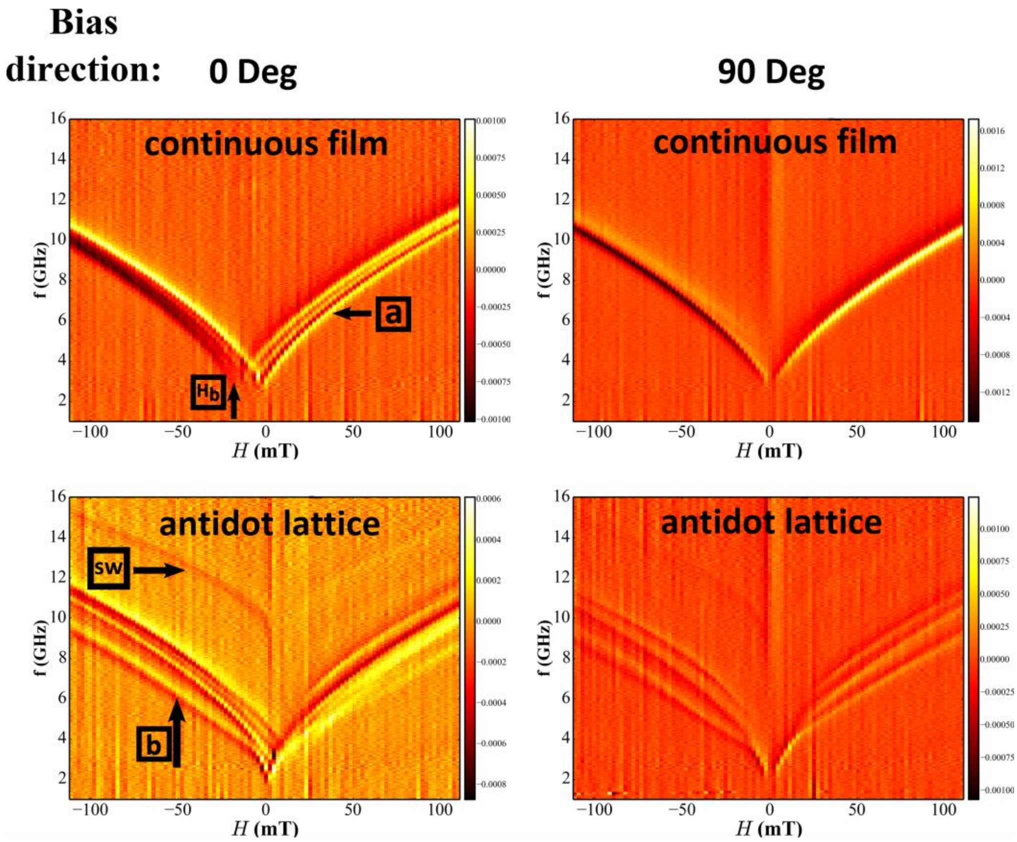


Figure 5- Ferromagnetic resonance spectra as function of the applied field for the continuous tri-layer system (TOP) and Patterned system (Bottom). Our ferromagnetic resonance studies will provide information on how the multiple resonance lines a and b behave as function of applied field. The variation of the exchange bias field, H_b is evaluated. Spin wave modes, sw, are also analysed.

[1] V. V. Kruglyak, S. O. Demokritov and D. Grundler; J. Phys. D: Appl. Phys. 43, 264001 (14pp) (2010)
[2] C.-L. Hu, R. Magaraggia, H.-Y. Yuan,C. S. Chang, M. Kostylev, D. Tripathy, A. O. Adeyeye and R. L. Stamps; Applied Physics Letters 98, 262508 (2011)
[3] D. Tripathy, A. O. Adeyeye; Journal of Applied Physics 105, 07D703 (2009)
[4] X. Kong, D. Krasa , H.P. Zhou, W. Williams, S. McVitie, J.M.R. Weaver, C.D.W. Wilkinson; Microelectronic Engineering 85, 988–991 (2008)

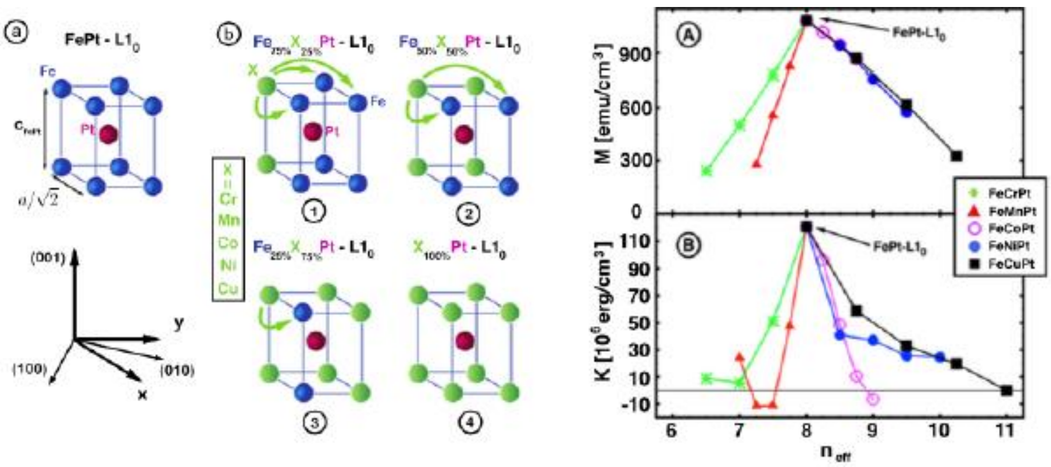
Magnetic structure and properties

P.30 Magnetic anisotropy of $Fe_{1-y}X_yPt$ [X=Cr,Mn,Co,Ni,Cu] bulk alloys

R Cuadrado[1], T J Klemmer[2] and R W Chantrell[1]

[1]University of York, UK, [2]Seagate, USA

We have developed a theoretical method to investigate the MAE of the FePt-$L1_0$ phase following gradual substitution of Fe by Cr, Mn, Co, Ni, and Cu keeping the Pt content fixed (Fig. a, b). The inclusion of the doping elements changes the in-plane and the out-of-plane lattice constants characterising the *fct* phase. In general, *a* increases with the reduction of the Fe content promoting a decrease of *c*. The magnetic moment of the magnetic and non-magnetic species also changes substitution. Due to the low Fe-Fe in-plane coordination that emerges after replacement of the Fe atoms, the indirect polarization of Pt and other species is reduced, disappearing for large dopant concentrations. On the other hand, the Fe tends to be magnetically isolated in a nonmagnetic environment and hence its MM tends to increases. The predicted variation of the magnetization as well as the MAE with the effective valence charge is in good agreement with prior experiments (Fig. A, B). The calculations also predict that the local, site resolved, anisotropy constant has a dispersion arising from differences in the local environment of doping atoms situated at different lattice sites. We also predict a species-dependence of the variation of MAE with band filling.



P.31 **Two-step magnetic ordering in intercalated niobium disulphide Mn_xNbS_2**

F Mushenok[1], D Korchagin[2] and A Shevchun[2]

[1]University of Exeter, UK, [2]Russian Academy of Science, Russia

Layered dichalcogenides are one of the promising materials for spintronic devices. Intercalation of layered dichalcogenides by transition metal ions proposes a unique possibility for control of physical properties and achievement of required parameters. Crystal structure and magnetic properties of Mn_xNbS_2 single crystals have been studied in this work.

Single crystals of Mn_xNbS_2 (where x = 0.30) have been prepared by chemical transport method. Crystal structure and composition have been checked by XRD and EDX methods. It was found that parameters of crystal structure (a = b = 11.532 Å, c = 12.502 Å, space group P-3m1) cannot be described by superstructures $2a_0$x$2a_0$ (a = 6.7, $Mn_{1/4}$NbS2) and $\sqrt{3}a_0$x$\sqrt{3}a_0$ (a = 5.7, $Mn_{1/3}$NbS2) which are usually observed in these compounds. The obtained parameters of crystal structure correspond to $2a_0$ x $\sqrt{3}a_0$ superstructure which was previously found in Li_xTiSe_2.

Two critical temperatures of magnetic ordering have been observed on temperature dependences of magnetization. First one (at T = 100 K) corresponds to ferromagnetic ordering and is usually observed in $2a_0$x$2a_0$ superstructure. Second one (at T = 40 K) corresponds to helical ordering and is usually observed in $\sqrt{3}a_0$x$\sqrt{3}a_0$ superstructure.

The work was supported by grant of President of Russia Federation for young scientists (MK-1474.2014.3).

P.32 **Development of a technique to determine anisotropy axes in soft magnetic materials using a standard vibrating sample magnetometer**

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Torque magnetometry is a powerful tool for anisotropy studies [1-3], allowing investigation of (i) the symmetry of anisotropy, (ii) anisotropy constants, (iii) competing anisotropies and (iv) magnetic instabilities. Measurements are usually carried out either directly, using a specialist torque magnetometer, or by an equivalent method utilising the in-plane transverse component, $mm\perp$, of a vector (biaxial) vibrating sample magnetometer (VSM). Such measurements are especially useful in characterising the easy and hard axes in soft magnetic materials.

Herein a method is developed whereby only the parallel moment, $mm\|$, as measured by a *standard* VSM, is used. From consideration of soft samples and the net moment at fields in-between saturation and rapid drop-off towards zero, it will be shown that the differential of $mm\|$ as a function of sample rotation approximates to $mm\perp$ such that the intercepts with the abscissa can be used to identify easy and hard axes. This is shown in figure 1 for a $NiFe_2O_4$ sample of known texture, alongside comparison with full biaxial-derived torque curves, identifying expected easy and hard axes at negative and positive intercepts respectively. Other sample results will be given and discussed regarding the effectiveness and limitations of this technique when using a standard VSM.

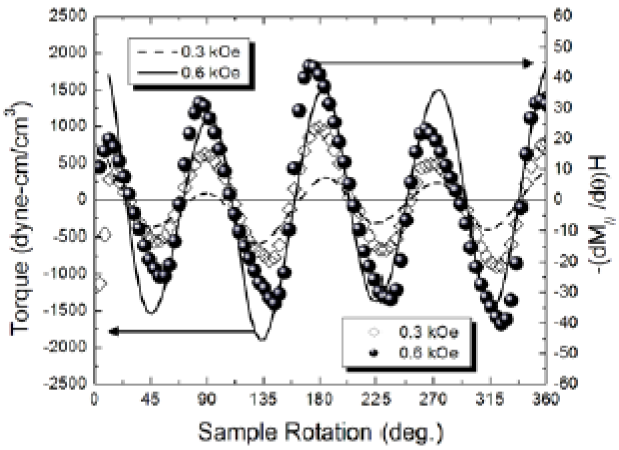

Figure 1. Comparison of calculated torque curves (lines) and differential of parallel signal (symbols) for NiFe2O4 orientated parallel to a plane of the form {100}.

[1] Cullity B.D. and Graham C.D., introduction to magnetic materials, 2nd ed. (John Wiley & Sons Inc., 2009)

[2] Garcia, J., Carrizo, J., Elbaile, L., Lago-Cachon, D., Rivas, M., Castrillo, D., and Pierna, A., Journal of Magnetism and Magnetic Materials 372, 27 (2014)

[3] Lisfi, A., Pokharel, S., Morgan, W., Warren, G., and Wuttig, M., Nanotechnology 25(41), (2014)

P.33 **Erbium, a magnetic spin spiral for the future**

J Cooper[1], N Satchell[2], C Kinane[1], G Burnell[2], P Curran[3], J Witt[2] and S Langridge[1]

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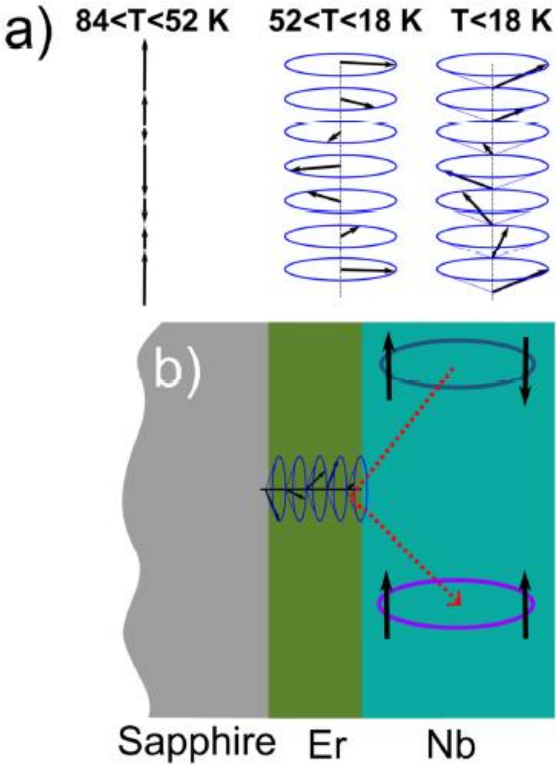
Erbium is magnetically complicated[1], but can form a magnetic spin spiral at low temperatures, see Fig 1 a). As well as potential uses for spin transfer torque[2] similar magnetic spiral systems have previously been used as a non-collinear magnetic interface to generate triplet Cooper pairs[3], Fig 1 b). Such technological applications require thin films and control over the magnetic state in such films. For instance, the triplet generation depends upon the length-scale of the non-collinearity, the moment on the site and on the degree of non-collinearity.

In bulk Er there are many magnetic phase transitions, Fig 1 a) though they fall into three main categories: sinusoidal antiferromagnetism along the *c*-axis, spin spiral and spin cone. The moment on the sites is close to the 9 μB predicted for a *J = 15/2* system, thus we have a large moment, highly non-collinear magnetic system.

In epitaxial thin films we have recovered, for the first time, bulk like behaviour for Er films of thickness 200 nm, with spiral phases commensurate with the lattice. We have used thin film neutron diffraction, neutron reflectivity, temperature dependant x-ray diffraction, x-ray reflectivity and SQUID magnetometry to fully characterise our thin film Er system. In previous studies[4,5], the extreme strain dependence of the transition temperatures has supressed the low temperature states in films even up to 1 μm in thickness. In our films, below 50 nm the conic phase is suppressed to below 2 K. For much thinner, and technologically relevant, samples (5 nm) full experimental characterisation becomes difficult, though we are still able to probe the layer and have some evidence for a highly non-collinear magnetic state.



[1] B.H. Frazer, J.R. Gebhardt, and N. Ali, J. Appl. Phys. 85, 6100 (1999)
[2] O. Wessely, B. Skubic, and L. Nordström, Phys. Rev. Lett. 96, 256601 (2006)
[3] J.W.A. Robinson, J.D.S. Witt, and M.G. Blamire, Science 329, 59 (2010)
[4] G. Helgesen, Y. Tanaka, J. Hill, P. Wochner, D. Gibbs, C. Flynn, and M. Salamon, Phys. Rev. B 56, 2635 (1997)
[5] J. Borchers, M. Salamon, R. Erwin, J. Rhyne, G. Nieuwenhuys, R. Du, C. Flynn, and R. Beach, Phys. Rev. B 44, 11814 (1991)

P.34 **Magnetic properties of vanadium doped chromium dioxide $Cr_{1-x}VxO_2$ x ≤ 0.5**

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CrO_2 is a half-metallic ferromagnet with near 100% spin-polarization at 2 K. It has the tetragonal rutile structure with the space group $P4_2/mnm$. Several related rutile compounds in the Cr–V–O system such as $Cr_{0.2}V_{0.8}O_2$, $Cr_{0.875}V_{0.125}O_2$ and even the high-temperature (rutile) phase of VO_2 have been predicted to be half-metals based on DFT calculations. A high-pressure phase of $CrVO_4$ ($Cr_{0.5}V_{0.5}O_2$) is also known to have the rutile structure, but its physical properties have never been investigated. We have investigated the magnetic properties of vanadium doped chromium dioxide $Cr_{1-x}V_xO_2$ x ≤ 0.5. The samples were prepared by high-pressure synthesis. Rietveld refinement of XRD patterns showed that the compounds retain the simple rutile structure with a random distribution of Cr and V on the Wyckoff 2a site. Lattice parameter *a* increases whereas *c* decreases linearly with increasing vanadium content. DC magnetic susceptibility measurements revealed that the magnetic ordering changes from ferromagnetic to ferrimagnetic to antiferromagnetic as the vanadium content increases. Thus, the rutile $CrVO_4$ is not a half-metal but an antiferromagnetic material with a Neel temperature of 15 K. X-ray absorption spectroscopy indicates that the valence state of chromium decreases from +IV towards +III with increasing vanadium content.

P.35 **The effect of non-magnetic phases on the development of new rare-earth permanent magnetic materials utilizing the Spark Plasma Sintering powder metallurgy process**

A Mackie, R Goodall and J Dean

University of Sheffield, UK

Rare-Earth permanent magnets are typically processed as powders and follow a pressing and sintering route. This process is long established but new powder metallurgical techniques are being introduced and should be investigated. Spark Plasma Sintering (SPS) of Sm_2Co_{17} powder has been incorporated to produce isotropic bulk permanent magnets. SPS offers multiple controllable parameters and produces high density with a rapid compaction. Utilizing these advantages, composite samples of Sm_2Co_{17} have been produced with varying weight percentages of CaF_2 and $BaTiO_3$ added. Their compositions have been designed to improve electrical resistivity and facilitate a reduction in rare earth element usage through improved efficiency and performance. The samples have had their microstructures characterized as well as their magnetic and electrical properties measured and compared.

When processing under parameters that deviate from the optimum, SPS produced material contain residual porosity. To better understand their effect, micromagnetic simulations, using Finite Element Methods (FEM), have also been developed which consider the effect of pores within a region of Sm_2Co_{17} magnetic material. These results are compared with the experimental results of samples of Sm_2Co_{17}, which have been produced via SPS with densities that correspond to the volume fractions porosity within the magnetic simulation. The potential for bulk permanent magnets processed by SPS will be discussed.

P.36 **Rotational excitations of cold polar molecules emulating ferromagnetic order**

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Rotationally excited polar molecules loaded into an optical lattice in two dimensions can emulate a spin- 1=2 XX ferromagnet with long range $1/r^3$ exchange. We theoretically study the collective dynamics of the rotational excitations and the many-body phases that form following a microwave pulse. We show that, owing to the long-range interactions between molecules and energy conservation in this isolated system, the rotational excitations can form a Bose-Einstein condensate with long-range order (corresponding to ferromagnetic order in the emulated magnet). This manifests itself as a divergent T_2 coherence time of the rotational transition even in the presence of inhomogeneous broadening or dilution of the optical lattice. The dynamical evolution of rotational excitations shows regimes of non-ergodicity and many-body localisation. Further, we find the maximal dilution of the optical lattice, above which no divergent coherence time can be observed.

[1] PACS numbers: 67.85.-d, 05.30.-d, 72.15.Rn

P.37 **Atomistic modelling of $Nd_2Fe_{14}B$-Fe core/shell nanoparticles for high performance permanent magnet applications**

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University of York, UK

Since its discovery in the 1980s, $Nd_2Fe_{14}B$ has become one of the most common permanent magnets in use today due to its high energy product. Due to the risks of climate change, there is renewed interest in developing ultrahigh performance permanent magnets to enhance the magnetoelectric efficiency of motors for use in hybrid electric vehicles. $Nd_2Fe_{14}B$'s performance is known to suffer greatly at the high temperatures required for motor applications (> 150 °C) and so one possible solution is to develop a composite material including α-Fe to enhance the Curie temperature while maintaining the high energy product. Here we have used an atomistic spin model to investigate the magnetic properties of core-shell α-Fe- $Nd_2Fe_{14}B$. We find that at typical motor operating temperatures (~200-500K), a small iron core (0-15 vol% of particle) reduces the coercive field significantly. However this is compensated for by an increase in the total magnetization of the particle (~51% increase is seen for a 16.6% α-Fe particle at 500K), which arises from the polarization of the NdFeB by the Fe. It is found that there is a small temperature regime where the maximum energy product does not suffer any drop, but the thermal stability of the particle is improved by the addition of the α-Fe. This property of the core/shell nanostructures would make them a suitable substitute for pure $Nd_2Fe_{14}B$, whilst simultaneously lowering the raw material cost of the permanent magnet component of high performance motors.

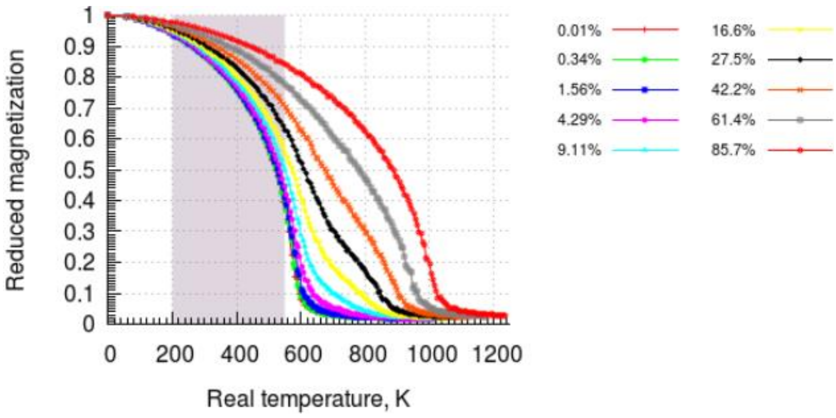

Figure 1: Calculated magnetization of a 16nm core/shell nanoparticle against temperature for varying α-Fe core sizes. The highlighted region indicates temperatures relevant for electric motors. The particle is seen to exhibit greater retention of magnetization for increasing iron content, as well as higher Curie temperature.

P.38 Collective properties of frustrated nano-disk arrays

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Abstract not available in digital format.

P.39 Investigation of polar and non-polar interfaces in EuO(001) based heterostructures

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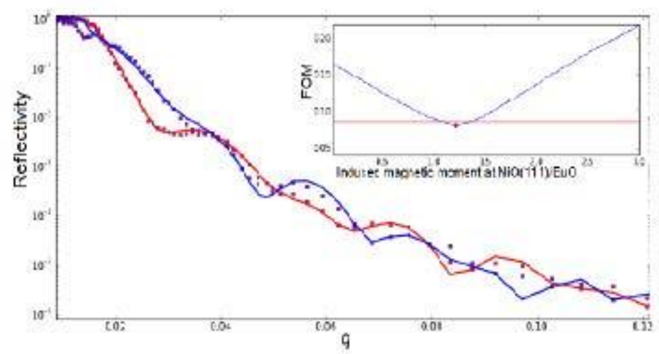
[1]University of Cambridge, UK, [2]ISIS Facility, STFC Rutherford Appleton Laboratory, UK, [3]Paul Scherrer Institut, Switzerland

Multi-layer oxide heterostructures are expected to exhibit new properties at the interface while leaving the bulk properties unchanged. Changes in the electical conductivity, magnetism [1], superconductivity [2] and the formation of a two-dimensional electron gas (2DEG) were reported at the interfaces of different oxides such as $LaAlO_3/SrTiO_3$ [3]. The effect of a spin-polarised 2DEG was suggested to occur at the interface of EuO and polar oxides below the Curie temperature of EuO (Tc=69K).

The spin distribution and exchange bias effect occuring at the polar EuO(001)/NiO(111) interface were studied using polarised neutron reflectivity (PNR). A 5nm NiO thick film was grown on MgO(111) using molecular beam epitaxy followed by 10nm of EuO(001) co-deposited at room temperature by mangetron sputtering and capped with 10nm of Au [4]. An EuO(001)/MgO(001) sample was used to ascertain the effect of spin polarisation on a non-polar interface. Both samples were measured at 67K, below the Tc of EuO.

Charge transfer and exchange bias effects at the polar surface were expected to create an unbalanced net magnetisation at the interface. However the splitting in the reflectivity curves was larger in the non-polar sample rather than in EuO/NiO. This is attributed to the pinning of the EuO magnetisation by the NiO antiferromagnetic domains which prevents the EuO domains to align with the applied field at elevated temperatures, when the EuO magnetisation is weak. The PNR fitting of NiO(111)/EuO(001) measured at 5K is shown in Figure 1.a.

Preliminary results from low energy muon spin rotation of the polar $LaAlO_3(001)$/EuO(001) interface measured with 30G transverse field at two implantation depths, in the bulk EuO and close to the interface (Fig. 1.b) will also be presented.



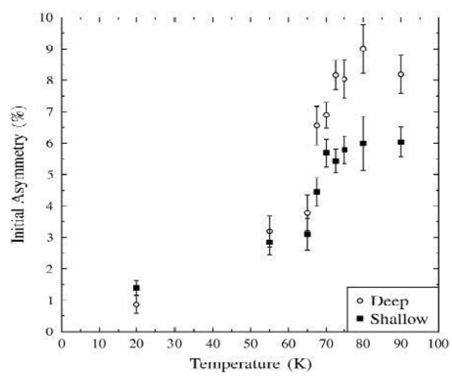


Figure 1.a: PNR fitting of NiO(111)/EuO(001) interface measured at 5K using a magnetic field of 50mT. The inset shows the figure of merit scan of the induced magnetic moment at the interface. Figure 1.b: Transverse field measurements at two implantation depth: near the $LaAlO_3(001)$ interface (17Kev) and in the bulk EuO (7Kev).

[1] A. Brinkman *et al*, Nature Materials 6, 493 (2007)
[2] N. Reyren *et al*, Science 317, 1197 (2007)
[3] A. Ohtomo and H. Y. Hwang, Nature 427, 423 (2004)
[4] P.M.S. Monteiro *et al,* Phys. Rev. Lett. 110, 217208 (2013)

P.40 **Competing interactions in doped rare-earth manganites nano- structural materials**

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The effect of Fe doping in $La_{0.65}Ca_{0.35}Mn_{1-x}Fe_xO_3$ (where $0 \leq x \leq 0.10$) nano-particles on the Mn site has been studied. Resistivity measurements of these particles from ambient temperature down to 77 K exhibit a peak at temperature T_p, which decreases with increasing Fe content. Substantial rise in resistivity corresponding to the T_p and increase spin disorder are also observed with increasing doping. Variable range hopping (VRH), and polaronic have been used to explain the DC transport mechanism in the insulating region above T_p. The localization length is found to decrease by increasing Fe concentration. The variations in the critical temperature T_p, T_c, confinement length, magnetic moment and magnetoresistance show a rapid change at about 4-5% *Fe*. Colossal magnetoresistance has been shifted to lower temperature, and enhanced by Fe doping. The maximum magnetoresistance is seen to increase consistently with the addition of *Fe* and increases upto 400% for 8% *Fe* concentration. However, conduction and ferromagnetism have consistently suppressed by Fe doping. The effect of *Fe* is seen to be consistent with the disruption of the *Mn-Mn* exchange possibly due to the formation of magnetic clusters. The formation of ferromagnetic and antiferromagnetic clusters and the competition between them with the introduction of Fe^{3+} ions, which do not participate in the double exchange (DE) process, have been suggested to explain the low value of magnetization at higher Fe concentration.

Magnetism and structure

P.41 Assessment of magnetic contribution of metallic Co nanoparticles to the total magnetization in Co doped In_2O_3

M S Alshammari[1], W G Dizayee[2], M AS Iqahtani[2], S M Heald[3], H J Blythe[2], A M Fox[2] and G A Gehring[2]

[1]King Abdulaziz City for Science and Technology (KACST), Saudi Arabia, [2]University of Sheffield, UK, [3]Argonne National Laboratory, USA

This study shows that the combination of magnetic measurements and magnetic circular dichroism (MCD) is a powerful tool to detect the contribution of metallic Co nanoparticles to the overall magnetism, and the result that the formation of nanoparticles is inhibited by the inclusion of tin. Thin films of cobalt-doped indium oxide, $(In_{1-0.95}Co_{0.05})_2O_3$ were deposited using pulsed laser deposition (PLD) on sapphire substrates. Extended X-ray Absorption Fine Structure (EXAFS) measurements shows that, the quantity of metallic Co nanoparticles increased with the oxygen deficiency in the PLD chamber and also after annealing in vacuum, resulting in an increase of the magnetization. The MCD spectra show two features one at 2.3eV and the other below the band edge of In_2O_3 at 3.5eV. The MCD spectrum is well fitted by a combination of the spectrum from the nanoparticles in the In_2O_3 matrix as calculated using Maxwell-Garnett theory and a contribution from polarized carriers as seen for substitutional cobalt [1]. The changes in the saturation magnetization and the two components of the MCD are used to get a quantitative estimate of the contribution of the nanoparticles magnetization to the total magnetization in each sample. The MCD signal due to Co nanoparticles was completely suppressed by adding 5% of Sn, and that from polarized carriers enhanced strongly. This indicates that, the magnetization of the carriers in Sn and Co co doped In_2O_3 is particularly high.

[1] A. M. H. R. Hakimi, M. G. Blamire, S. M. Heald, M. S. Alshammari, M. S. Alqahtani, D. S. Score, H. J. Blythe, A. M. Fox and G. A. Gehring, Physical Review B 84, 085201 (2011)

P.42 **Energy and magnetic characteristics of multilayer magnetic films**

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The investigation of a nature of magnetism in Fe, Co, and Ni ultrathin films has a large fundamental interest through an observable dimensionality crossover of magnetic characteristics. It has been established that the long-range ferromagnetic order arises in films at some effective film thickness. However, the nature and regularities of this phenomenon remain not quite clear.

In this work, we use the spin-density functional method for theoretical description of multilayer film formation in process of Fe, Co, and Ni ions adsorption on a nonmagnetic metal substrate. We include into consideration the thermal effects of transition metal ions intermixing inside film and their substitution with atoms of substrate layer. The energy and magnetic characteristics of multilayer films were calculated for systems Fe(110)/W(110), Fe(110)/Ag(111), Ni(111)/Cu(111), and Co(111)/Cu(111) in dependence on their thickness in the units of number N monolayers for different temperatures (Fig.1).

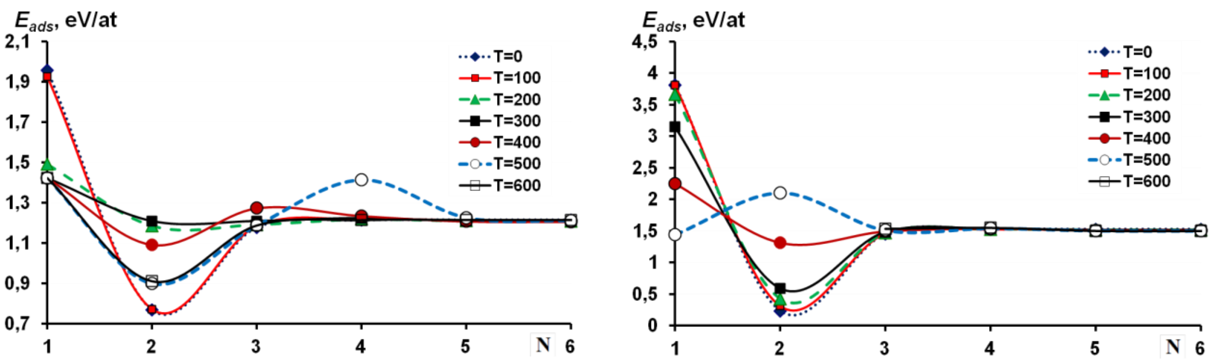


Fig.1. The dependence of adsorption energy for Ni/Cu(111) and Co/Cu(111) systems on thickness N for Ni and Co films.

It was shown that the energies of interfacial interaction and adsorption considerably depend on the thickness films, temperature, and properties of metal substrate with significant difference of the monolayer film properties from properties of films with large thicknesses. The energy and magnetic characteristics demonstrate that for film thickness N ≥ 5 their values cease to depend on properties of metal substrate and further begin to depend on surface properties of films.

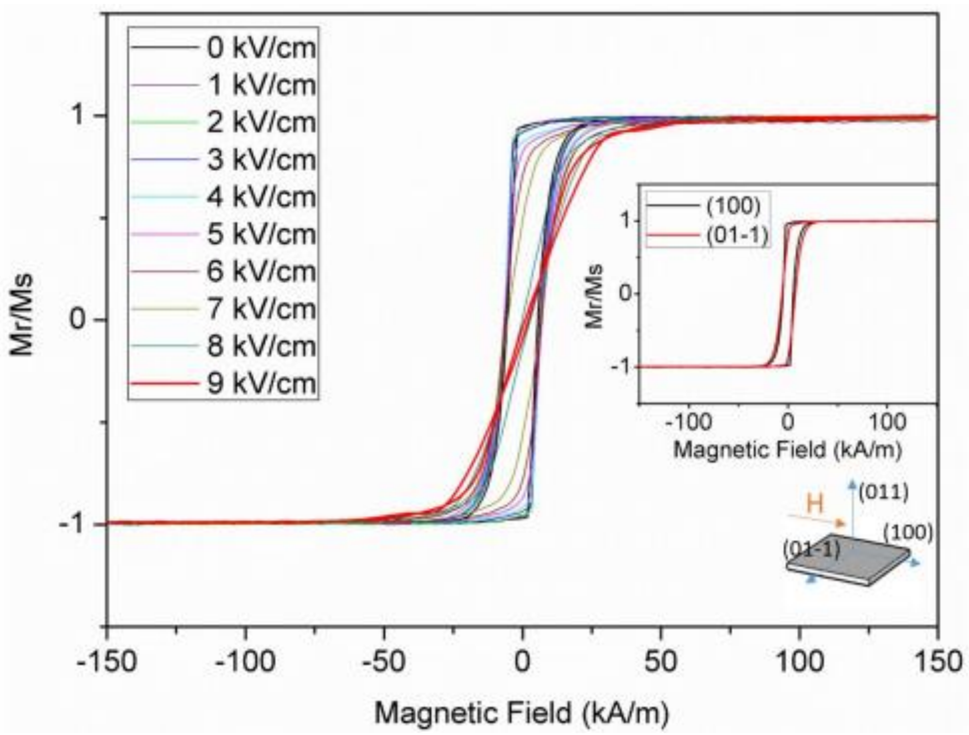
Investigations were supported by Russian Scientific Fund through project No. 14-12-00562.

P.43 **Electric-field control of magnetic properties in a multiferroic heterostructure**

W M Rainforth, W-G Yang, N A Morley and J Sharp

University of Sheffield, UK

Recently, multiferroic materials have attracted much interest due to their potential application in multifunctional devices or non-volatile, lightweight, and energy-efficient electronic devices. The work presented here studies ferroelectric/magnetostrictive bilayers consisting of ~60 nm $Co_{50}Fe_{50}$ sputtered at 75W onto (011) $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMN-PT) substrate. Cross-sectional high-resolution transmission electron microscopy (HRTEM) image showed a uniform columnar growth structure of the CoFe film and an average columnar grain size of 3.3 ± 0.5 nm. Selected area electron diffraction (SAED) pattern showed the CoFe polycrystalline structure, with columnar grains composed of randomly oriented nanocrystals. Giant magnetoelectric (ME) coupling was observed in the heterostructure. A large remanence ratio (Mr/Ms) tunability of 95% has been demonstrated, corresponding to a giant ME constant (α) of 2.5×10^{-6} s/m, when an external electric field (E-field) of 9 kV/cm was applied. A large E-field induced effective magnetic anisotropy field (Heff) of 38.2 kA/m was also observed. Such a multiferroic heterostructure provides great opportunities for electric-field controlling magnetic devices.



Electric dependence of magnetic hysteresis loops measured along (100) in CoFe/(011)PMN-PT heterostructure. The inset shows easy and hard axis loops of the as grown sample.

P.44 **Dimensional effects in ultrathin magnetic films**

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Omsk State University, Russia

Abstract not available in digital format.

P.45 **The effects of different precursors in the production of PLD targets on the magnetism of cobalt doped ZnO films**

M Ying[1,2], W Dizayee[1], S M Heald[3], H J Blythe[1], A M Fox[1] and G A Gehring[1]

[1]University of Sheffield, UK, [2]Beijing Normal University, China, [3]Argonne National Laboratory, USA

Zn_xCo_{1}-$_xO$ films have been prepared by PLD. We formed solid state targets for Zn_xCo_{1}-$_xO$ starting from mixtures of ZnO with one of the following compounds: metallic Co, CoO and Co_3O_4, to find out if the precursor material containing Co used for the target is important. All the films were initially grown at base pressure, 2×10^{-3}mTorr. We also grew films using the metallic cobalt precursor at 10mTorr and 100mTorr of oxygen. The optical absorption was measured to find the band gaps and to check for film quality and the nature of the cobalt dopant and its environment was established using X-ray absorption spectroscopy. Hysteresis loops taken at 5K and 300K were analyzed to find the ferromagnetic and paramagnetic components of magnetization and coercive fields. Magnetic circular dichroism, MCD, spectra were taken in order to look for magnetic defect phases. The $Zn_{0.95}Co_{0.05}O$ films grown at base pressure were all ferromagnetic at low temperatures with saturation magnetizations given by 6, 10 and 13 emu/cm^3 for precursors CoO, Co^3O^4 and Co meta respectively and small coercive fields (~ 100 Oe). However this magnetization had vanished by RT. We also grew films in 10mTorr and 100mTorr and found that the metallic fraction had vanished, the crystal quality improved and the magnetism remains at RT.

Hence a conclusion of this work is that the choice of precursor is important and that adding oxygen in the growth chamber may not be equivalent to including more oxygen in the target.

P.46 **Substitutional and metallic Cobalt in ZnO films**

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[1]University of Sheffield, UK, [2]Shanxi Normal University, China, [3]Argonne National Laboratory, USA

The study of $Zn_{1-x}Co_xO$ has excited much interest due to its possible use in spintronic devices. There are some samples where the Co^{2+} resides on Zn sites that are magnetic at room temperature with small coercive fields, typically less than 100 Oe at room temperature and less than 200Oe at helium temperatures. The Co^{2+} ions are themselves paramagnetic [1].

There are other samples where the magnetisation may be due to metallic nanoparticles. In this case they often block at low temperatures so that the material is characterised by a large coercive field e.g. >500Oe at low temperatures falling to almost zero at room temperatures.

There is a third category where both types of magnet coexist. These are characterised by a large coercive field at low temperature but also a sizeable one at room temperature. In this work we have grown samples of all three types. The amount of Co that is metallic has been established by x-ray near edge absorption and EXAFS and also from a study of the MCD spectra. The existence of coupling between the nanoparticles and the magnetic matrix has been established from measurements of the hysteresis loops using MCD at different energies so as to focus on either the cobalt metal or the characteristic electrons of the ZnO [3].

[1] Thomas Tietze, Milan Gacic, Gisela Schütz, Gerhard Jakob, Sebastian Brück, Eberhard Goering, 2008 *New J. Phys.* 10, 055009

[2] M. Opel, K.-W. Nielsen, S. Bauer, S. T. B. Goennenwein, J.C. Cezar, D. Schmeisser, J. Simon, W. Mader, R. Gross, 2008 *Eur. Phys. J. B* 63, 437

[3] J. R. Neal, A. J. Behan, R. M. Ibrahim, H. J. Blythe, M. Ziese, A. M. Fox, G. A. Gehring, 2006 *Phys. Rev. Lett.* 96, 197208

[4] David S Score, Marzook Alshammari, Qi Feng, Harry J Blythe, A Mark Fox, Gillian A Gehring, Zhi-Yong Quan, Xiao-Li Li, Xiao-Hong Xu, 2010 *Journal of Physics: Conf. Series* 200, 062024

P.47 Extracting intrinsic switching field distribution in granular system

S Ruta[1], O Hovorka[2], K Wang[3], G Ju[3] and R Chantrell[1]

[1]University of York, UK, [2]University of Southampton, UK, [3]Seagate Technology, USA

The intrinsic switching field distribution (SFD) is a fundamental characteristic of granular magnetic materials, which determines the quality of recording media. Being able to evaluate the intrinsic SFD of a system of grains will help improve the current PMR technology and allow optimising the future technologies such as HAMR.

SFD is determined by intrinsic factors (volume distribution, anisotropy value and orientation distribution), but also by external factors such as thermal effects and interactions (magnetostatic and exchange interaction). Due to the complexity introduced by the interplay between thermal effects and interactions, extracting the intrinsic SFD is not trivial. To accomplish this task, magnetic SFD determinations have been carried out by various means such as FORC [1] or ΔH(M, ΔM)methods [2][3], for example.

Here we present a comparison of the FORC and ΔH(M, ΔM) methods to investigate their accuracy in the parameter range relevant to magnetic recording media. To study this question, we consider a realistic kinetic MonteCarlo

(kMC) model of interacting StonerWohlfarth grains, including volume and anisotropy distributions. Both thermal and interaction effects are included in the kMC model. For elongated grains the dipole approximation fails and consequently we calculate the magnetostatic interactions based on individual grain shape. We proceed by calculating recoil curve data and subjecting them to the FORC and ΔH(M, ΔM) analysis and also the reference function ΔH(M, ΔM) method (RFM), which involves comparison with precalculated reference recoil curve sets. We find that the FORC method does not reliably separate the interaction effects from the intrinsic SFD. The RFM combined with a realistic kinetic MonteCarlo (kMC) model gives the most reliable measurement of the SFD. Discrepancies arise at nonzero temperatures due to temperature driven dynamics at the turning point of the recoil curve data, and it is concluded that correct identification of SFD information requires the application of models including thermal activation.

[1] A. Stancu, C. Pike, L. Stoleriu, P. Postolache, and D. Cimpoesu, “Micromagnetic and Preisachanalysis of the First Order Reversal Curves (FORC) diagram,” Journal of Applied Physics, vol. 93, no. 10, p. 6620, 2003

[2] O. Hovorka, Y. Liu, K. Dahmen, and a. Berger, “On the ability to determine intrinsic switching field distributions from hysteresis loops in the partially correlated magnetization reversal regime,” Journal of Magnetism and Magnetic Materials, vol. 322, pp. 459–468, Feb. 2010

[3] O. Hovorka, R. F. L. Evans, R. W. Chantrell, Y. Liu, K. a. Dahmen, and A. Berger, “Validation of ΔH(M,ΔM)technique for identification of switching field distributions in the presence of thermal relaxation,” Journal of Applied Physics, vol. 108, no. 12, p. 123901, 2010

P.48 **Temperature and distance dependence of intergranular exchange coupling**

M O A Ellis, R F L Evans and R W Chantrell

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For high density magnetic recording devices an understanding of the intergranular exchange coupling is key. In typical granular media there is distribution of grain sizes and separation which, as well as temperature, has strong effect on the intergranular exchange. Knowledge of these intergranular exchange distributions is important for micromagnetic calculations of granular media. To model the intergranular exchange it is assumed that magnetic atoms are present in the interlayer and allow the grains to couple to each other. Here an atomistic spin model is used to simulate a set of cobalt grains with a diffuse magnetic interlayer. A hybrid constrained Monte-Carlo method[1, 2] is used which allows the orientation of each grains magnetisation to be fixed in a certain direction but with the interlayer atoms free. The intergranular exchange is shown to depend strongly on the density of atoms in the interlayer with negligible exchange for densities lower than 20%. The temperature dependence of the exchange is shown to behave as a power law, shown in figure 1. The exponent is shown to decrease rapidly with density and increase with the grain separation. The distance dependence of the exchange behaves exponentially which agrees well with experimental measurements[3].

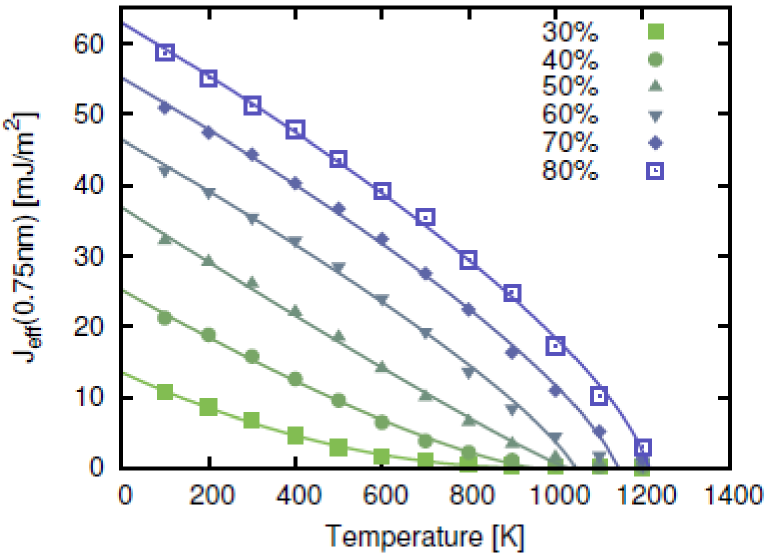

Figure 1. Temperature dependence of the intergranular exchange J_{eff} for different densities of magnetic atoms with the grain interlayer with a grain separation of 0.75nm. Lines are a fitted power law behaviour, $J_{eff} \propto (1-T/T_c)^{\beta}$ which shows significant dependence of the exponent with density.

[1] R. F. L. Evans, W. J. Fan, P. Chureemart, T. A. Ostler, M. O. A. Ellis, and R. W. Chantrell, Journal of physics. Condensed matter 26, 103202 (2014)

[2] P. Asselin, R. Evans, J. Barker, R. Chantrell, R. Yanes, O. Chubykalo-Fesenko, D. Hinzke, and U. Nowak, Physical Review B 82, 1 (2010)

[3] V. Sokalski, D. E. Laughlin, and J.-G. Zhu, Applied Physics Letters 95, 102507 (2009)

P.49 **Atomistic spin model simulations on the indirect exchange interactions of Co-doped ZnO**

M Arucu[1,2], R F L Evans[1], T A Ostler[1], R W Chantrell[1] and S Aktas[2]

[1]University of York, UK, [2]Marmara University, Turkey

Recently, ZnO-based diluted magnetic semiconductors (DMS) have received a great deal of attention since the discovery of ferromagnetism. Among all known transition metal(TM)-doped ZnO systems, Cobalt-based materials are among the most interesting due to reports of room temperature ferromagnetism. Magnetic semiconductors are potentially important for spintronics, where integration of metal layers can be problematic. Here we have simulated the magnetic properties of Co-doped ZnO using a classical spin model.

ZnO is a semiconductor which well-known hexagonal-close-packed (Wurtzite crystal structure) such as shown in Fig. 1(b). The crystal is randomly doped with Co atoms with the desired percentage, to give a diluted magnetic semiconductor. The exchange interactions are given by the RKKY interaction between spins, leading to a spin-glass, ferromagnetic and anti-ferromagnetic like behaviour according to the density [1]. The temperature dependent properties were calculated using the vampire software package [2] using a Monte Carlo algorithm [3]. A plot of the calculated RKKY exchange interaction dependent Fermi vector (k_F) for different k_F value is shown in Fig.1 (a). The results show a critical value dependence of the magnetization. At higher densities an antiferromagnetic ground state is apparent, arising from the oscillating distant dependent nature of the exchange interactions. This investigation has shown not only the spin glass and antiferromagnetic properties, but also they shown ferromagnetic properties in our systems at some densities. Further calculations include the size dependence of the magnetization, field cooled magnetization curves, the effects of anisotropy and dynamic spin dynamic properties.

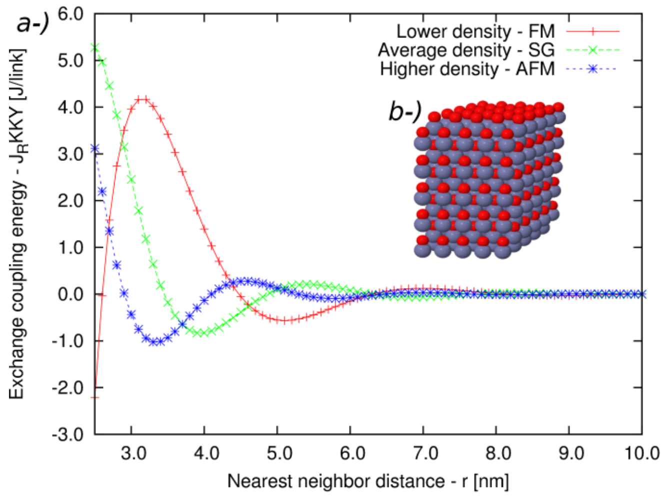

Figure 6: a) A plot of the J_RKKY-r for different density b) 5×5×5 ZnO wurtzite Crystal Structure.

[1] Monte Carlo simulation of magnetic phase transitions in Mn-doped ZnO, *JMMM*, 323, 23, (2011), 3001–3006

[2] http://vampire.york.ac.uk

[3] R F L Evans *et al*, Atomistic spin model simulations of magnetic nanomaterials, *J Phys Condens Matt* (2014) 26 103202

P.50 Angular dependence of switching fields of L10 $(Fe_{0.5}Mn_{0.5})_{68}Pt_{32}$ ferromagnetic-paramagnetic dot pattern fabricated by Mn ion irradiation

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Maintaining a planar disk surface is an important requirement for bit-patterned media (BPM). Ion irradiation is a possible candidate for the fabrication of planar BPM as this creates a magnetic rather than a topological pattern. In our previous report, FeMnPt was changed from a ferromagnetic (FM) state to a paramagnetic (PM) state as the $L1_0$ structure changed to the A1 structure [1]. In this study we make use of this effect to fabricate a dot pattern by Mn ion irradiation. Figure 1(a) shows a remanent state MFM image following saturation in the perpendicular direction. Circular dots are observed with little contrast outside the dot areas. It is evident that only the magnetic phase of the spacing (irradiated) areas changed from FM to PM. Figure 1(b) shows X-ray magnetic circular dichroism (XMCD) hysteresis curves of the dot pattern at room temperature. Ku was estimated to be 8.6×10^6 erg/cm^3. Figure 1(c) shows the angular dependence of normalized switching fields. The continuous film is comparatively close to 1/cosθ, which shows that magnetization reversal is dominated by the domain wall motion, whereas the dot pattern exhibits a Stoner–Wohlfarth (SW) like angular dependence with a minimum close to 45 degrees.

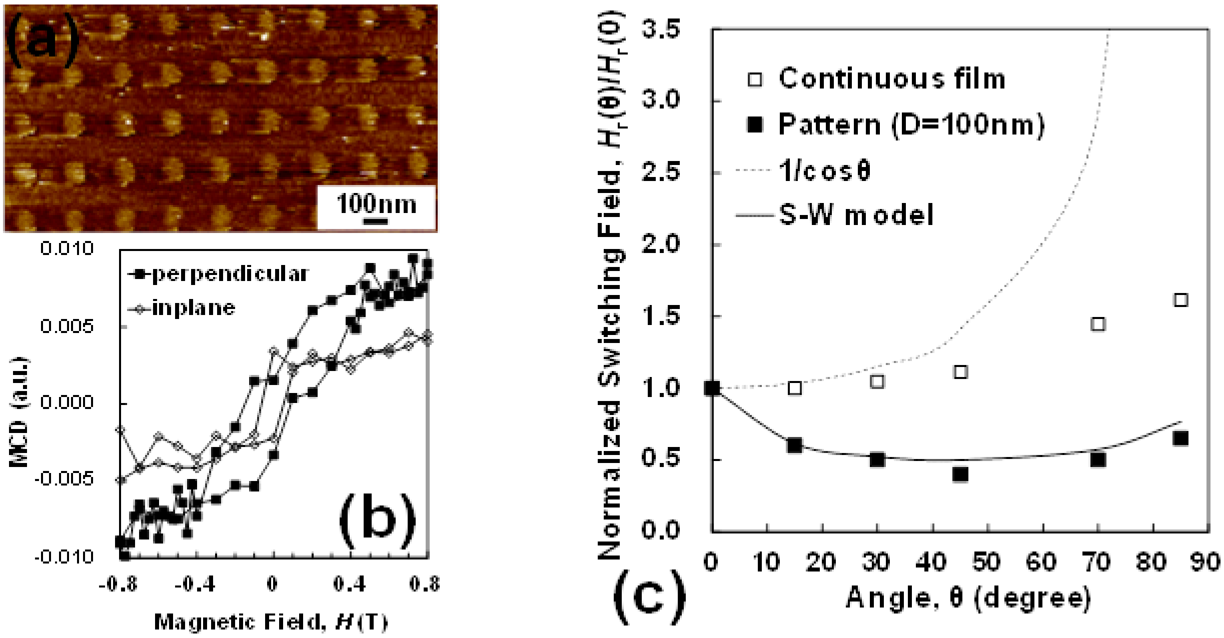

Fig 1 (a) MFM image and (b) XMCD hysteresis curves of the dot pattern with 100 nm in diameter. (c) Angular dependence of normalized switching fields.

This work was supported by NEDO (11B07008d) and SPring-8 (2014B1826)

[1] T. Hasegawa et al., Abstracts of 58th MMM (2013), p.p.287-288 (CT-06)

P.51 Atomistic modelling of magnetic reversal mechanisms in CoFeB-MgO tunnel junctions

A Meo[1], P Chureemart[2], R Chepulskyy[3], A Khvalkovskiy[3], D Apalkov[3], R Chantrell[1] and R Evans[1]

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Magnetic Random Access Memory (MRAM) is a non-volatile memory technology utilizing a magnetic tunnel junction (MTJ) to sense the magnetic state. A promising material for MRAM is an MTJ consisting of CoFeB/MgO due to its strong thermal stability, low damping and high tunnelling magnetoresistance. Here we investigate the intrinsic material properties of CoFeB/MgO bilayers using an atomistic spin model. The system consists of a single high anisotropy monolayer in contact with MgO, and a thicker bulk layer with very low anisotropy. Due to the strong variation of the anisotropy one would expect noncollinear reversal modes, particularly at sizes beyond the single domain limit and at elevated temperatures. We have systematically investigated the effects of temperature, system size and thickness on the coercivity of the system, and found a reduction in the coercivity with increasing system size indicative of a non-collinear reversal mode. A snapshot of the reversal in Fig. 1 shows the magnetic configuration during switching. Here the thermal fluctuations play an important role in the reversal process, inducing a nucleated reversal of the MTJ. Further analysis should lead to a better comprehension of the reversal processes and of the properties of these important structures.

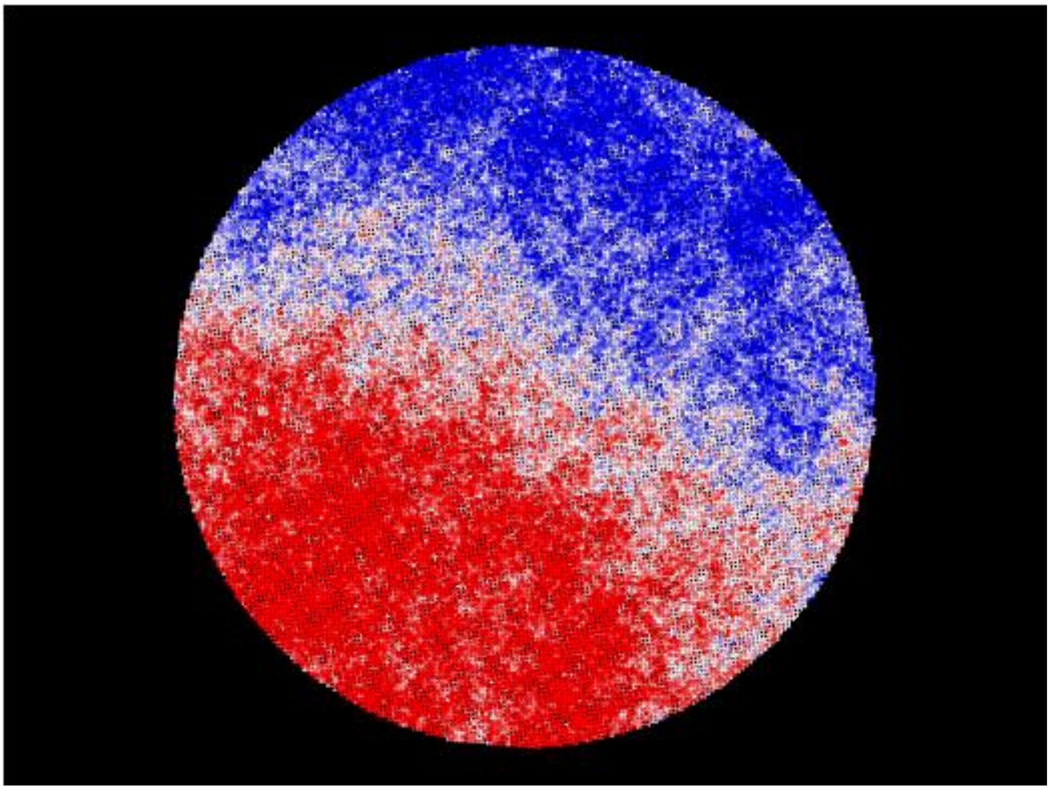

Figure 1: Magnetic configuration during the switching of CoFeB/MgO within the bulk layer. We can observe as the spins point in different directions: upward (blue), downward (red) and transversal (white). It is also evident the nucleation process identified as a clear domain propagation through the media.

P.52 **Electric field control of magnetic thin film properties using ionic liquid electric double layers**

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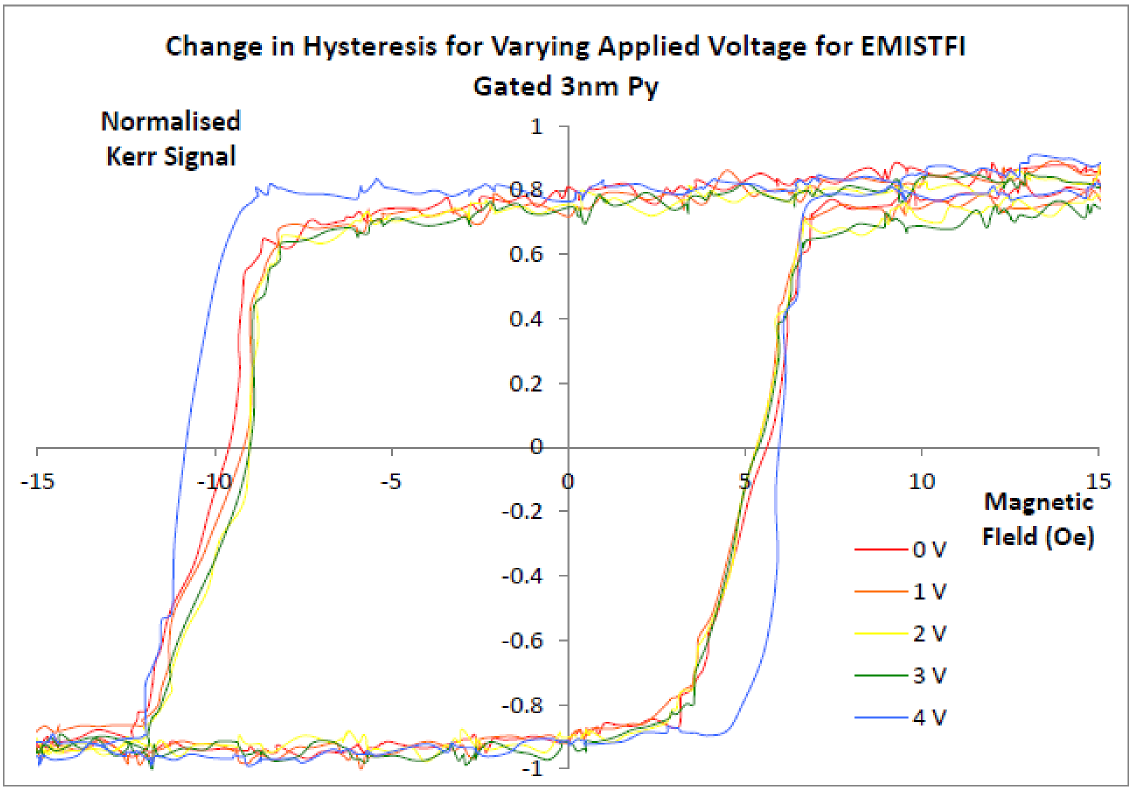
We show how magnetic properties of soft ferromagnetic (FM) thin films can be controlled by application of large electric fields. Controlling magnetic properties with electric fields is highly desirable in offering reduced power consumption in future data storage, integrated circuit and sensor applications. Here, we investigate the changes in the magnetic properties of Permalloy ($Ni_{80}Fe_{20}$) thin films of thicknesses ranging from 3 to 10nm. The films are covered with an ionic liquid (IL) and a voltage applied across this using the magnetic film as one of the electrodes. This creates an electric double layer at the interface with the Permalloy and generates very high electric fields. 1-Ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide (EMITSFI) is used as an IL here because of its large electrochemical window and stability in air. Due to EMITSFI's large electrochemical window, electric fields of up to 10's of GVm^{-1} are generated at the FM/EMITSFI interface. Magneto-optic Kerr effect measurements of the Permalloy thin films show a change in hysteresis loop shape with applied voltage and a change in coercivity of up to 15.5%. This can be attributed to an electric-field-inducted change in switching mechanism or surface anisotropy of the film.



P.53 **Fabrication and characterisation of remote plasma sputtered $L1_0$ FePt thin films and bit patterned media**

S Zygridou, P W Nutter and T Thomson

University of Manchester, UK

$L1_0$ ordered FePt is currently the leading candidate material for magnetic recording media both as heat assisted and as bit patterned media (BPM). Combining both schemes would allow even greater areal densities > 5 Tb/in^2 [1].

In this work, we investigated the fabrication of FePt thin films using remote plasma sputtering in order to determine if this offers advantages over the conventional dc magnetron approach. FePt films 10 nm thick were deposited directly on MgO (001) at a range of substrate temperatures and target bias voltages. Post-annealing was needed at temperatures in the range 700-750°C in order to induce perpendicular magnetic anisotropy (PMA). The ordering of FePt and its orientation were investigated for the different deposition conditions. Figure 1 shows high PMA for FePt thin film with $L1_0$ phase demonstrated by (001) and (002) diffraction peaks.

Initial results from patterning these films for BPM show that unlike patterned Co/Pd multilayer films [2], there is no systematic change with island size.

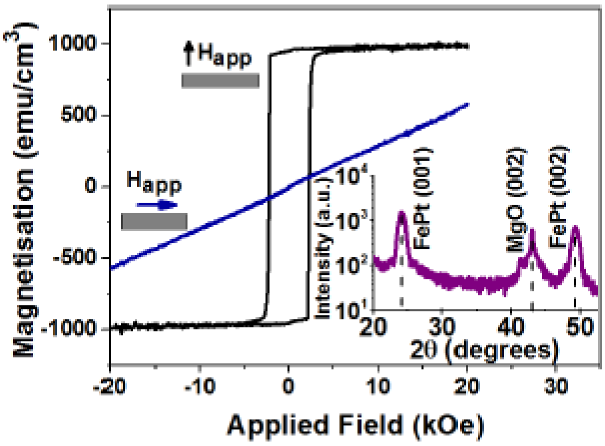


Figure 1. VSM and XRD measurements of FePt thin film deposited at 200°C with 200 V followed by post-annealing at 750°C.

[1] T.W. McDaniel, J. Appl. Phys., 112, 093920, 2012
[2] T. Thomson, et al., Phys. Rev. Lett., 96, 257204, 2006

P.54 **Towards atomic scale characterisation of perpendicular anisotropy materials for spintronics**

D Huskisson, T Thomson, E Hill and S Haigh

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Materials with perpendicular magneto-crystalline anisotropy, specifically FePt, FeRh and MnAl, offer improved magnetic properties over conventional in-plane materials. They give potential benefits to many applications, including high density data storage above $_1$Tbit/in^2 [1] and efficient spin torque oscillators [2]. This study aims to characterise these materials on the nano-scale and develop their potential in thin-film devices.

Mechanical polishing is used as a relatively quick, effective method for atomic-resolution sample preparation. TEM observations are made of grain size in sputtered FePt thin films, shown in figure 1, which is critical for the correlation of structural with magnetic properties. Single-crystal MgO substrates facilitate the growth of the $L1_0$ (001) texture which leads to high perpendicular anisotropy.

Work will be extended to in situ annealing to observe the ordering process of $L1_0$ FePt, as well as the antiferromagnetic-ferromagnetic phase transition in FeRh. Future work will focus on $L1_0$ MnAl as a novel, economic ferromagnetic material.

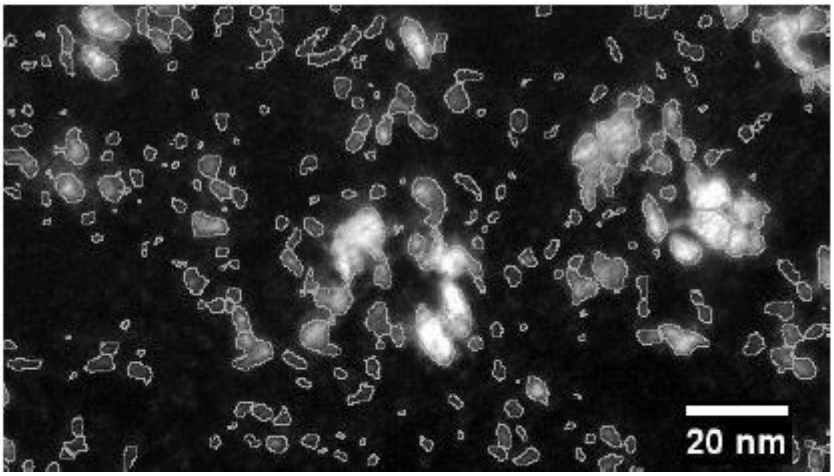

Figure 1: Section of a dark field, plan view image of 10nm as-deposited FePt thin film showing outlined grains. Average grain size of 13.8 ± 1.2 nm from a total count of 843 grains.

[1] Maat et al, *Phys. Rev. B.*, 2005, 72, 214432
[2] Firastrau et al, *J. Appl. Phys.*, 2013, 113, 113908

P.55 **Fluence study of Co_2MnSi thin films for suitability in spin Seebeck devices**

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Loughborough University, UK

The Heusler alloy *Co_2MnSi* (CMS) has been theorised to exhibit 100% spin polarisation at the Fermi energy[1] and as a result is of particular interest in the field of spintronics. More recently, the observation of the spin Seebeck effect in CMS[2] suggests potential energy harvesting applications that could rival conventional thermoelectric technology.

In this study, CMS thin films were grown on glass substrates by pulsed laser deposition (PLD) as a function of laser fluence, and the structural, magnetic and transport properties were studied. The impact of the deposition conditions on key parameters such as the coercive field (see Figure 1), film structure and electric characteristics will be discussed with regards to the suitability of CMS in spin Seebeck devices.

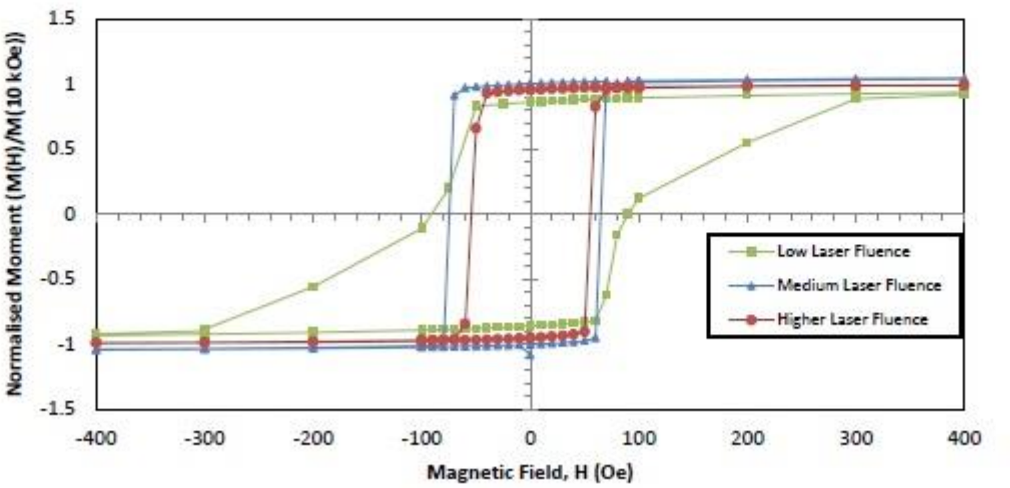


Figure 1: Normalised $M(H)$ loops for thin films deposited on glass at 170°C using different laser fluences.

[1] M. Jourdan *et al.*, Nat. Commun. 5, 3974 (2014)
[2] S. Bosu *et al.*, Phys. Rev. B 83, 224401 (2011)

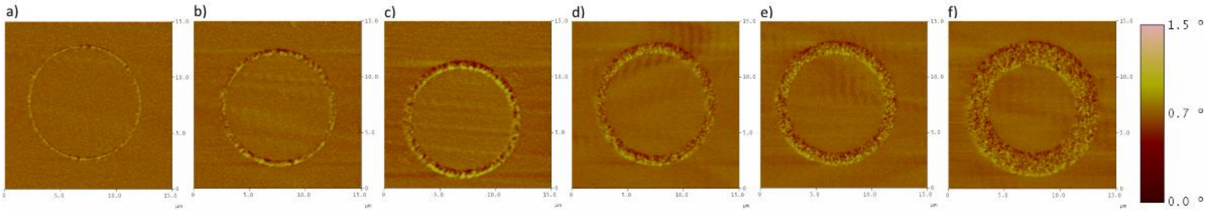
P.56 **Optimisation of Fe_3O_4 nanostructures for atom trapping applications**

R C Bradley, D A Allwood and T J Hayward

University of Sheffield, UK

We have previously proposed a method of using the stray field from a domain walls (DWs) in $Ni_{80}Fe_{20}$ nanowires to trap ultra-cold atoms [1,2]. However, using a material with higher electrical resistivity would substantially increase the lifetimes of the traps. Mn-doped Fe_3O_4 is a promising candidate material, and here we will assess its suitability by attempting to form 180° DWs in a range of ferrite nanorings.

We have fabricated Fe_3O_4 thin films grown at T=300-500°C on Si/SiO_2 and MgO(100) substrates using reactive sputtering. The roughness and magnetic properties of these films were characterised as a function of growth temperature, thickness and substrate using atomic force microscopy and magneto-optic Kerr effect measurements. We show that the films grown on MgO(100) substrates are the best candidates for nanostructure fabrication due to their low roughness (<1nm), and that films grown at 500°C are most promising for the formation of DWs due to their low coercivity. We then present magnetic force microscopy measurements of nanorings with widths (100nm – 2μm), patterned from the precursor films using electron beam lithography and ion milling, in order to assess the ease with which DWs can be formed. Finally, we discuss the prospects of creating usable atom traps from nanostructures similar to those we have fabricated.



MFM images of Fe_3O_4/Si nanorings grown at 500°C with a radius of 5μm. Nanoring widths are 100nm (a), 300nm (b), 500nm (c), 800nm (d), 1μm (e) and 2μm (f).

[1] D.A. Allwood et al, Applied Physics Letters 89 (2006) 014102

[2] T.J. Hayward et al, Journal of Applied Physics 110 (2011) 123918

P.57 **Magnetic and structural properties of Ni_2MnAl alloy grown at elevating temperatures**

H Wu, T Huminiuc, J Sinclair, O Whear, A Hirohata, G Vallejo Fernandez and K O'Grady

University of York, UK

IrMn has currently been used in a magnetic read-head element in a hard disk drive (HDD) due to its high thermal stability of the antiferromagnetism corrosion resistance [1]. Because of the increasing demand for the HDD and the scarcity of Ir, this study aims to replace IrMn with an antiferromagnetic Heusler alloy.

50nm thick Ni_2MnAl films were deposited on Silicon substrates with a 18nm silver seed layer and a 3nm aluminium capping layer using a HiTUS system. The substrates were heated at above 250°C during the deposition. The films were then characterised by vibrating sample magnetometry (VSM) and X-ray diffraction (XRD). According to a hysteresis loop measured by VSM, the film grown on a heated substrate shows ferromagnetic behaviour, whereas the post annealed shows paramagnetic behaviour as shown in Fig.1.

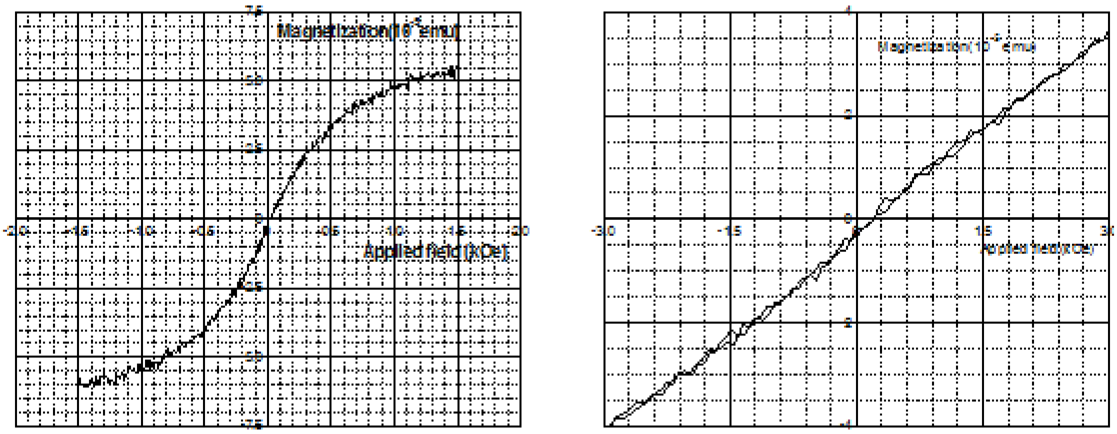


Fig 1. Hysteresis loops for Ni_2MnAl thin films grown at 250°C and post annealed at 250°C for 3 hours.

To find the antiferromagnetic behaviour of Ni_2MnAl, the layer was grown with an additional CoFe ferromagnetic layer on top of the Ni_2MnAl layer. Atomic substitution of the constituent element would allow Ni_2MnAl to improve the antiferromagnetism.

[1] http://www.harfir.eu

P.58 **Growth of Fe/MgO/GaN(0001) heterostructure by molecular beam epitaxy**

N Khalid[1,2], J-Y Kim[1], A Ionescu[1], F Oehler[1], I Farrer[1], R Ahmad[1], T Hussain[2] and C Barnes[1]

[1]University of Cambridge, UK, [2]Government College University, Pakistan

Ferromagnetic metal/semiconductor heterostructures with an oxide tunnelling-barrier in between have important technological implications in the context of spin-transport electronics, usually referred to as spintronics [1,2]. Moreover, low spin-orbit interaction and subsequent long spin lifetime [3] make GaN a promising material for spintronics research. In this paper, we have studied the structural and magnetic properties of fully epitaxial Fe(110)/MgO(110)/GaN(0001) tunnel barrier structures grown by molecular beam epitaxy. The out-of-plane X-ray diffraction spectra show an epitaxial Fe(110) film, while reflective high energy electron diffraction images (RHEED) (Fig. 1 (a)) show the epitaxial growth of Fe(110) on top of epitaxial MgO(110) on GaN(0001). X-ray reflectivity measurements confirm relatively smooth interfaces with roughness of approximately 0.3 nm and 0.7 nm for the MgO/GaN and Fe/MgO interfaces, respectively. From hysteresis loops obtained by *in-situ* magneto-optic Kerr effect (MOKE) measurements the appearance of an exchange bias field was detected (Fig. 1 (b)), which is assumed to arise from the presence of antiferromagnetic FeO at the Fe/MgO interface [4]. MOKE results also showed that an 1 nm thick Fe film is already ferromagnetic at room temperature and indicated an increase in the coercivity with an increase in thickness in agreement with previous studies on Fe(110)/GaN(0001) structures [5].

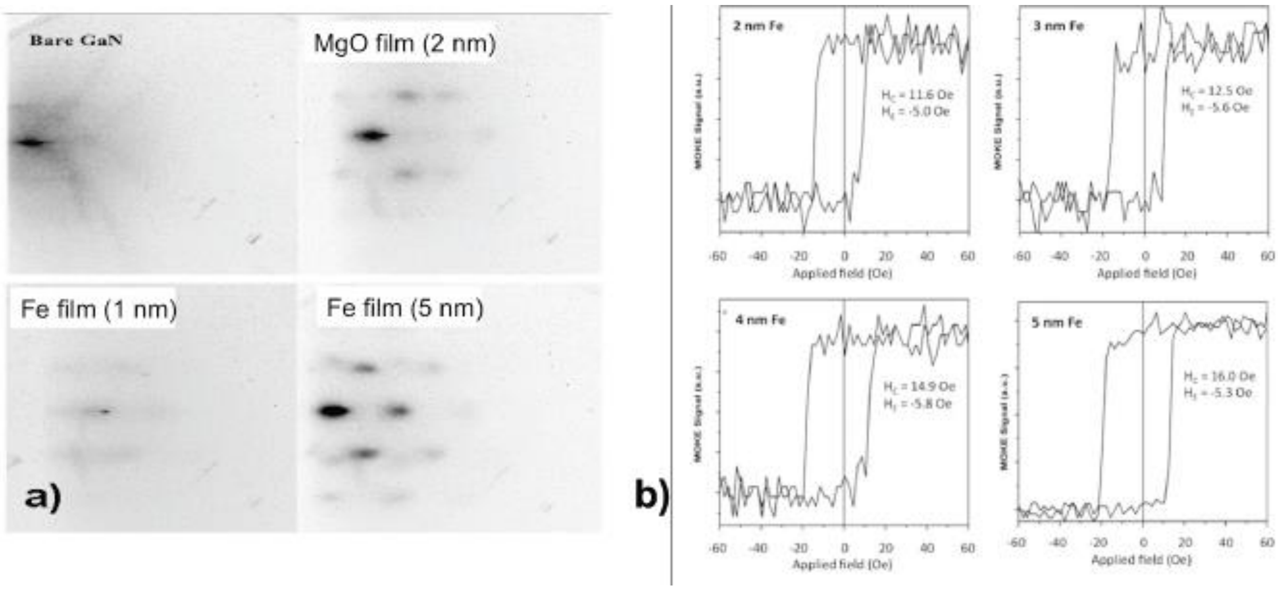


Figure 1: a) RHEED images taken at 15 kV along the [11-20] direction of the GaN substrate, 2 nm epitaxial MgO film and 1 and 5 nm Fe films confirming full epitaxial relations. b) MOKE *M-H* loops of thin epitaxial Fe films (t= 2, 3, 4 and 5 nm) on MgO/GaN(0001) substrates.

[1] S. Datta and B. Das, Applied Physics Letters 56, 665 (1990)
[2] G. Schmidt *et al*., Physics Review B 62, R4790 (2000)
[3] S. Krishnamurthy *et al*., Applied Physics Letters 83, 1761 (2003)
[4] Y. Fan *et al.*, Nature Nanotechnology 8, 438 (2013)
[5] J.-Y. Kim *et al.*, in preparation

P.59 **Effect of Fe Underlayer in Ultrathin FeRh films**

C Barton[1], G Hrkac[2], L Saharan[2] and T Thomson[1]

[1]University of Manchester, UK, [2]University of Exeter, UK

Recently, stabilized ferromagnetic phase in FeRh has been observed in thin films less than 10nm [1]. The aim of this study is to understand the role of Fe diffusion at the interface of MgO and its importance in stabilizing the ferromagnetic phase in FeRh. In our experiment we deposit $Fe_{50}Rh_{50}$ from an alloy target onto (001) MgO substrate with and without an Fe underlayer.

Figure 1(a) shows the ratio of the normalized magnetization as measured 300K to that measured immediately after the transition (without Fe). It is seen that as the thickness is reduced below 5nm the ratio increases dramatically and demonstrates that in FeRh thin films stabilized ferromagnetic behavior is present.

Figure 1(b) shows the lattice constant of a 10nm FeRh obtained by XRD measured perpendicular to the sample plane. It can be seen that as the temperature increases there is a sudden increase in the lattice constant, in the z-direction, as the film passes the FM transition. These data show that is possible to observe the transition from a structural perspective and can give information about the critical transition temperature in the absence of applied field at a particular pressure.

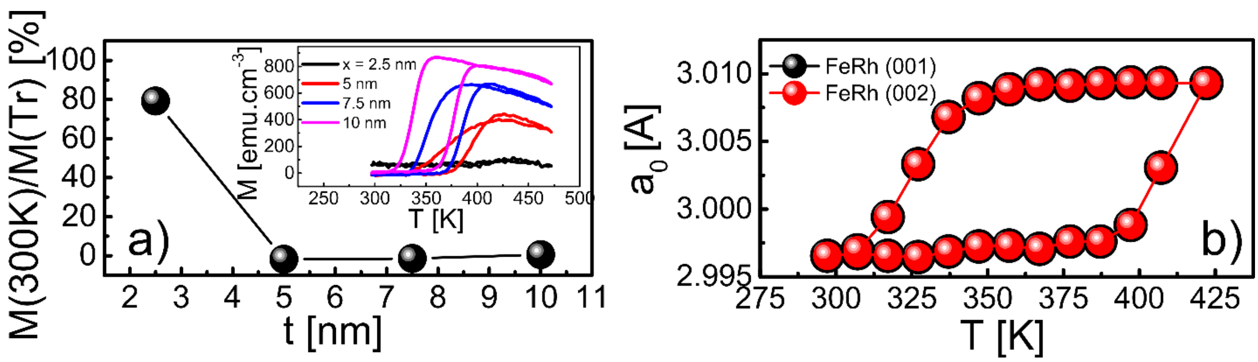


Fig 1: a) magnetization ration at room temperature to that immediately after the FM transition; inset is magnetometry obtained in a 1kOe applied field using VSM; and b) demonstrates the lattice constant as a function of temperature.

[1] Han, G. C., et al, J. Appl. Phys, 113, 17C107 (2013).

P.60 **Surface relaxation, Ga segregation and electronic structure in MnSb (0001) epitaxial films on GaAs(111)A from first principles**

H Wang[1], J D Aldous[2], S A Hatfield[1] and G R Bell[1]

[1]University of Warwick, UK, [2]University College London, UK

MnSb is a highly attractive ferromagnetic material for hybrid semiconductor spintronics. For spin injection applications, optimized surface and interface structures are critical. Surface relaxations and formation energies were calculated for differently-terminated MnSb(0001)-(1 × 1) surfaces using density functional theory (DFT) implemented in the CASTEP code. After geometry optimization, we find that the Sb-terminated surface experiences smaller relaxations and is much more stable under both Mn-rich and Sb-rich conditions (Fig. 1). These results are in agreement with experimental medium energy ion scattering (MEIS) data and behavior observed in molecular beam epitaxy (MBE). In addition, Ga surface segregation through the MnSb film from the GaAs substrate during MBE was confirmed from our MEIS experiment. Structural models incorporating Ga in the near-surface region were tested in DFT and occupation of Mn substitutional sites just below the surface is found to be favourable under all allowed conditions of chemical potential, which explains the observed segregation (Fig. 2).

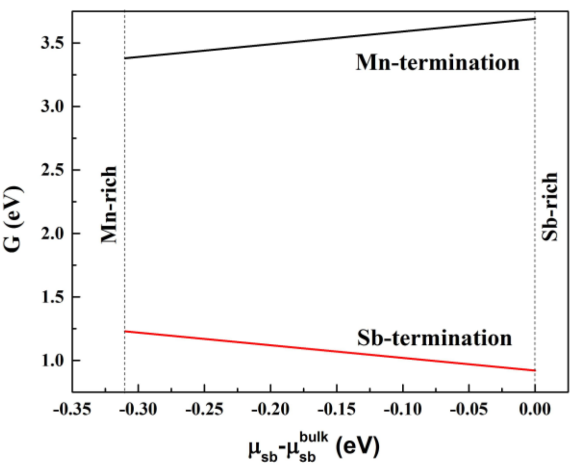


Fig. 1

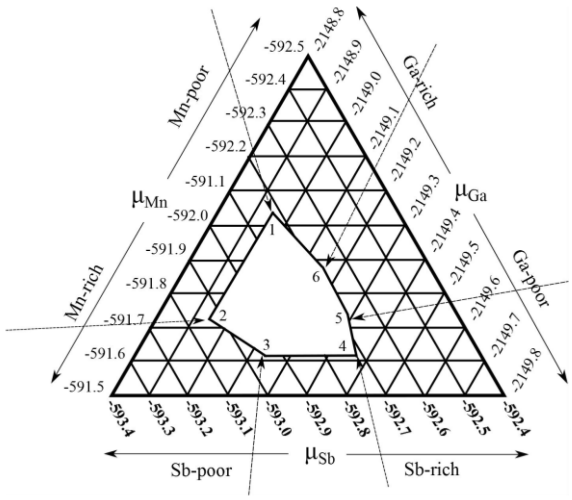


Fig. 2

Fig. 1: The relationship between free energy of MnSb(0001)-(1 × 1) surface and Sb chemical potential $\mu_{Sb} - \mu_{Sb}^{bulk}$, in the allowed range defined by the vertical dashed lines. Fig. 2: The allowed region of chemical potential phase space within which Ga(Mn)Sb surface can be thermodynamically stable (white polygon). In this whole region, Ga is preferentially located sub-surface rather than at the surface or in deeper layers.

P.61 **Direct band-gap measurement on a NiMnSb Heusler alloy at room temperature**

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We recently developed a new technique to measurement a band-gap (E_g) in a half-metallic ferromagnet using circularly polarised photoexcitation [1]. We reported E_g of the minority spin band in full-Heusler alloys and have extended our study to a half-Heusler alloy of NiMnSb. E_g of bulk NiMnSb half-Heusler alloy was measured at room temperature (RT) using our recently developed technique. E_g measurements were conducted by introducing circularly polarised IR light (*hv*) with the energy matching with expected E_g for NiMnSb at RT.

E_g for NiMnSb has been calculated to be 500 meV at 0 K, shrinking at higher temperatures as the overall magnetisation drops [2]. The reflected intensity of NiMnSb was first measured without applying a magnetic field followed by measurements with the fields with N- and S-pole upwards. By maintaining the circular polarisation, one of the field orientations should only provide a dip in the reflection intensity due to the absorption corresponding to minority E_g. The dip should also become prominent by taking differences (ΔV) between the measurements with the N- and S-pole upwards. As shown in Fig. 1, a small dip at ~ λ = 7 μm was clearly observed. A similar dip was also seen with the field with the N-pole upwards. We have attributed this dip to be the evidence of the IR absorption at E_g. E_g for NiMnSb is hence estimated to be ~175 meV, which is consistent with the expected reduction in E_g at RT. These measurements confirm the ability of our technique to measure E_g of a wide range of Heusler alloys at RT.

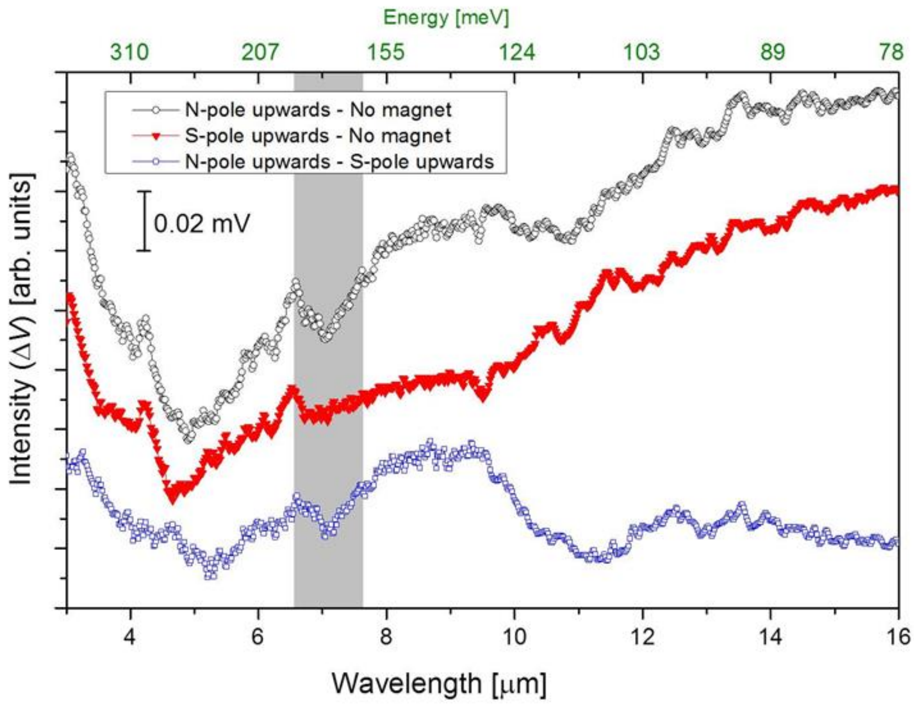

Figure 1: Intensity differences (ΔV) between with and without magnetic fields together with those between the N- and S-pole upwards for NiMnSb.

[1] T. F. Alhuwaymel *et al.*, *IEEE Trans. Magn*. 50, 2600504 (2014)

[2] J. D. Aldous *et al.*, *Phys. Rev. B* 85, 060403 (2012)

P.62 **Characterisation of pollycrystalline heusler alloys**

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Heusler alloys have significant potential for applications in spintronic devices because of their 100% spin polarisation at the Fermi level at room temperature. There are a large range of Heusler alloys, some of which exist in a ferromagnetic state [1] and the others which are predicted to be antiferromagnetic [2]. The possibility of producing an antiferromagnetic Heusler alloy would give a material suitable to create a pinning layer via exchange bias. The standard alloy used to create an exchange biased pinning layer is IrMn where Ir is a scarce element. Ni_2MnAl and Fe_2VAl were the alloys chosen for which the structural and magnetic properties have been studied. Polycrystalline thin films of these materials were deposited using a HiTUS system. The thickness of the films was (100 ± 2) nm. The samples were annealed in a vacuum furnace at a base pressure of 10^{-5}mbar at temperatures in the range 250 to 700°C.

Prior to annealing the samples exhibited a paramagnetism. It is predicted that the B2 phase of the Heusler alloys may develop an antiferromagnetic structure [3]. The degree of B2 ordering increases with both annealing time and temperature. An increase in coercivity is observed when using Ni_2MnAl as a pinning layer for the ferromagnetic Co_2FeSi as shown in *Figure 1*. $Fe_{2.5}V_{0.5}Al$ is also predicted to have an antiferromagnetic phase [2]. Seed layers, heated substrate growth and doping have been investigated to promote crystallisation of the AF phase and an increase in the Neel temperature.

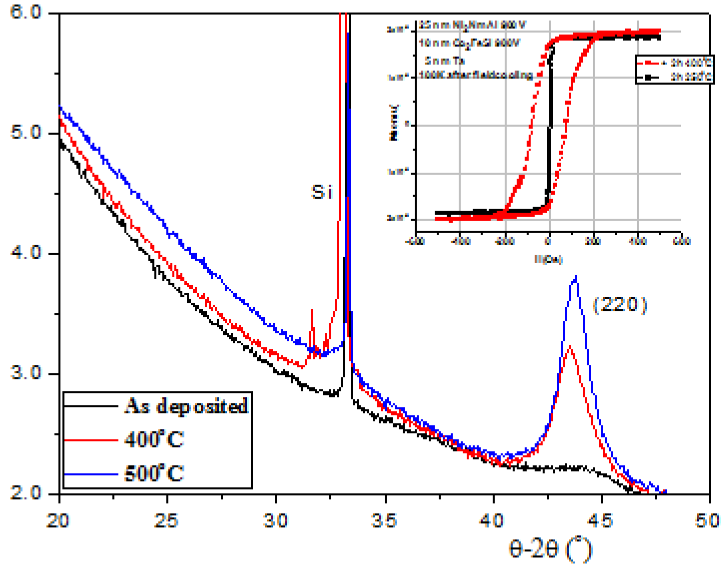

Figure 1: Crystallisation of Ni_2MnAl used as a pinning layer for Co_2FeSi.

[1] Endo et al, *J. Phys. D: Appl. Phys*. 44 (2011)
[2] Singh and I. Mazin, *Phys. Rev. B* 57, 14352 (1998)
[3] Acet et al, *J. Appl. Phys*, 92, 3867 (2002)

P.63 Exchange bias induced at a $Co_2FeAl_{0.5}Si_{0.5}$ /Cr interface

C N T Yu, A J Vick and A Hirohata

University of York, UK

Four sets of epitaxial thin films were grown on MgO (1 1 0) substrates by an UHV molecular beam epitaxy (MBE) system. All samples have the structure of Cr (3nm)/Ag (30nm)/ [CFAS (1nm-4nm)/Cr (0.9nm)]$_3$/ /MgO (3nm). By depositing Cr onto $Co_2FeAl_{0.5}Si_{0.5}$, Cr lattices are expected to stretch on the Heusler layer and induce an exchange coupling to the interfacial moments in the Heusler alloy layer [1].

ADE Model 10 virbrating sample magnetometer (VSM) was used for the magnetic measurement at room temperature. CFAS is reported to be cubic to exhibit fourfold magnetic anisotropy [2]. However, from Fig. 1, it only shows uniaxial anisotropy in the thinner region which is not consistent with the theory but similar to ultrathin Fe film [3]. This effect is most likely induced by the lattice mismatch due to the presence of Cr layers.

For 2 nm thick Heusler alloy sample, the magnetic anisotropy is found to be the maximum and it is tilted to 30° from the MgO [1 1 0] axis. This minor tilt agrees with the X-ray diffraction (XRD) result. The largest value of squareness (M_r/M_s) is 0.98 and the smallest M_r/M_s is 0.34 in 2 nm of Heusler alloy layers sample. As the thickness of the Heusler alloy layer increases above 3 nm, H_c is found to decrease, which is the result of emerging bulk-like properties of the Heusler-alloy layers.

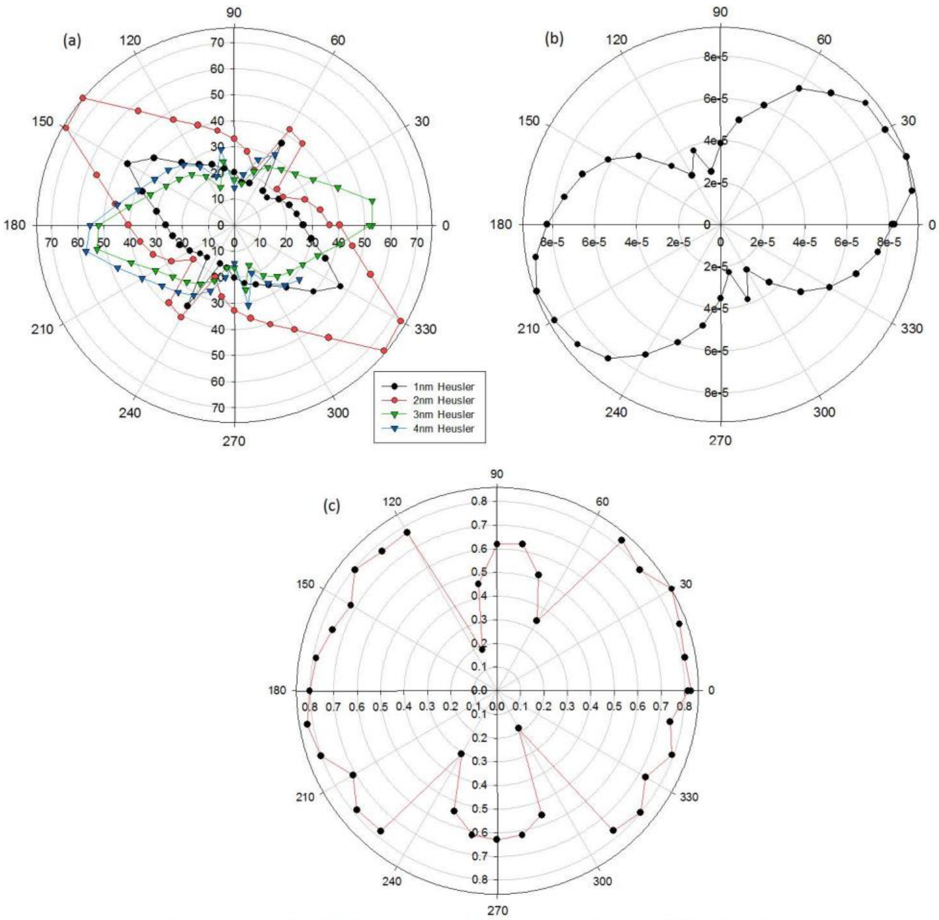

Figure 1: (a) Coercivity polar plot of four samples, (b) remanence polar plot of 2nm Heusler sample and (c) CFAS(2nm)/MgO(3nm).

[1] C. A. Culbert *et al*, *J. Appl. Phys*. 103, 07D707 (2008)
[2] C. Felser *et al*, *Spintronics: From Materials to Devices, p. 326-327 (2013)*
[3] J.-B. Laloë *et al., IEEE Trans Mag., VOL. 42, NO. 10,* (2006)

P.64 **Crystallographic optimisation of Co_2FeSi with perpendicular anisotropy**

W Frost and A Hirohata

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Heusler alloys are a potential replacement for conventional ferromagnets, e.g. FeCo, in spintronic devices. This is due to the potential to generate 100% spin polarisation at the Fermi level and high Curie temperatures. Crystallographic optimisation of Heusler alloys such as Co_2FeSi is vital for device implementation. Silver with a Chromium smoothing layer has become the seed layer of choice for GMR devices [1]. In this work Vanadium has been compared to Silver as an alternative seed layer in an attempt to induce perpendicular anisotropy and film texture and to reduce annealing temperatures and times for crystallisation. Polycrystalline samples were grown on Silicon substrates in a HiTUS deposition system. The thicknesses of the two seed layers have been varied and the corresponding properties have been analysed using XRD and VSM.

Initial measurements indicate a higher level of texture in Vanadium seed layer films with a *B2* structure as well as a greater crystallisation. A thickness of 15nm was found to maximise M_S and loop squareness in a perpendicularly magnetised film. An M_S value of 800 emu/cm^3 is obtained as compared to the theoretical value of 1200 emu/cm^3 for Co_2FeSi.

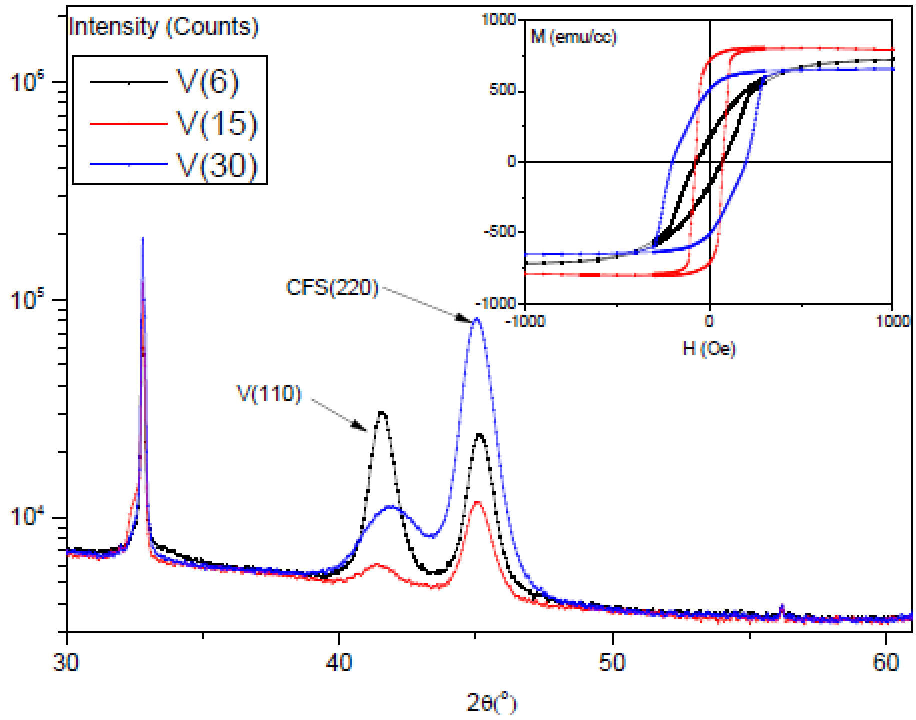

Fig. 1: XRD scans and out-of-plane hysteresis loops for Co_2FeSi films grown on Vanadium seed layers at varying thicknesses.

[1] Sakuraba *et al*, J. Magn. Soc. Jpn., 38, 45-49 (2014)

P.65 **Characterisation of néel transitions in heusler alloys**

J Sinclair, T Humunic, H J Wu, G Vallejo-Fernandez and A Hirohata

University of York, UK

In the past few years there has been a large increase in demand for Iridium due to its applications in magnetic memory and storage. This is due to its ability to form a sheet antiferromagnet with a blocking temperature above 300K when combined with Manganese. Unfortunately as a consequence of this increase in demand for Iridium, the price has soared making it necessary to explore other options for creation of antiferromagnetic layers in spintronic devices.

The most promising group of materials for this application are Heusler alloys with a number predicted to exist in an antiferromagnetic state [1]. To achieve this it will be necessary to characterise the magnetic ordering temperatures of the alloys of interest, namely Ni_2MnAl and Fe_2VAl. Sheet resistance measurements are achieved using 4 point measurement with Van der Pauw geometry in an Oxford Instruments cryostat, to increase our testing capabilities much of the procedure has been automated. This will allow not only measurement of the Néel temperature for the two alloys mentioned above, but also exploration of the dependence of the Néel temperature on annealing time and crystallinity. These properties can be controlled through the use of a vacuum annealing furnace and deposition parameters on the HiTUS sputter deposition system used to produce the flims.

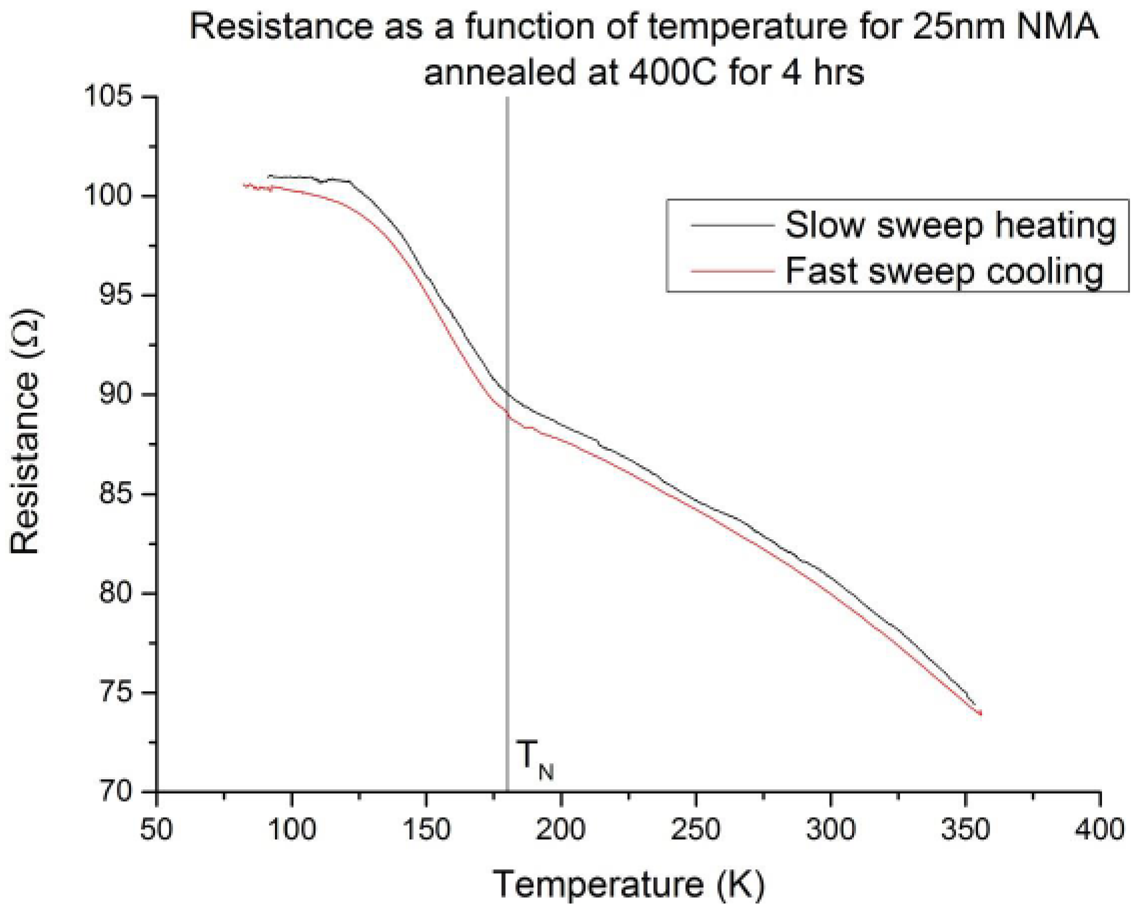

Figure 1 - Temperature dependence of resistance for Ni2MnAl, showing a clear transition to the AF state at ~180K with little variation with temperature sweep speed and direction.

[1] Singh and Mazin, *Phys. Rev. B 57*, (2011)

P.66 **Amorphous glass-coated nanowires and submicron wires prepared by rapid quenching from the melt**

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Rapidly solidified amorphous glass-coated nanowires and submicron wires are a novel class of ultra-thin magnetically soft materials with high prospects of being employed in novel micro and nano-sensing devices. Samples with both nearly zero magnetostriction ($Co_{68.15}Fe_{4.35}Si_{12.5}B_{15}$) and highly positive magnetostriction ($Fe_{77.5}Si_{7.5}B_{15}$) have been prepared and studied experimentally to understand the peculiarities of their magnetic behaviour. The SEM image of a rapidly solidified $Fe_{77.5}Si_{7.5}B_{15}$ amorphous glass-coated nanowire with the nucleus diameter of 100 nm is shown in Fig. 1.

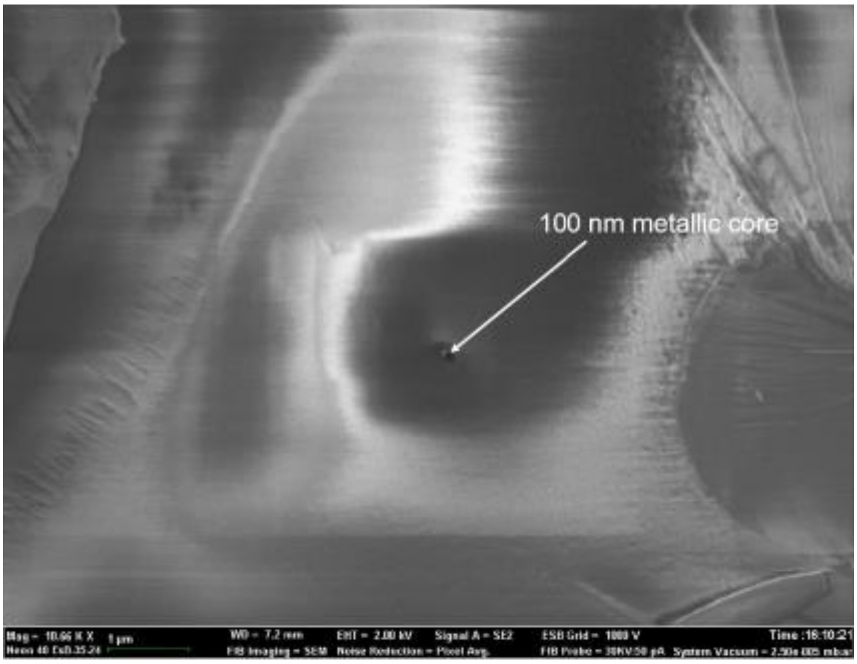

Fig. 1. SEM image of a glass-coated amorphous nanowire.

The volume hysteresis loops have been measured using an inductive technique. Magneto-optical Kerr effect (MOKE) has been employed to measure the surface loops. Both indicate the appearance of a one-step axial magnetisation reversal through the displacement of a domain wall along the sample length. The wall propagation characteristics have been measured using the Sixtus-Tonks method. The simultaneous use of MOKE and Sixtus-Tonks method allowed us to explore the shape of the propagating walls.

The interpretation of the results revealed the origin of the magnetic anisotropy and its relation with the domain wall velocity and mobility of these nanowires.

Work supported by the Romanian Ministry of Education and Scientific Research through contract no. 46/2013 (project no. PN-II-ID-PCE-2012-4-0424) and by the European Commission under the FP7-REGPOT-20012-2013-1 project NANOSENS (grant agreement no. 316194).

P.67 The effect of post-annealing conditions on the iron oxides thin films grown on MgO(100)

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Growth defects, domain structures and off-stoichiometric compositional deviation are the cause of anomalous magnetic and transport properties of magnetite (Fe_3O_4) thin films. Post-annealing at high temperature of Fe_3O_4 films in a CO/CO_2 atmosphere results in a significant improvement of magnetic and magnetotransport properties [1,2] compared to bulk specimens. In this work, we present atomistic study on the oxidation of Fe thin films as well as FeOx with aim to understand the correlation between the structure and functional properties of iron oxide films. Control of the oxidation and structure was achieved by *in-situ* oxygen plasma annealing followed by *ex-situ* postannealing in various gas mixtures. By optimizing post-annealing conditions, we show the influence of annealing temperature and flux of CO/CO_2 gas mixture on the structure of the iron oxides films by means of x-ray photo electron spectroscopy, magnetoresistance, alternating-gradient magnetometer and transmission electron microscopy techniques.

[1] K. Matsuzaki et al., *J. Phys. D: Appl. Phys.* 46 *022001* (2013)
[2] D. Gilks et al., *J. Appl. Phys.* 115 *17C107* (2014)

P.68 Exchange bias films with perpendicular anisotropy

K Elphick[1], G Vallejo-Fernández[1], T J Klemmer[2] and K O'Grady[1]

[1]University of York, UK, [2]Seagate Media Research Centre, USA

For many potential device applications of CPP, GMR or TMR there is a requirement for one of the ferromagnetic (F) layers in the stack to have its magnetisation fixed or pinned perpendicular to the plane of the film. The most commonly used F layer for perpendicular anisotropy is a Co/Pt multilayer, [1]. To create the exchange bias effect the multilayer was grown on an antiferromagnetic (AF) layer of IrMn. [2]

The $(Co/Pt)_n$ multilayers were sputtered using a HiTUS deposition system. [3] The multilayers were exchange biased using a 10nm IrMn layer which was grown on a Ta(5nm)/Ru(5nm) or a Cu(5nm) seed layer. The samples were capped with 5 nm of Ta. The number of repeat bilayers n was varied in order to control the perpendicular anisotropy.

Seed	N	H_{ex} (Oe) (±5 Oe)	$\langle T_B \rangle$ (±2K)
Ta/Ru	3	65	465
	5	70	431
	10	33	425
Cu	3	638	>500
	5	376	>500
	10	121	-

Table 1

The data in table1 shows a number of unexpected features. The first of these is that the texture of the IrMn dominates the coupling. It is known from previous work [4] that the Ta/Ru seed layer induces good (111) texture in the IrMn. A Cu seed layer induces weak (111) texture in the IrMn which will have a larger fraction of the (111) planes lying out of the plane of the film. For the sample with n=3 grown on a Cu seed a value of Hex of over 700 Oe was found which is well within the range required for device applications.

[1] Lui, J. W. Cai, S. L. He, *J. Phys. D. Appl*. Phys. 42 115002 (2009)
[2] J. Sort, et al., *Phys. Rev.* B 71, 054411 (2005)
[3] Vopsariou, et al., *J. Phys. D: Appl*. Phys. 38 (2005) 490-496
[4] Aley, et al., IEEE Trans. Mag. 45 10 pp3869-3872 (2009)

P.69 **Hexapod Hall scanner for high-resolution magnetic imaging**

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Imperial College London, UK

Scanning Hall probe microscopy is a powerful magnetic quantitative imaging technique that offers a unique combination of a large scan range with a submicron lateral resolution and a large measured magnetic field range [1-3].

In this work, we report the design, construction and performance of a scanning Hall probe microscope (SHPM) that uses six bending piezoelectric actuators arranged in a hexagonal configuration, which allows both translation and rotation of a mounted Hall probe along the three Cartesian coordinates. Combining such general advantages of the technique as the high scan range (demonstrated in Fig.1) and the submicron resolution (provided that a high-resolution Hall probe is used), the constructed SHPM offers a unique opportunity of the *in situ* adjustment of the alignment of the sensor with respect to the sample surface that enhances the lateral resolution of the imaging device.

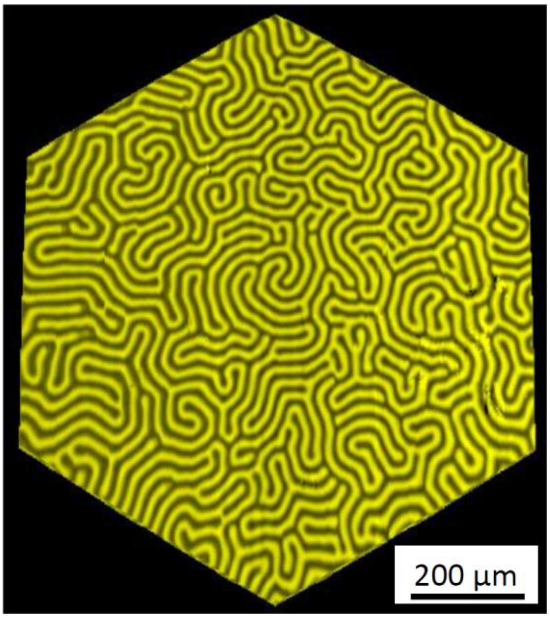

Fig.1. Magnetic image of the domain structure in a ferrite garnet film that illustrates the maximum scan range (image area ~ 0.65 mm^2).

[1] A. Oral, S.J. Bending, M. Henini, *Appl. Phys. Lett.* 69, 9, (1996)

[2] V.V. Khotkevych, M.V. Milošević, S.J. Bending, *Rev. Sci. Instrum.* 79,123708, (2008)

[3] Chiu-Chun Tang, Hui-Ting Lin, Sing-Lin Wu, Tse-Jun Chen, M. J. Wang, D. C. Ling, C. C. Chi, and Jeng-Chung Chen, *Rev. Sci. Instrum.* 85, 083707 (2014)

P.70 **Determining the anisotropy of bit patterned media for optimal performance**

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[1]University of Manchester, UK, [2]Copperbelt University, Zambia

In conventional recording theory the transition width should be minimised by writing the transition at the location of the maximum head-field gradient, and this should be achieved by setting the coercivity equal to the head field at the location of maximum head field gradient (taking appropriate account of the variation of coercivity with field angle). In BPM it would therefore be natural to assume that the system could be optimised by setting the island switching field in a similar manner. In this work we investigate what strategy of optimisation gives the minimum error rate, or maximum write-window.

To investigate error rates for different designs we have employed a statistical model that uses single spin or two-spin magnetic models of islands and a vector head field to predict error rates and write-windows, which has verified against micromagnetic models and experimental results [1]. We have studied both Exchange Coupled Composite (ECC) islands and single layer islands, with comparable designs, which have shown that the predicting optimum hard-layer anisotropy by the maximum head field gradient design does not return minimum error rate in all cases.

We conclude that design of BPM systems should not be based upon maximum write field gradient but requires a statistical model of the write process. We propose that the design of BPM should be calculated from the far and near points of the write-window, which must be chosen to occur at the same head field gradient. This is equivalent to saying that design should be derived from the errors that occur at the extremities of the population, not by the average island characteristics [2].

[1] J. Kalezhi, S. J. Greaves, Y. Kanai, M. E. Schabes, M. Grobis, and J. J. Miles, “A statistical model of write-errors in bit patterned media,” J. Appl. Phys., vol. 111, no. 5, p. 053926, 2012

[2] J. Talbot, J. Kalezhi, C. Barton, G. Heldt, and J. Miles, “Write Errors in Bit Patterned Media: The Importance of Parameter Distribution Tails,” IEEE Trans. Magn., vol. 50, no. 8, 2014

Magnetocaloric, ferroelectrics and magnonics

P.71 Optimization of magnetocaloric properties of arc melted and spark plasma sintered $LaFe_{11.6}Si_{1.4}$

P Shamba[1], N Morley[1], O Cespedes[2], I Reaney[1] and M Rainforth[1]

[1]University of Sheffield, UK, [2]University of Leeds, UK

In the last years, there has been a considerable increase in research on near room temperature magnetic cooling[1, 2]. This new cooling technology which is expected to supersede the conventional refrigeration technology based on gas-compression/expansion is of special interest because of its considerable economic benefits. Magnetic refrigeration is based on the magnetocaloric effect (MCE) which results from the coupling of a system of magnetic moments with an external magnetic field resulting in the cooling or heating of a system[3]. The $La(Fe_xSi_{1-x})_{13}$ compounds with $NaZn_{13}$ structure are strong contenders for use in magnetic refrigeration[4-6]. They also have an added advantage of consisting of low cost elements. The only drawback of this material system, however, is the problem of low productively in manufacturing $La(Fe_xSi_{1-x})_{13}$ type materials. Currently, they are synthesized using the arc melting technique and in order to obtain the $NaZn_{13}$ phase, the alloy requires a long heat treatment of at least 14 days. The main aim of this work is to find a sustainable, cost effective processing route of synthesizing these alloys so as to increase the affordability of the $La(Fe_xSi_{1-x})_{13}$ based magnetic refrigerators. In this work the effect of a solid state reaction using the spark plasma sintering (SPS) technique to form the $NaZn_{13}$ structure is investigated and compared with the conventional arc melting method with the ultimate aim of solving the low productivity problem in manufacturing $La(Fe_xSi_{1-x})_{13}$ type materials by providing a method of manufacturing which does not require a long heat treatment time. The magnetic entropy change, ΔS_M as a function of temperature for the arc melted $LaFe_{11.6}Si_{1.4}$ alloy is shown in Fig. 1 and it is observed that a maximum magnetic entropy change of 29.4 J/kgK in a field change of 5 T, occurs around a Curie Temperature, T_C of 185 K, which to the best of our knowledge is the highest reported value to date for the arc melted $LaFe_{11.6}Si_{1.4}$ alloy. We have also optimized the SPS synthesis for the $LaFe_{11.6}Si_{1.4}$ compounds by varying sintering conditions such as temperature, pressure and holding time. We have also carried out a detailed study of the microstructure of our SPS samples and we have correlated these results with results from the magnetic measurements. This will help elucidate the effect of microstructure on the magnetic as well as magnetocaloric properties of SPS synthesized $LaFe_{11.6}Si_{1.4}$ alloys. Such a study is vital in revealing the intrinsic relationship between composition, structure and magneto-thermal properties in improving magnetocaloric effects.

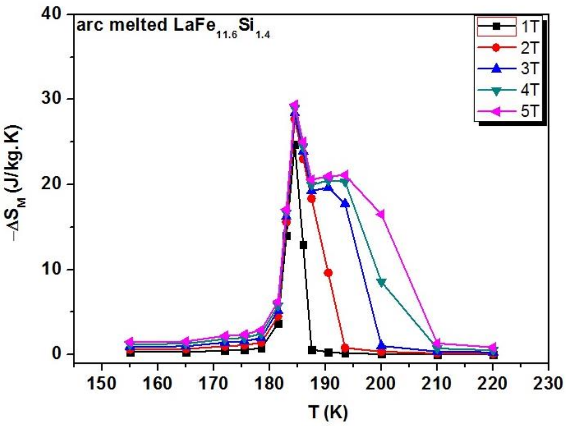

Figure 1. The magnetic entropy change, ΔS_M of the arc melted $LaFe_{11.6}Si_{1.4}$ alloy measured in the magnetic field range of 0 - 5T.

[1] H. Wada, S. Tomekawa and M. Shiga, *Cryogenics* 39, (1999) 915
[2] V. K. Pecharsky and K. A. Gschneidner, Jr., *Phys. Rev. Lett.* 78, (1997) 4494
[3] K. A. Gschneidner and V. K. Pecharsky, *J. Appl. Phys.* 85 (8), (1999) 5365
[4] C. Xu, G.D Li, L.G. Wang, *J. Appl. Phys.* 99, (1999) 123913
[5] J. Lyubina, K. Nenkov *et al.*, *Phys. Rev. Lett.* 101, (2008) 177203
[6] Z. Lin, S. Li *et al.*, *J. Alloys Compd.* 489, (2010) 1

P.72 **Magnetoelastic coupling in $EuTiO_3$: An examination by resonant ultrasound spectroscopy**

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Coupling of ferroelectricity and magnetism with strain is understood to be key to the multiferroic behaviour of $EuTiO_3$. This is shown, for example, by epitaxial films exhibiting ferroelectricity and ferromagnetism rather than the incipient ferroelectricity and antiferromagnetism of the bulk. Magneto-elastic coupling phenomena in a single crystal observed by resonant ultrasound spectroscopy in the range 2-300 K with external magnetic field up to 14 T show four distinct temperature regimes. The octahedral tilting transition at ~284 K is accompanied by elastic softening due to classical strain/order parameter coupling but with dependence on sample history and measurement type. At lower temperatures, down to a local maximum stiffness at ~140 K, there is hysteresis and a significant dependence of acoustic loss which is interpreted in terms of changes in microstructure and magnetic defects. Evidence for freezing of defect motion, followed by anomalous softening then occurs down to ~20 K. Additional anomalies at the lowest temperatures are clearly associated with magnetic ordering, indicating that significant coupling of strain with magnetic order parameters also occurs. In all, a rich pattern of magnetoelastic phenomena is described, and this sheds significant light on seemingly incompatible results previously described in the literature.

P.73 **Magnetic and Magneto-optical properties of films of multiferroic $GdMnO_3$ grown on $SrTiO_3$ and LSAT (100) and (111)**

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[1]University of Sheffield, UK, [2] National University of Science and Technology "MISiS", Russia

Bulk $GdMnO_3$ is a canted antiferromagnet below ~ 40K and ferroelectric below ~8K and is orthorhombic with axes a = 5.310 Å, b = 5.840 Å, c = 7.430 Å. This is formed from the cubic perovskite structure by a rotation of the oxygen octahedra in which the a and b axes are rotated by $\pi/4$ from the original cubic, x,y axes and the c axis is doubled. This involves a larger compressional mismatch for LSAT ($(La_{0.18}Sr_{0.82})(Al_{0.59}Ta_{0.41})O_3$) which has a lattice constant of 3.868 Å which compares with that 3.905 Å for $SrTiO_3$. Hence our experiments investigate the change in the magnetic properties due to a compressional strain.

There are two advantages of LSAT for our measurements, first it allows us to make measurements over a larger spectral range as it is not limited by the very strong absorption that occurs for $SrTiO_3$ at energies above 3.25eV and secondly the low temperature data is not contaminated by the structural transition that occurs in $SrTiO_3$ at ~110K.

The magnetic properties were measured using zero field cooled and field cooled magnetisation data and hysteresis loops obtained using a SQUID magnetometer for magnetic fields both in and out of the plane. At 5K the easy direction is in plane for LSAT (100) of the canted moment is larger 0.26 (μ_B/f.u.) which is significantly larger than that of 0.19 (μ_B/f.u.) which was found for epitaxial $GdMnO_3$ grown on $SrTiO_3$ [1]. The coercive field for the film grown on LSAT(100) was smaller than the one we had found grown on $SrTiO_3$ but comparable to a thinner film grown by PLD [2]. Both the moments and coercive fields were significantly smaller for the film grown on LSAT (111).

The two features in the optical spectrum that are well known from bulk studies; the charge transfer transition between Mn d states at ~2eV and the band edge transition from the oxygen p band to the d states at ~3eV are observed in the magnetic circular dichroism (MCD).

[1] Mohammed S. Al Qahtani, Marzook S. Alshammari, H.J Blythe, A.M. Fox, G.A. Gehring, N. Andreev, V. Chichkov, and Ya. Mukovskii Journal of Physics: Conference Series 391 012083 (2012)
[2] Xiang Li, Chengliang Lu, Jiyan Dai, Shuai Dong, Yan Chen, Ni Hu, Guangheng Wu, Meifeng Liu, Zhibo Yan, Jun-Ming Liu Scientific Reports 4, 7019 (2014)

P.74 **Exploring the mechanism of relaxation across the first-order metamagnetic phase transition in magnetocaloric La(Fe,Si)$_{13}$**

E Lovell[1], A M Pereira[2], A D Caplin[1], J Lyubina[1] and L F Cohen[1]

[1]Imperial College London, UK, [2]Universidade do Porto, Portugal

The $LaFe_{13-x}Si_x$ family of materials are of considerable interest for solid state magnetic cooling because of large entropy changes and small thermal and magnetic hysteresis [1]. The metamagnetic transition is easily tuned over a wide temperature range by substitution of appropriate elements or by hydrogenation [2]. Unlike many of the original giant magnetocaloric materials [3], $LaFe_{13-x}Si_x$ is an itinerant ferromagnet with large spin fluctuations close to the magnetic transition [4], sharp specific heat features and a large latent heat component [5] resulting in the system being driven out of isothermal equilibrium when the magnetic field is cycled on laboratory times scales [6]. Interestingly the system shows significant long-time magnetic relaxation across the phase transition related to the first order nature of the transition [7, 8]. A number of groups have begun to study the magnetic relaxation dynamics as a function of temperature [9] and field [7]. Here we show that the relaxation rate slows as the temperature is increased towards a tri-crticial point, above which the metamagnetic transition becomes second order and the relaxation dynamics disappear.

Funding Acknowledgement: EC FP7 310748 “DRREAM” and EPSRC EP/G060940/1.

[1] F. Hu et al, *Appl. Phys. Lett.* 78, 3675 (2001)
[2] A. Fujita et al, *Phys. Rev. B* 67, 104416 (2003)
[3] V. K. Pecharsky et al, *Phys. Rev. Lett.* 78, 4494 (1997)
[4] A. Fujita et al, *J. Appl. Phys.* 85, 4756 (1999)
[5] K. Morrison et al, *Phil. Mag.* 92, 292 (2012)
[6] J. Moore et al, *Appl. Phys. Lett.* 95, 252504 (2009)
[7] H. Yako et al, *IEEE Trans. Mag.* 47, 2482 (2011)
[8] E. Lovell et al, *Adv. Energy Mater.* 1401639 (2014)
[9] M. Kuepferling et al, *J. Appl. Phys.* 115, 17A925 (2014)

P.75 **Magnonic beam splitter: The building block of parallel magnonic circuitry**

C Davies[1], A V Sadovnikov[2], S V Grishin[2], V V Kruglyak[1], D V Romanenko[2], Y P Sharaevskii[2] and S A Nikitov[3]

[1]University of Exeter, UK, [2]Saratov State University, Russia, [3] Kotel'nikov Institute of Radioengineering and Electronics, Russia

We demonstrate a magnonic beam splitter that works by inter-converting magnetostatic surface and backward volume spin waves[1] propagating in orthogonal sections of a 0.5mm wide T-shaped yttrium iron garnet (YIG) waveguide structure. The inter-conversion is enabled by the overlap of the spin wave bands, which originates from two effects. Firstly, the edge magnetic charges create a demagnetising field in the transversely magnetised section(-s) of the structure. Secondly, the finite width leads to the quantization of the transverse wave number of the propagating spin waves, which are therefore better described as waveguide modes. In agreement with numerical micromagnetic simulations, our Brillouin Light Scattering[2] imaging experiments reveal that, depending on the frequency, the incident fundamental waveguide magnonic modes may also be converted into higher order waveguide modes (Fig.1). The magnonic beam splitter demonstrated here is an important step towards the development of parallel logic circuitry of magnonics.

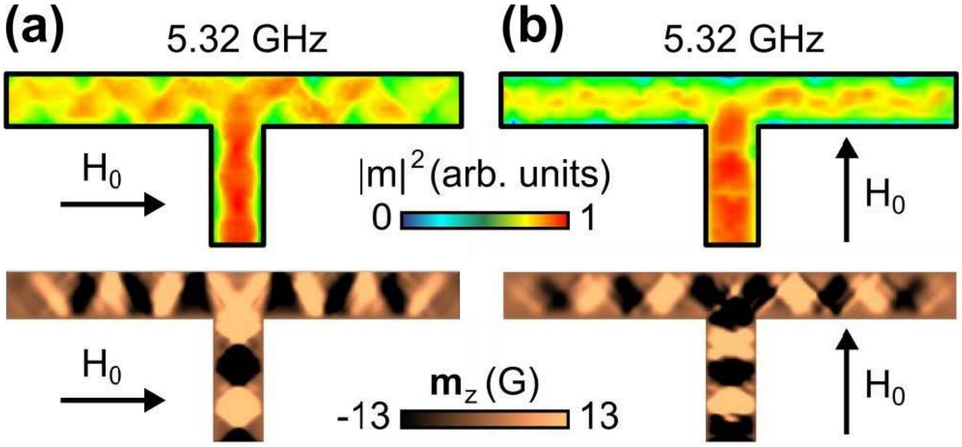


Fig. 1 Upper panels: amplitude-resolved BLS maps of the spin-wave propagation across the T-junction, where the bias field is oriented (a) orthogonal or (b) parallel to the leg of the T-junction, respectively. Lower panels: the simulated phase-resolved images of the spin wave are shown for the experimental images presented in the upper panels.

[1] R. W. Damon and J. R. Eshbach, J. Phys. Chem. Solids 19, 308 (1961)
[2] S. O. Demokritov, B. Hillebrands, and A. N. Slavin, Phys. Rep. 348, 441 (2001)

Skyrmions and topological effects

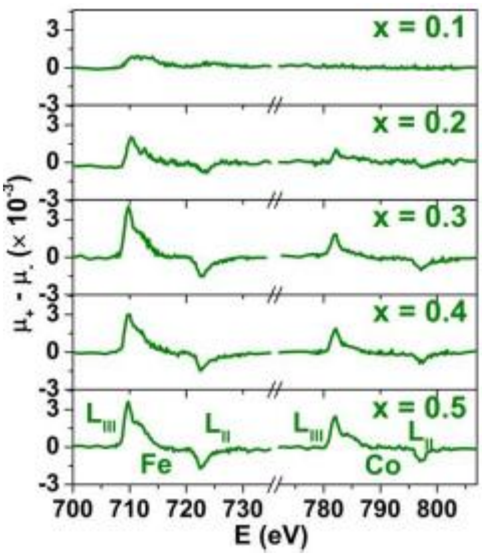
P.76 Itinerant magnetism in highly spin polarised B20 ε-$Fe_{1-x}Co_xSi$ epilayers

P Sinha[1], N A Porter[1], C SS pencer[1], D A Arena[2] and C H Marrows[1]

[1]University of Leeds, UK, [2]National Synchrotron Light Source, USA

FeSi is a non-magnetic narrow bandgap semiconductor, upon doping with Co a magnetic n-type semiconductor is obtained[1]. We previously reported the presence of highly spin-polarised electron gas for x<0.25 using a combination of Ordinary Hall Effect and saturation magnetic moment [3].

Electronic structure and magnetism were probed by soft X-ray absorption(XAS) and X-ray magnetic circular dichroism(XMCD) spectroscopy in total electron yield mode(TEY) by studying the $L_{2,3}$ edges of Fe and Co. Branching ratios[4] from XAS spectra of Co increases from 0.51(x=0.1) to 0.56(x=0.5) and that of Fe deviates little from 0.56, suggesting that the number of holes associated with Co increases from x=0.1 to x=0.5 where as that associated with Fe changes little. Variation in the occupation states of Fe and Co atoms coupled with shift in $L_{2,3}$ edges (~500meV) and the evolution of the L3 edge line shape indicates a modified band structure. Evolution of XMCD on both Fe and Co edges with doping is shown in Fig1. Whilst the magnetism in $Fe_{1-x}Co_xSi$ system arises from the Co doping, these asymmetry spectra clearly show that the magnetic moment is delocalised on both Co and Fe sites.



Work was supported by EPSRC, FP7-ITN-Q-NET, and U.S. Dept.of Energy, Office of Basic Energy Sciences.

[1] N.Manyala *et al*., Nature 404, 581 (2000)
[2] N. A. Porter *et al*., Phy.Rev.B, 86, 064423 (2012)
[3] P. Sinha *et al*., Phy.Rev.B, 89, 134426 (2014)
[4] B. T. Thole, *et al*., Phys. Rev. B. 5, 38 (1988)

P.77 **Superconductor skyrmion proximity in $Fe_{0.7}Co_{0.3}Si$/Nb bilayers**

N Satchell[1], N A Porter[1], P Sinha[1], M C Rosamond[1], S Langridge[2], C H Marrows[1] and G Burnell[1]

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At the interface between a superconductor and ferromagnet, singlet Cooper pairs are destroyed over a couple of nanometers within the ferromagnet, as a result of the ferromagnetic exchange energy. An inhomogeneity at this interface, however, can convert a singlet Cooper pair into the (spin aligned) long ranged triplet component (LRTC) [1]. Recent work in our group has shown a topological Hall effect (THE) in thin film $Fe_{0.7}Co_{0.3}Si$, close to the typical Tc of a singlet superconductor. THE is interpreted to be evidence for magnetic texture with non-zero skyrmion winding number (NZ-SWN). The THE is field history dependent, allowing measurement at an applied field in either a ferromagnetic or NZSWN state [2].

Here we present experimental work on a bilayer comprising of superconducting Nb, in proximity to $Fe_{0.7}Co_{0.3}Si$. When the NZ-SWN state is created (as indicated by the THE), we find evidence for the generation of the LRTC. As for superconducting spin valves [3]; both Tc and critical current density (J_c) of the Nb is suppressed. This is attributed to Cooper pairs passing from the Nb into the $Fe_{0.7}Co_{0.3}Si$ as LRTC. Inserting an insulating layer between the $Fe_{0.7}Co_{0.3}Si$ and Nb suppresses the effect, providing strong evidence of its electronic origin. This system has the significant advantage over previous works of being a single ferromagnetic layer with non-colinearity controlled by field history above T_C, not requiring a field rotation.

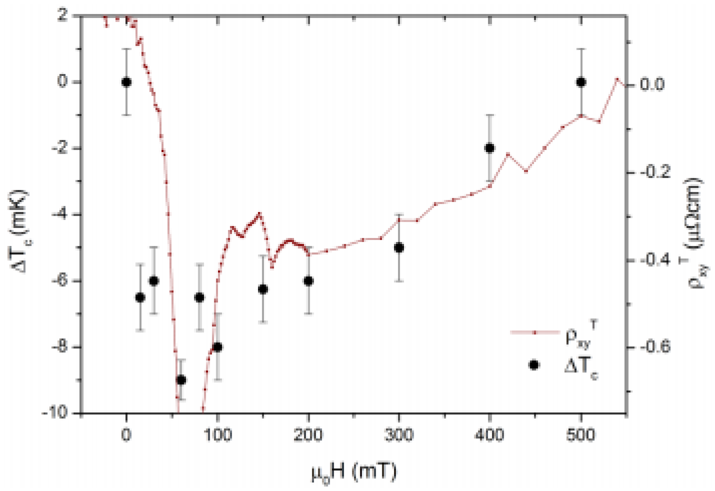

Fig.1: Shift in T_c (ΔT_c) plotted with the Topological Hall Effect (ρ^{T}_{xy}) when a field history creates the topological non-zero skyrmion winding number state, relative to the ferromagnetic state.

[1] M. Eschrig, Physics Today 64, pp. 43–49 (2011)
[2] N. A. Porter, arXiv:1312.1722 [cond-mat], (2013)
[3] P. V. Leksin, et al. Phys. Rev. Lett. 109, 057005 (2012)
[4] M. G. Flokstra et al. Phys. Rev. B (in press), arXiv:1404.2950 [cond-mat] (2014)

P.78 Depth profiling of the magnetic order in Cr-doped Bi_2Se_3 thin films

N J Steinke[1], L J Collins-McIntyre[2], S E Harrison[3], P Schoenherr[2], C J Kinane[1], T R Charlton[1], D Alba-Venero[1], A Pushp[4], A J Kellock[4], S S P Parkin[4], J S Harris[3], S Langridge[1], G van der Laan[5] and T Hesjedal[2]

[1]ISIS – Science and Technology Facilities Council, UK, [2]University of Oxford, UK, [3]Stanford University, USA, [4]IBM Almaden, USA, [5]Diamond Light Source, UK

Bi_2Se_3 belongs to a class of materials known as 3-dimensional topological insulators. These materials have remarkable properties because they do not only possess a bulk energy band gap but also gapless surface state with the dispersion relation of massless Dirac fermions (Dirac cone) and counter-propagating channels of fully spin polarized electrons. The surface states may host a variety of intriguing phenomena, such as the quantized anomalous Hall effect [1,2], if their time reversal symmetry can be broken and a band gap can be opened at the Dirac point [3,4]. One route to achieving this is transition metal doping (such as Fe [5], Mn [6], Cr [7]) of the host topological insulator.

Here we present our work on the magnetic ordering in MBE-grown, epitaxial, Cr-doped thin Bi_2Se_3 films. Structural characterisation by RHEED and XRD show that the films are of high quality with sharp diffraction lines and no parasitic phases within the detection limit for doping levels up to 12% of the Bi sites ($(Cr_xBi_{1-x})_2Se_3$). The films are ferromagnetic and SQUID magnetometry show clear open loops with a coercivity of Hc ~100G (in-plane), a moment of about $2.1_{\mu B/Cr\text{-}atom}$ and a Curie temperature of around ~8.5K. We used polarized neutron reflectometry to investigate the magnetisation depth profile of the 12% Cr doped film, Fig. 1. Our results clearly show that the film is homogeneously magnetised throughout its depth with no surface enhancement or reduction [8].

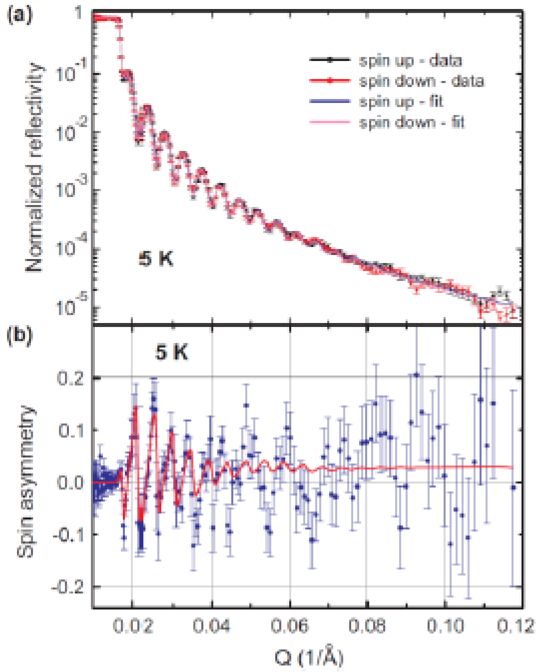

Fig. 1: a) Polarized neutron reflectometry data and fit for the 12% Cr-doped sample. b) Spin-asymmetry and fit.

[1] Science, 329 (2010) 61
[2] Science 340 (2013) 167
[3] Phys. Rev. B, 78 (2008) 195424
[4] Science, 329 (2010) 659
[5] Physics B, 311 (2002) 292
[6] New J. Phys., 15 (2013) 103016
[7] Appl. Phys. Lett., 100 (2012) 082404
[8] Europhys. Lett., 107 (2014) 57009

Spin currents, spin torque and spin-orbit effects

P.79 **Temperature dependence of spin Hall magnetoresistance in W/YIG thin films**

S Marmion[1], B Hickey[1], M Ali[1], M McLaren[1] and D Williams[2]

[1]University of Leeds, UK, [2]Hitachi Laboratory, UK

We report on the temperature dependence of spin Hall magnetoresistance (SHMR) in YIG/W thin films prepared by RF sputtering. The SHMR has gained much interest recently with both the thickness and temperature dependence of this effect being demonstrated in several different YIG/Pt systems that show conflicting results. Our work shows, not only that the effect is larger in amorphous tungsten, we see that the temperature dependence is different to that of platinum and that it has variations in its trend. Here we offer an explanation for these differences and compare to other work seen in the literature. The key find is that these differences appear to be linked to the thickness of the YIG as well as the metal that raises questions about the YIG manufacturing process when dealing with thin films. This suggestion is further supported by a corresponding trend seen in the magnetic properties of the YIG as a function of temperature.

P.80 **Magnetic, structural and electrical characterisation of CoFeTaB/Pt bilayer films**

O A Inyang, D Atkinson and A Hindmarch

Durham University, UK

Pure spin current, rather than charge current, is gaining importance in modern spintronics. In a bid to produce and understand pure spin current, recent studies have demonstrated the generation and detection of spin current by spin-Hall magnetoresistance (SHMR); a magnetoresistance arising due to spin Hall effect and inverse spin Hall effect in ferromagnetic insulator-normal metal bilayers [1, 2].

Magnetic, structural, and electrical properties have been investigated in thin film bilayers of an amorphous, highly resistive, ferromagnetic material (CoFeTaB) capped with paramagnetic materials with strong spin orbit interaction, such as platinum. The aim of this study is to demonstrate SHMR in this novel material system.

Thin films of CoFeTaB/Pt with different Pt thicknesses have been prepared using sputter deposition. X-ray measurements were used to measure the sample layer structure and probe the roughness of the CoFeTaB/Pt interface. Room temperature magneto-optical characterisation showed a uniaxial magnetic anisotropy, with easy-axis coercivity of around 5 Oe for films capped with Pt, and 10 Oe for CoFeTaB films without Pt; shown in the figure below.

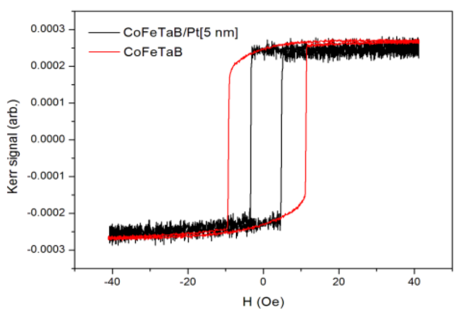

Fig. 1. Magneto-optical Kerr effect hysteresis loops for CoFeTaB and CoFeTaB/Pt.

[1] H. Nakayama et al. PRL 110, 206601 (2013)
[2] Vlietstra et al. Phys. Rev. B 87, 184421 (2013)

P.81 **Spin accumulation and relaxation characterisation in isolated CoFe nanoparticles**

R C Temple, C H Marrows and B J Hickey

University of Leeds, UK

Incorporating nanoparticles into tunnel junction structures allows current to be controlled down to the single electron sequential level. When magnetic materials are used in the right conditions, spin accumulation is induced on the magnetic island and spintronics is examined on a nanometre scale. Our recent theoretical research [1] has highlighted the possibilities of using such structures as simultaneous spin injectors and detectors. Here we present experimental evidence of spin accumulation in a single nanoparticle. Pure bcc crystalline CoFe nanoparticles are deposited in situ onto a magnetic tunnel junction stack with an MgO barrier. Cryogenic scanning tunnelling microscopy (STM) is used to address individual isolated particles and forms the top electrode of the junction. We are able to quantify the spin accumulation in the magnetic island and find it oscillates with applied bias. By varying the tunnelling resistance over several orders of magnitude we are able to determine the spin relaxation time on the island. We find a value of ~10μs, 10^7 times greater than bulk CoFe.

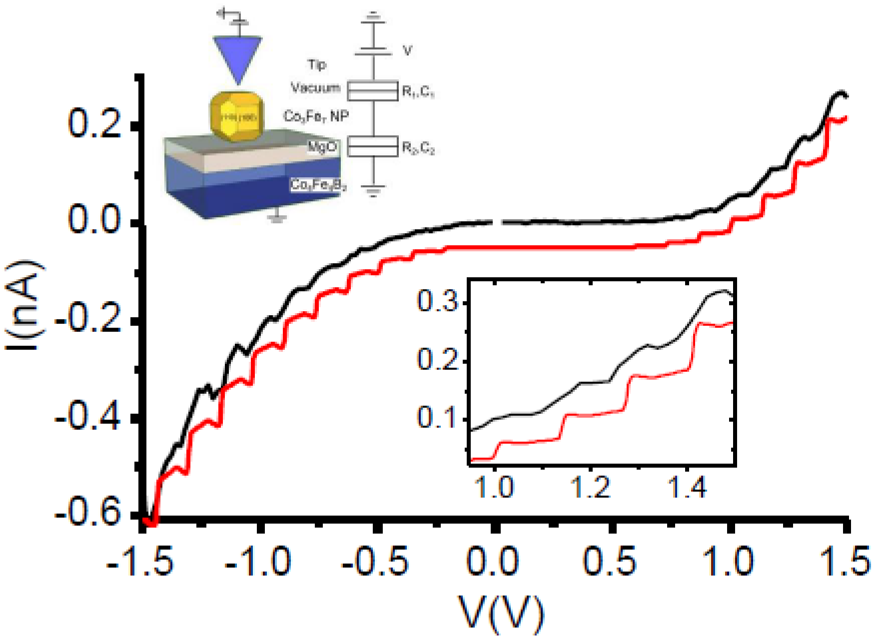

Figure 1: Black line shows STS data with Coulomb blockade features. Simulation (red) of data shows spin accumulation is occurring and gives a spin lifetime >10^7 times bulk relaxation time. Inset (top left) the diagram shows the set up for characterising particles using an STM tip, inset (bottom right) is a expanded view of the data/simulation.

[1] Temple et al. Phys. Rev. B 88, 184415 (2013)

P.82 **Perpendicular anisotropy in ultrathin Co based layers sandwiched by large spin hall angle heavy metals**

K Shahbazi, T A Moore and C H Marrows

University of Leeds, UK

Spintronic devices need to make use of larger spin currents every day, and spin Hall effect (SHE) is a major source of these kind of currents. Spin Hall angle is the term which shows effectiveness of induced spin current in such devices and increasing this term in a perpendicularly magnetized thin film stack is favourable. Having an ultrathin ferromagnet sandwiched by dissimilar heavy metals with opposite spin Hall angles would cause a substantial enhancement to the spin Hall effect. For example, growing β-Ta in one side of the ferromagnetic layer and Pt on the other would give us a big SHA, as SHA of β-Ta and Pt are both large, also has opposite sign. As the first step of working towards this goal, we investigate different combinations of three layer structures (SiO_2/HM1/FM/HM2) to get a perpendicular anisotropy. Multilayer structures of SiO_2/Ta/CoFeB/Pt using 3 different combinations of Co, Fe and B were failed to have out-of-plane anisotropy (also tried Ta/Pt/CoFeB/Ta), but fill in Co instead of CoFeB and inverting the stack, we had soft perpendicularly magnetized multilayers as desired. Strangely, Ta/Co/Pt multilayers on SiO_2 had in-Plane anisotropy which suggests probable inter-diffusion of Co and Ta layers and needs more investigation.

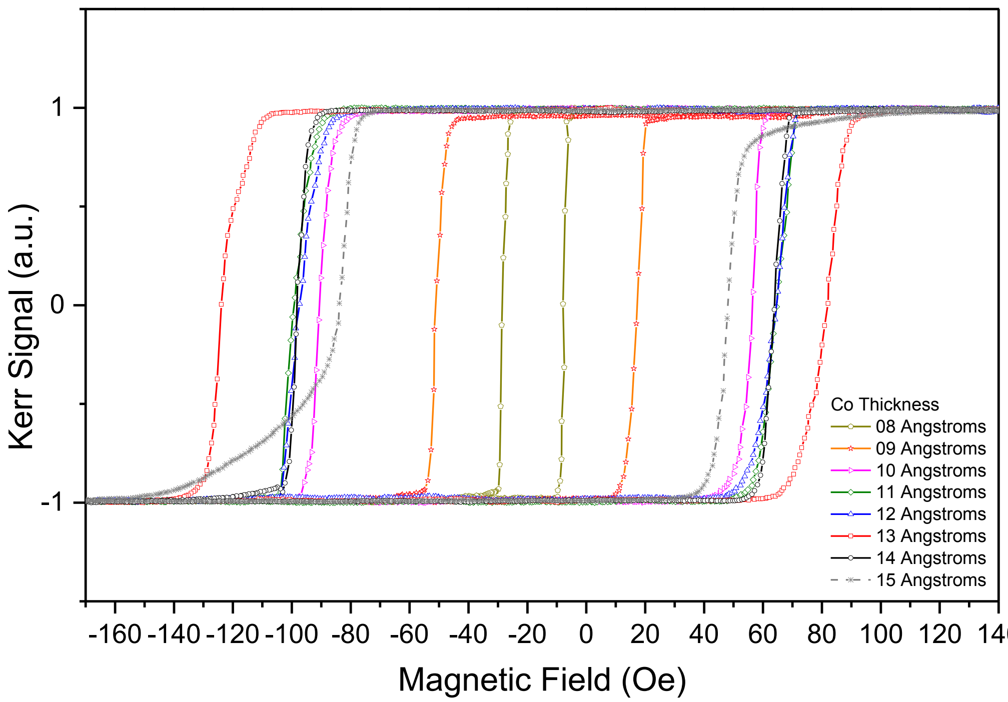

Figure: Polar laser MOKE loops of $\mathrm{SiO_2/Ta(20Å)/Pt(20Å)/Co(x)/Ta(40Å)}$ multilayers confirming perpendicular magnetic anisotropy of the samples.

P.83 **Microwave emission characteristics of spin-Hall nano-oscillators**

T Spicer[1], P S Keatley[1], P Dürrenfeld[2], A Houshang[2], M Ranjbar[2], A A Awad[2], R K Dumas[2], J Åkerman[2,3,4] and R J Hicken[1]

[1]University of Exeter, UK, [2]University of Gothenburg, Sweden, [3]KTH Royal Institute of Technology, Sweden, [4]NanOsc AB, Sweden

Spin-Hall nano-oscillators (SHNOs) are novel spin-torque oscillators driven by pure spin current generated by spin-Hall and Rashba-like effects [1]. The resulting auto-oscillation is a non-propagating spin-wave mode owing to local injection of spin current and frequency dependent damping caused by spin-wave radiation in the magnetic film [1]. In this work we use microwave electrical measurements to characterise the dependence of the frequency, threshold current, amplitude, and linewidth of auto-oscillations observed in SHNOs consisting of a microscale NiFe(5)/Pt(6)-bilayer disc (thickness in nm) with Au(150) coplanar nano-contacts (NCs) [2]. When an in-plane magnetic field of 850 Oe is applied 55° from the direction of the in-plane DC current, the auto-oscillation frequency was 6 GHz at a DC current of 18 mA. The threshold current, amplitude and linewidth all exhibit a dependence on the magnitude and direction of the applied field in addition to the NiFe/Pt disc diameter. The dependence on NC separation showed a complicated behaviour that may result from the change in spin current localization and the corresponding effect on the non-linear damping. Electrical characterisation of SHNOs is an essential prerequisite for investigations of the spatial characteristics of generated auto-oscillations using time-resolved magneto-optical Kerr microscopy of injection locked SHNOs [3].

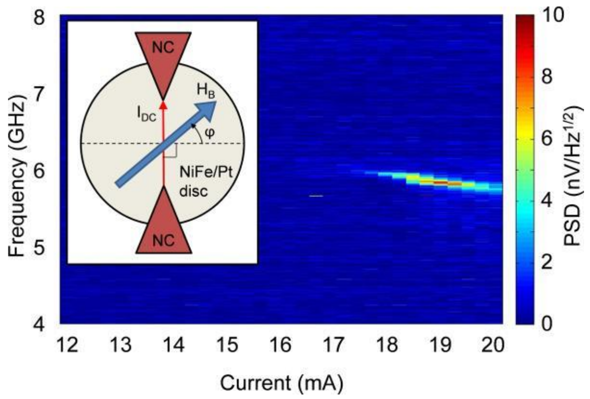

Figure 1. Frequency as a function of DC current. The colour scale represents the measured power spectral density (PSD). The magnitude HB and angle φ of the in-plane magnetic field was 850 Oe and 35° respectively, while the NC separation and disc diameter were 100 nm and 4 µm. Inset, the schematic (not to scale) shows the measurement geometry and the position of the coplanar NCs on top of the NiFe microscale disc.

[1] V.E. Demidov, S. Urazhdin, H. Ulrichs, V. Tiberkevich, A. Slavin, D. Baither, G. Schmitz, and S.O. Demokritov, Nat Mater 11, 1028 (2012)

[2] M. Ranjbar, P. Durrenfeld, M. Haidar, E. Iacocca, M. Balinskiy, T.Q. Le, M. Fazlali, A. Houshang, A.A. Awad, R.K. Dumas, and J. Akerman, Magnetics Letters, IEEE 5, 1 (2014)

[3] V.E. Demidov, H. Ulrichs, S.V. Gurevich, S.O. Demokritov, V.S. Tiberkevich, A.N. Slavin, A. Zholud, and S. Urazhdin, Nat Commun 5 (2014)

P.84 **Fabrication and measurement of a lateral spin-transfer nano-oscillator**

B A Murphy[1], A J Vick[1] and A Hirohata[1,2]

[1]University of York, UK, [2]PRESTO, Japan Science and Technology Agency, Japan

The novel geometry of the device that we present has appications in GHz frequency operation and in the control of magnetic nanoparticles for drug delivery [1,2]. We have produced a lateral Spin Transfer Nano-Oscillator device, where the magnetisation of a ferromagnetic disc is oscillated by the application of an alternating spin-transfer torque.

The oscillator was fabricated in the form of an ellipse with an aspect ratio of 4:3 with a 200nm major axis and was expected to contain a single magnetic domain due to the Py being 20nm thick [3]. The oscillator was overlaid with a Cu wire to deliver spin currents injected through two Py contacts alternatively. The Py contacts were formed by a discontinuous horse-shoe shape to encourage magnetic coupling but to avoid conduction to ensure opposing, non-interfering spin sources.

The resistance of the interface between the Permalloy (Py) and Cu channel was found to be of the order $1{\times}10^{11}\Omega cm^{-2}$. Preliminary experiments have shown the non-local spin signal in a 300nm Cu channel, $\Delta R/R$, to be 60 ± 3 %. This predicates the possibility of manipulation of a ferromagnetic disc by the application of a spin torque.

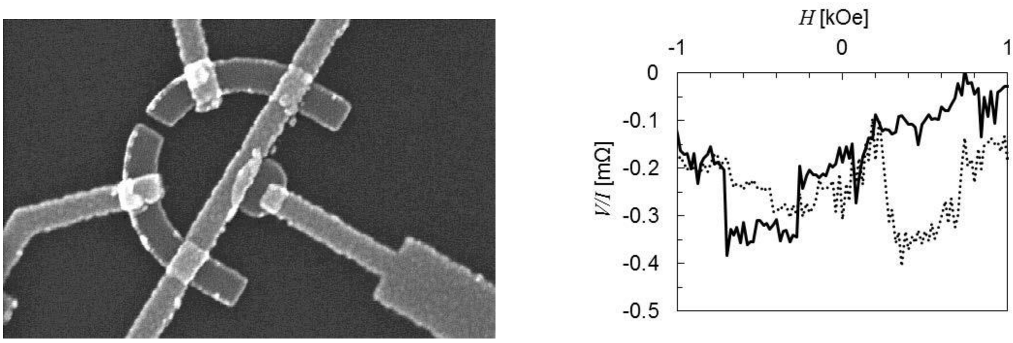

Fig. 1: a) SEM image of the nano-oscillator and b) a DC measurement of a lateral spin valve of similar dimensions.

[1] A. Dussaux et al., *Nature Communications* 1, article no. 8 (2010)
[2] C. Sun, J. S. H. Lee and M Zhang *Adv. Drug. Deliv. Rev*. 60, 1252–1265 (2008)
[3] A. Hirohata et al., *IEEE Trans. Magn*. 35, 3886-3888 (1999)

Spin ice and artificial spin ice

P.85 Induced magnetoresistance in hybrid semiconductor / artificial spin ice structures

S Riley, M Rosamond, D Mistry, L Li, J Cunningham and C Marrows

University of Leeds, UK

The formation of periodic, ferromagnetic stripes, on the surface of a semiconductor incorporating a two-dimensional electron gas (2DEG) results in an induced magnetoresistance owing to commensurability between the cyclotron radius of electrons in the 2DEG with the stripe periodicity [1]. Such structures are of interest owing to their potential application in memory storage and as magnetic field sensors [2].

In this work, the effect of replacing the periodic arrays of stripes with an artificial spin ice is investigated. Artificial spin ice systems are two dimensional regular arrays of frustrated, single-domain nanomagnets, in which the frustration arises owing to the pattern geometry precluding all pairwise interactions from simultaneously being in their lowest energy state [3]. Such structures are studied extensively since they reproduce the three dimensional frustration observed in both water ice and pyrochlore spin ice.

The effects on magnetoresistance, measured via the Quantum Hall effect, of an artificial spin ice formed on a 2DEG-containing semiconductor is investigated, and compared with a range of periodic ferromagnetic structures. The effects of strain-induced oscillations, which can mask observation of commensurability oscillations, will also be discussed.

[1] H. A. Carmona *et al.*, Phys. Rev. Lett 74 (1995) p.3009-3012
[2] V. Kubrak *et al*., J. App. Phys. 87 (2000) p.5986-5988
[3] J.P. Morgan *et al*., Nature Physics 7 (2011) p.75-79

P.86 Influence of disorder on critical ageing in 3d ising-like ferromgnets

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Omsk State University, Russian Federation

Abstract not available in digital format.

Superconductors

P.87 The superconducting spin valve containing highly spin polarized $Fe_{0.8}Co_{0.2}Si$

B Steele, N Satchell, P Sinha, C H Marrows and G Burnell

University of Leeds, UK

At the interface between a superconductor and ferromagnet, an inhomogeneity can convert singlet Cooper pairs into the (spin aligned) long ranged triplet component (LRTC) [1]. This necessary inhomogeneity can be engineered in a multilayered structure such as spin valves (SV) [2]; when the relative angle of the ferromagnetic layers is none zero, the LRTC is created. The LRTC mediates new leakage channels for Cooper pairs, suppressing the superconductors T_c, typically by between 10 and 50 mK [2].

Motivated by a recent report of 'colossal proximity effects' in a $F_1/F_2/S$ SV containing 100% spin polarized CrO_2 as the bottom drainage layer [3], we explore the possibility of using highly spin polarized perpendicularly magnetised, $Fe_{0.8}Co_{0.2}Si$ [4] as F_1. The structures used are Si/$Fe_{0.8}Co_{0.2}Si$/Cu/Co/Nb and a Si/Cu/Co/Nb control. The magnetisation direction of the Co layer will cant out of plane with the applied field (0.1 T). Both samples show an increase in T_c as the applied field is rotated (by θ) into the sample plane (δT_c), but the SV sample shows a lower T_c than the control (ΔT_c) consistent with a LRTC as the angle of magnetisation between F_1 and F_2 is increased.

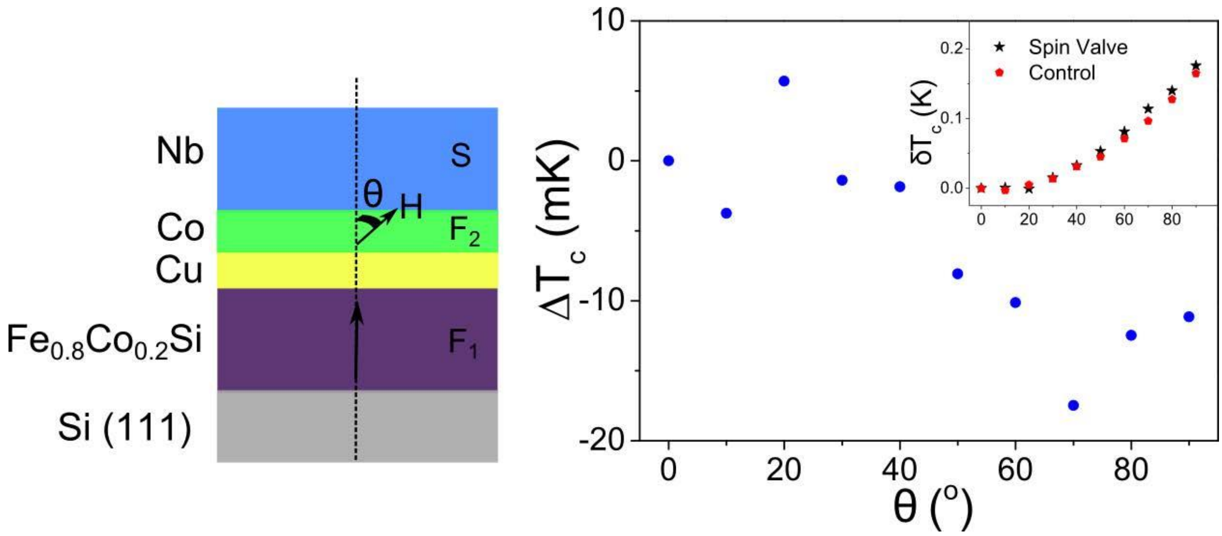

Fig.1: Difference in the superconducting Nb critical temperature of the spin valve, compared to the control sample (without the $Fe_{0.8}Co_{0.2}Si$ drainage layer) (ΔT_c) with the angle of applied field (θ). Inset: The change in T_c during rotation (δT_c) for the two samples

[1] M. Eschrig, Physics Today 64, pp. 43–49 (2011)

[2] P. V. Leksin, *et al*. Phys. Rev. Lett. 109, 057005 (2012) / M. G. Flokstra *et al*. Phys. Rev. B (in press) arXiv:1404.2950 [cond-mat] (2014)

[3] A. Singh, *et al*. arXiv:1410.4973 [cond-mat] (2014)

[4] P. Sinha, *et al*. Phys Rev B, 89, 134426 (2014)

P.88 **Development of 22 T VSM system using novel improvements in HTS conductor**

D Bracanovic, J Good and T Ritman-Meer

Cryogenic Ltd, UK

Current research has identified a need for greater magnetising fields during vibrating sample magnetometer (VSM) measurements and other measurement options. We present here the methodology involved in our development of a VSM system with 22 T superconducting magnet, a unique system and the highest field combined with a VSM anywhere in the world.

Recent developments in HTS conductors have allowed greater reliability than previous coils made from YBCO and BISCO and thus facilitate the consistent achievement of higher magnetising fields at the sample with operation at 4.2 K rather than 2.2 K.

Cryogenic Ltd wind HTS coils in both solenoid and pancake forms with an emphasis on solenoids, since they have been found to give a more reliable performance with less thermal transfer to the surrounding liquid helium. The 22T VSM system has been developed using 2G YBCO coated and BSSCO tape which exhibit critical currents up to 5 times greater than those seen in YBCO and BISCO at 4.2 K.

Vortices

P.89 **Detection of asymmetry circular gyration of the vortex core via second order harmonic magnetoresistance oscillation**

S Sugimoto[1,2], N Hasegawa[1], Y Niimi[1], Y Fukuma[3], S Kasai[4] and Y Otani[1,2]

[1]University of Tokyo, Japan, [2]RIKEN, Japan, [3]Kyushu Institute of Technology, Japan, [4]National Institute for Materials Science, Japan

The vortex state in magnetic texture has been attracting attentions from the early stage of studies of domain wall dynamics [1,2], as the one of the simplest form of the soliton type pseudo particle motion [3,4] and this feature could have rich applicational potentials to such like the race track memory[5], magnonic crystals [6], and spin torque oscillator [7]. The scale of the vortex core is defined by the direct exchange length of the material and usually stay as 10 nm order. Therefore electrical detection of vortex core dynamics usually requires high MR ratio or large distortion of the rotating orbital [8]. Here we have demonstrated alternative electrical detection method utilized by the rectification effect [9], which assures high sensitivity enough to detect from single vortex core. Different from conventional homodyne detection, this method is utilized by second order harmonic wave of excitation frequency, and it can be available at completely symmetry system depicted in Fig. (b) for $(x_R - x_0) = 0$ whereas signals at homodyne detection would be proportional to the distance of core shift $(x_R - x_0)$. This second order harmonic detection is proportional to the square of core orbits, and expected to be more suitable to discuss spin excitation mechanism such like quantity of spin transfer torque coefficient [10] and additional excitation by current induced field under non distorted excitation conditions.

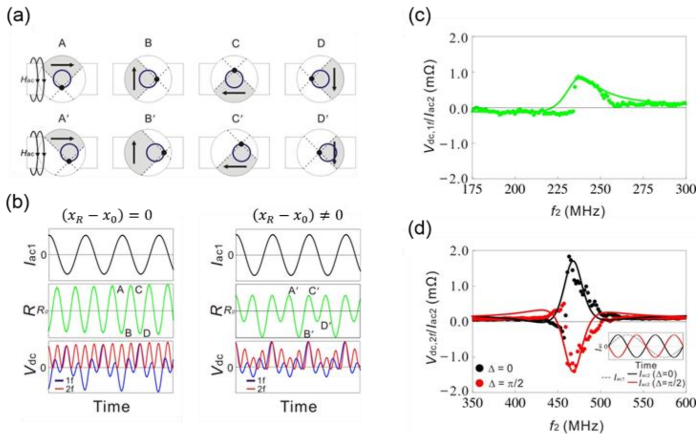

Figure: (a) Orbitals of the vortex core at centered (A to D) and off-centered (A′ to D′) excitations. (b) Time evolutions of the excitation current I_{ac1}, the anisotropic magnetoresistance R and the rectified voltage V_{dc} under centered $(x_R - x_0) = 0$ and off-centered $(x_R - x_0) \neq 0$ excitations. Resonant spectra of rectified voltages as functions of the frequency of (c) 1st and (d) 2nd order harmonic detection current f_2. The inset in Fig. (d) shows time evolutions between the excitation current I_{ac1} and the detection current I_{ac2}.

[1] S.-B. Choe, Y. Acremann, A. Scholl, A. Bauer, A. Doran, J. Stöhr, and H. A. Padmore. Science 304, 420 (2004)
[2] T. Shinjo, T. Okuno, R. Hassdorf, K. Shigeto, and T. Ono. Science 289, 930 (2000)
[3] A. A. Thiele. Phys. Rev. Lett. 30, 230 (1973)
[4] D. L. Huber. Phys. Rev. B 26, 3758 (1982)
[5] R. Moriya, L. Thomas, M. Hayashi, Y. B. Bazaliy, C. Rettner, and S. S. P. Parkin. Nat. Phys. 4, 368 (2008)
[6] J. Shibata, and Y. Otani. Phys. Rev. B 70, 012404 (2004)
[7] V. S. Pribiag, I. N. Krivorotov, G. D. Fuchs, P. M. Braganca, O. Ozatay, J. C. Sankey, D. C. Ralph, and R. A. Buhrman. Nat. Phys. 3, 498 (2007)
[8] S. Kasai, Y. Nakatani, K. Kobayashi, H. Kohno, and T. Ono. Phys. Rev. Lett. 97, 107204 (2006)
[9] S. Sugimoto, N. Hasegawa, Y. Niimi, Y. Fukuma, S. Kasai, and Y. Otani. Appl. Phys. Exp. 7, 023006 (2014)
[10] S. Zhang and Z. Li. Phys. Rev. Lett. 93, 127204 (2004)

P.90 **Lorentz microscopy study of possible interfacial exchange interactions in thin films with planar magnetisation**

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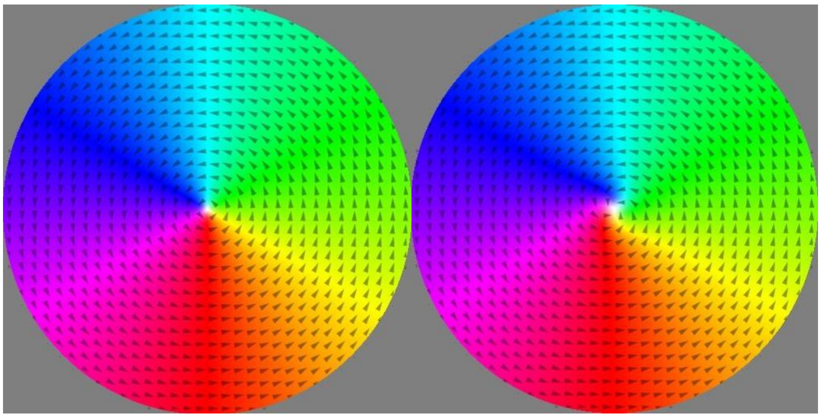
There has been considerable interest recently in the Dzyaloshinskii-Moryia interaction (DMI), particularly in the case of the interface between thin films of a ferromagnetic material and a non ferromagnetic heavy metal [1]. The interfacial DMI energy has the form $\mathbf{D}\times(\mathbf{S}_i\times\mathbf{S}_j)$, relating the DMI vector, **D**, to neighbouring spins $\mathbf{S}_i$ and $\mathbf{S}_j$. Much of the emphasis of the recent work has focused on very thin, perpendicularly magnetised films, where the DMI results in Néel walls of a preferred handedness. Whilst in these cases it is straightforward to understand why Néel wall handedness occurs, no such effect should be expected for Néel walls within films with in-plane magnetisation. However, when a vortex is present, the out of plane core gives the possibility of the DMI influencing the magnetisation around the core. Here, we simulated a vortex in a thin (2nm) magnetic disk of permalloy with and without a DMI term. The inclusion of the DMI changed the vortex structure from pure rotational magnetisation to rotation plus divergent magnetisation (see figure). The magnitude of the divergent component is dependent on the strength of **D**. Furthermore, we also calculated hysteresis loops for these structures and predict that the field required to expel the vortex from the disk depends on the magnitude of **D**. Lorentz microscopy has been used to study experimentally fabricated structures of permalloy and permalloy/platinum with a view to providing an estimate of $|\mathbf{D}|$. Initial indications suggest measureable effects are observed and we will report on the details of these findings.



a) b)

Figure 1. Simulated magnetisation configuration for 512 nm diameter, 2 nm thick disk of permalloy for a D value of a) 0 mJ/m^2 and b) 2 mJ/m^2.

[1] S.-G. Je, D.-H. Kim, S.-C. Yoo, B.-C. Min, K.-J. Lee, and S.-B. Choe, Phys. Rev. B 88, 214401 (2013)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