Current Research in Magnetism (CRIM)
2013

9th September 2013
Queen Mary, University of London

Organised by Alan Drew (A.J.Drew@qmul.ac.uk), on behalf of the IOP Magnetism Group

We gratefully acknowledge:
Institute of Physics Magnetism Group for lunch and coffee
The QMUL Materials Research Institute for the evening reception
QMUL for the venue
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Abstracts (talks)
Magnetic nanoparticles have many potential clinical applications, however, the currently available MNPs namely iron oxide are sub-optimal in terms of their physical and biochemical properties. They have lower saturation magnetisation and often are not well biofunctionalised for specific biological target. In this presentation, novel class of MNPs with different size, shape (cube, octopods, rods, multipods, star), chemical composition (e.g., metallic Co, alloy FePt, trimetallic FePtPd, etc..), coating and surface chemistry have been fabricated using wet chemical methods. Multifunctional/hybrid MNPs with noble metal Au and semiconductor quantum dots CdSe were also synthesised. Magnetic nanoparticles could be used to track neural stem cells after a transplant in order to monitor how the cells heal spinal injuries.

**Fig 1:** Tunable shapes of magnetic nanoparticles: Fe-Pt, Fe-Pd and Fe-Pt-Pd alloys
Fig 2. CoPt-labeled NSCs detected by MRI after transplantation into rat spinal cord slices

Fig 3. Superparamagnetic Fluorescent Nickel-Enzyme Nanobioconjugates
Fig 4. Core@Shell Structure of FePt@CdSe Nanoparticles

References:

Oxidation of pseudo-single domain Fe₃O₄ particles and associated magnetic response examined by environmental TEM and off-axis electron holography

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In order to interpret palaeomagnetic measurements reliably, the mechanisms that induce and alter chemical remanent magnetisation (CRM) in naturally occurring magnetic recorders must be fully understood. Current models of CRM processes only exist for the smallest uniformly-magnetised single domain (SD) grains. However, magnetic signals from rocks are often dominated by larger grains that contain non-uniform pseudo-SD (PSD) magnetisation states.

Magnetite (Fe₃O₄) is the most magnetic naturally occurring mineral on Earth, carrying the dominant magnetic signature in rocks and providing a critical tool in paleomagnetism. The oxidation of Fe₃O₄ to other iron oxides, such as maghemite (γ-Fe₂O₃) and hematite (α-Fe₂O₃), is of particular interest as it influences the preservation of remanence of the Earth’s magnetic field by Fe₃O₄.

The complementary use of environmental transmission electron microscopy (ETEM) and off-axis electron holography techniques can be used to reveal local changes in magnetisation in minerals as they alter during in situ heating in a controlled oxidising atmosphere. Such experiments can provide direct information about the relationship between magnetic domain structure and chemical alteration features, phase boundaries and crystalline microstructure.

In the present study, synthetic Fe₃O₄ particles with sizes in the PSD range (< 300 nm) were heated in situ in an ETEM under an oxygen atmosphere. Oxidation of the Fe₃O₄ particles was investigated using bright-field and dark-field imaging, electron diffraction and electron energy-loss spectroscopy. The associated alteration in CRM exhibited by individual Fe₃O₄ particles was investigated using off-axis electron holography, in the form of reconstructed magnetic induction maps (Figure 1).

Figure 2 (a) Off-axis electron hologram of an individual Fe₃O₄ particle in the PSD size range (~ 200 nm) and (b) the corresponding magnetic induction map.
Axial Gap, Trapped Flux-Type Superconducting Electric Machine Design

Mark Ainslie(1), John Durrell(1), Enric Pardo(2), Tony Dennis(1), Yunhua Shi(1), Damian Hampshire(3), Mark Raine(3), Archie Campbell(1), David Cardwell(1)

(1) Bulk Superconductivity Group, Department of Engineering, University of Cambridge, UK
(2) Institute of Electrical Engineering, Slovak Academy of Sciences, Slovakia
(3) Superconductivity Group, Department of Physics, University of Durham

The Bulk Superconductivity Group at the University of Cambridge is currently investigating the use of high temperature superconductors in wire and bulk form in order to increase the electrical and magnetic loading of an axial gap, trapped flux-type superconducting electric machine. In electric machines, the use of superconducting materials can lead to increases in efficiency, as well as the power density, which results in reductions in both the size and weight of the machine.

Investigating and modelling the electromagnetic behaviour of superconductors is crucial to the design of superconducting electric machines. The authors are developing accurate 2D axisymmetric and 3D finite element models of superconducting coils and bulks, which combine conventional, magnetic and superconducting materials. Research carried out to date on the electromagnetic properties of superconductors operating within complex geometries has produced a number of interesting results; in particular, how the use of hybrid combinations of magnetic materials and superconductors can affect the superconductor's electromagnetic properties [1,2]. There is significant promise for magnetic materials to be used together with superconducting materials to further enhance the remarkable properties of these materials, such as the reduction of AC loss in coils made from superconducting tape [3], which can be problematic in applications where a time-varying current and/or magnetic field is present, and shaping and enhancing the trapped magnetic field in bulk superconductors.

Here, the authors present the challenges and goals of this project, as well as the progress made so far.

References:
Magnetisation reversal and domain wall propagation in edge modulated nanowires

D.M. Burn$^{1,2}$ and D. Atkinson$^1$

$^1$ Department of Physics, Durham University  
$^2$ Department of Physics, Imperial College London

The behaviour of domain walls in magnetic nanowires has received significant interest due to the potential for the development of novel spintronic devices. High operation speeds, reliability and packing density are important factors for the success of such devices. However, Walker breakdown$^1$ at high driving fields affects the wall chirality and limits domain wall mobility in both nanowires$^2$ and thin film$^3$ structures.

Nanowires with rough edges show improved domain wall mobility due to interactions between the domain wall and nanowire structuring.$^4$ Here, artificial roughness is introduced in the form of periodic modulations to a nanowire’s edge geometry. Experiments and micromagnetic simulations are used to investigate the influence of the modulation upon both the static and dynamic magnetisation processes.

Field driven reversal processes in these wires were investigated first via direct reversal from an initially uniform magnetisation state at a relatively high field and then through domain wall mediated reversal at lower fields. Experimentally determined reversal fields are shown in figures 1(a) and 1(b) for these two reversal modes respectively. These results have been interpreted using micromagnetic simulations and through the development of a model based on the demagnetisation effects of the modulation upon the spin structure of the wire.

Further micromagnetic simulations were used to investigate dynamic domain wall processes. Matching the periodicity of the wire structuring to the frequency of Walker breakdown structural transitions leads to the suppression of Walker breakdown by triggering energy dissipation through spin wave emission.$^5$


![Figure 1](image_url)

Figure 1: Magnetisation reversal field for a nanowire as a function of edge modulation wavelength.  
a) Direct nucleation limited reversal where the lines show the best model fit to the long wavelength data and b) domain wall mediated reversal using nucleation pad and stripline domain wall injection techniques.
The incorporation of nanocarbon semiconductors into spintronic devices is an attractive prospect due to the long spin diffusion length of such materials. Recently, there have been reports of successful spin injection into C$_{60}$ using standard spin valve geometries [1-2]. In contrast to previous reported results in C$_{60}$ spin valves, we have observed an asymmetric behaviour of the junction resistance in positive and negative in plane magnetic fields in some samples at low temperature as shown in Fig. 1a and b for normal magnetoresistance and asymmetric magnetoresistance respectively. In standard spin valves there is no explanation for this observation. To further understand this interesting behaviour one has to consider the interaction between C$_{60}$ and ferromagnetic materials. We have observed an induced magnetization of C$_{60}$ molecules in C$_{60}$/Co multilayers which is a result of spin polarised electron transfer between the C$_{60}$ and Co. There can be a spin transfer of up to 0.1 $\mu$B per carbon atom and there is antiferromagnetic coupling between the Co and C$_{60}$ [3]. We present TEM of a C$_{60}$/Co multilayer in Fig. 1c showing smooth and sharp interfaces suggesting this behaviour is not a result of roughness. We propose that this induced magnetization and electron transfer has lead to asymmetric spin filtering effects.

Figure 1: a) Typical low temperature MR for a Co/Al$_2$O$_3$/C$_{60}$(15 nm)/Py/Al junction at 2 K. b) The MR of some samples at low temperatures shows field asymmetry, with lower resistance states for equivalent up/down in plane magnetic fields. MR for a Co/Al$_2$O$_3$/C$_{60}$(30 nm)/Py/Al junction. c) TEM of C$_{60}$/Co multilayers showing smooth and sharp interfaces.

The drive to find novel materials for applications such as data storage, spintronics, and microelectronic devices has led to a resurgence in research into multiferroic materials. Bismuth ferrite is the most widely studied multiferroic material primarily due to its room temperature (anti)ferromagnetic ($T_N \sim 360 \, ^\circ C$) and ferroelectric ($T_C \sim 825 \, ^\circ C$) ordering. Bismuth ferrite, however, exhibits a complex antiferromagnetic spin cycloid structure (as shown in figure 1) whereby the net magnetic moment is spatially averaged to zero over a large 64 nm periodicity. Moreover, limitations in the application of BiFeO$_3$, such as high conductivities and leakage currents coupled with the complex magnetic structure has led authors to investigate the effects of doping both the A (Bi$^{3+}$) and B-sites (Fe$^{3+}$) on the observed structural, electric and magnetic properties. Recently the replacement of Bi$^{3+}$ with Dy$^{3+}$ has been shown to lead to an effective suppression of the magnetic spiral spin structure resulting in the observation of a net magnetic moment. Furthermore, increasing Dy content in these materials has been shown to lead to a composition driven structural phase transition away from polar rhombohedral symmetry towards non-polar orthorhombic symmetry resulting in the loss of room temperature ferroelectric character. In this paper we will discuss the magnetic structure of BiFeO$_3$ as well as doping strategies aimed at attempting to promote ferromagnetic ordering in these materials.

References
Mechanisms of Magnetic Hyperthermia

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Magnetic hyperthermia is the process by which cycling magnetic nanoparticles in a magnetic field leads to heat dissipation [1]. It is a very attractive approach for the treatment of cancer and reduction in size of non-malignant tumours because it generates no side effects unlike more conventional therapies such as chemotherapy. However, at the present time the mechanisms by which heat is generated are not fully understood. Understanding these mechanisms is critical so as to produce particles with optimised properties for specific applications at nominal dose.

The dominant mechanism is dependent on the grain size in the sample, the frequency and amplitude of the field at which the heating is measured and the viscosity of the colloid as shown in Figure 1. A combination of experimental and theoretical results will be presented. It will be shown that heating experiments should be carried out in samples disperse in wax, i.e. solid matrix, to remove effects that will not occur in-vivo. The role of the distribution of anisotropy constants will be discussed.

Figure 1. Schematic diagram showing the critical sizes at which different loss mechanisms dominate.

References

Metal-organic coordination polymers are self-assembly materials in which transition metal ions are linked via organic molecules into chain or plane-like structures. Of interest is the effect of pressure on coordination polymers that include hetero-ligand Jahn-Teller (JT) active metals centers, where the transition metal ion sits in a position of octahedral symmetry, surrounded by an asymmetric ligand environment. In such systems each unique metal-organic ligand provides an additional degree of freedom on the JT-axis, meaning that small perturbations of the metal-ligand environment can be enough to switch the JT-axis and radically modify the material properties.

One such material which we have focused on is CuF$_2$(H$_2$O)$_2$(pyz)$_2$ (pyz=pyrazine, C$_4$H$_8$N$_4$) [1, 2]. This is a Cu$^{II}$ co-ordination polymer, in which strong hydrogen bonds exist between the copper pyrazine chains, leading to two-dimensional magnetic properties at ambient pressure. This system has an active Jahn-Teller center, where the magnetic orbitals are elongated along a particular axis, allowing the magnetic properties to be selectively modified through perturbation of the co-ordination environment. We have recently carried out high pressure measurements up to 22 kbar [3], using a modified radio-frequency technique which can be used to extract the absolute magnetisation [4]. We will show that pressure can be used to switch the Jahn-Teller axis, and hence modify the orbital orientation and the magnetic properties; leading to a sharp transition from two-dimensional to one-dimensional magnetism at 9.1 kbar.

![Figure 1: Crystal structure at (a) ambient pressure, and (b) 13.9 kbar. The JT-axis is shown by the red striped bonds. Also shown is (c) the critical field and (b) the primary exchange energy $J$, as a function of pressure.](image-url)
Enhanced heating properties of microwave-synthesised iron oxide nanoparticles for \textit{in vitro} magnetic hyperthermia


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The use of alternative techniques for the treatment of cancer to restrict their action to the affected areas has been a major focus in recent years due to the high occurrence of this disease and the limitations of the existing procedures, such as chemotherapy, radiotherapy or surgery. The use of elevated temperatures as a treatment for cancer has the potential to aim for unhealthy cells while leaving unaffected their normal counterparts, as cancer cells are more sensitive to temperatures above 41.8°C.[1, 2] The use of iron oxides in tumour heating was first proposed by Gilchrist \textit{et al.}[3] in 1957 and, from that moment, more than 4000 reports have been published.

Iron oxide nanoparticles have already been used for magnetic hyperthermia leading to promising results as an alternative cancer treatment.[4] Nevertheless, most of these materials are obtained in organic solvents and require complex post-synthesis purification and phase-transfer steps. To this aim, we present the use of a microwave reactor for the simple and easy synthesis of iron oxide nanoparticles by co-precipitation for their use as heating vectors in magnetic hyperthermia. The intrinsic loss power (ILP) generated by the obtained nanoparticle suspensions was studied with a patented Magnetic Alternating Current Hyperthermia (MACH) system working at a frequency of 1MHz and a field amplitude of 10 kA.m\(^{-1}\). A complete physical and morphological characterisation of these materials was also conducted to study their effect on the heating properties. The as-synthesised iron oxide nanoparticles were found to have superior performance in magnetic hyperthermia than the commercial Resovist(R). Finally, the generated nanoparticles were tested for \textit{in vitro} magnetic hyperthermia in DX3 human melanoma cells. Cell response to the treatment was found to be field strength and frequency dependent leading to a maximum 90% cell death upon 2h of treatment at 911 KHz and 16.1 kA.m\(^{-1}\).

To summarise, our results indicate that DX3 melanoma cells, loaded with MNPs, may be specifically treated upon application of an AC magnetic field. Such technique show potential application in the treatment of melanoma and other cancers.


Title: Fabrication of Molecular Thin Films Based on Magnetic Charge-Transfer Salts

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Abstract:

Molecular-based magnets are of interest for spintronic devices[1,2,3]. Composed of low atomic number elements such as C, N and O, the long spin lifetime in molecular-based magnets is longer than the conventional magnets. Of the molecular-based magnets, charge-transfer (CT) salts based on Manganese tetrphenylporphyrin (MnTPP) and tetracyanoethylene (TCNE) have shown unusual magnetic properties, such as high coercivity and large remanent magnetization[4]. Magnetic CT salts of the [MnTPP][TCNE] family are primarily synthesized via solution processes, often leading to intercalation of unwanted solvent molecules as well as complex solvent-induced pseudo-polymers. Here, Organic Molecular Beam Deposition (OMBD) is used to obtain solvent-free molecular thin films based on analogues of [MnTPP][TCNE]. The high vacuum environment provided by OMBD allows for good control over the thin film growth.

Molecular thin films based on magnetic CT salts were fabricated using co-evaporation of an electron donor and acceptor, MnTPP-Cl and tetracyanoquinodimethane (TCNQ), respectively. As a comparison, metal-free tetraphenylporphyrin (H₂TPP) was used as a donor for co-evaporation with TCNQ. The resulting molecular thin films based on CT salts were characterized using various ex-situ techniques, including UV/visible spectroscopy, Nomarski microscopy, scanning electron microscopy, atomic force microscopy and X-ray diffraction. The presence of charge transfer in the molecular thin films was identified using Infrared Spectroscopy. Finally, the magnetic properties of the molecular thin films are obtained using SQUID magnetometry.

References:

Ferromagnetic-organic interfacial states detected by transient conductivity and their role on low voltage current injection in organic spinvalves

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In recent years, there has been an increasing interest in utilising organic materials as spin transport layers as they have very long spin-coherence times due to low spin-orbit and hyperfine coupling present in these materials. Whilst there has been considerable research into organic spinvalves, with devices demonstrating magnetoresistances of up to 300% there is a fundamental unsolved problem of how spin injection occurs. All organic spinvalves have been found to operate best at exceptionally low voltages, in the order of millivolts, where our traditional understanding of the injection mechanism suggest that there should be no carrier injection.

In this work we investigate the role of hybrid interface states (HINTS) between a ferromagnetic contact (FM) and an organic semiconductor. Using transient conductivity measurements on a variety of devices, the presence of these HINTS in a real device but only in the presence of a FM contact. We then consider the consequences that these filled HINTS will have on the electrical properties of devices. We argue that the filling of these HINTS introduces a large electric field at the interface between the FM contact and the OSC layer, which causes an effect analogous to “band-bending” in conventional semiconductors. This explains the Ohmic injection seen in organic spinvalves which results in significant hole injection even at very low (e.g. millivolt) applied voltages.

Stefan Mathias: Ultrafast spin-dynamics

Femtomagnetism, which is the manipulation of magnetic order on femtosecond timescales by ultrashort laser pulses, was first observed by Eric Beaurepaire et al. in 1996 [PRL 76, 4250 (1996)]. Since then, femtomagnetism has become a challenging research topic of increasing interest because of its importance for uncovering fundamental new science and for technological applications. Can we measure, manipulate and control magnetization dynamics on femtosecond-to-attosecond timescales? The answer to this challenge is governed by the non-equilibrium interactions between photons, electrons, spins, and phonons after excitation of the material by an ultrashort laser pulse (see Fig. 1, from [PNAS 109, 4792 (2012)]). One of the key challenges is to carefully disentangle the various dynamical processes shown in Fig. 1 to establish how they contribute to the behavior of a complex magnetic system far from equilibrium. In this tutorial, I will first give an overview of current progress and key-problems in the field of femtomagnetism. In the second part, I will introduce new experimental capabilities based on the use of ultrashort X-ray pulses, which have the potential to elucidate some of the challenging questions in the field.
Ultrafast optical parametric pumping of magnetization reorientation and precessional dynamics in DyFe$_2$/YFe$_2$ exchange springs

L. R. Shelford,$^1$ Y. Liu,$^1$ U. Al-Jarah,$^1$ P. A. J. de Groot,$^2$ G. J. Bowden,$^2$ R. C. C. Ward,$^3$ and R. J. Hicken$^1$

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Optically-induced magnetization dynamics of a [DyFe$_2$ (20 Å) / YFe$_2$ (80 Å)]$_{40}$ exchange spring multilayer have been explored in all-optical pump probe experiments. An exchange spring is formed when the magnetization within a soft YFe$_2$ layer rotates to follow an external field, while remaining strongly pinned at the interfaces with the more strongly anisotropic DyFe$_2$ hard layer. Ultrafast optical heating by a femtosecond laser pulse was used to modify the magnetic parameters of the multilayer, while the time resolved magneto-optical Kerr effect was used to probe its response. Oscillatory dynamics were observed only when the system was prepared in an exchange spring state. Large amplitude precession and winding of the exchange spring within the soft YFe$_2$ layer are shown to dominate the observed response, with resonance frequencies in the range 4-8 GHz. However, reorientation of the DyFe$_2$ hard layer magnetization is also detected on timescales less than 100 ps, confirming that the hard layer anisotropy is dramatically reduced. The data are compared with micromagnetic simulations that allow the role of different magnetic parameters to be explored. Optically induced demagnetization of about 20% was observed within the experiments while simulations revealed that the observed hard layer reorientation requires a 90% reduction of the anisotropy parameter. Simulations performed for a larger reduction of the hard layer anisotropy show that, with an appropriately tuned bias field, optically-induced switching may be achieved. Exchange spring multilayers are of great interest for high density [1,2] and heat assisted magnetic recording [3], while antiferromagnetically-coupled multilayers exhibit tuneable coercivity [4,5] and giant magnetoresistance [6]. The present work establishes the feasibility of switching exchange springs by optical parametric excitation.

Walker breakdown is predicted to be suppressed for the propagation of magnetic domain walls (DWs) in cylindrical nanowires and nanotubes, which has prompted their study as a candidate for memory and logic devices [1]. However, the DWs in these cylindrical nanostructures have a complicated, three dimensional, often chiral nature that is not yet fully understood. Using micromagnetic simulations, we present phase diagrams (including metastable states) of the structure of head-to-head DWs as a function of nanowire/ nanotube dimension. We predict the existence of a hitherto unreported DW in soft magnetic nanowires - the vortex/anti-vortex DW - and describe its spin structure, energetics and dynamics. In addition, it is shown that the DWs may be distinguishable when observed in Lorentz transmission electron microscopy, and we describe practical aspects of their experimental realisation.

Current driven magnetic resonance in exchange biased Ferromagnetic/Antiferromagnetic layers

V. Tshitoyan¹, C. Ciccarelli¹, A. Mihai², T. Moore², A. Ferguson¹

¹Cavendish Laboratory, University of Cambridge
²School of Physics and Astronomy, University of Leeds

Abstract

The electrical transport characteristics of ferromagnets govern the operation of most modern spintronic devices, for example, the tunnel magneto-resistance effect enables the reading of magnetic random access memories [1]. Much less attention has been paid to antiferromagnets due to their zero net magnetization which makes investigation of the magnetic order harder. However, recent experiments suggest that antiferromagnets can also be used as active components of spintronic devices [2]. We investigate antiferromagnets electrically using microwave techniques and magnetoresistive detection of magnetic resonance similar to the case of ferromagnets [3]. We report on measurements done in thin IrMn/NiFe exchange bias coupled layers. Current driven magnetic resonance measurements were performed at low temperatures. A resonance was observed and the resonance condition was found to vary depending on the current density. A correlation between the resonance and exchange bias was found based on measurements at different temperatures. Symmetries of the effect were also investigated. We discuss possible origins of the resonance, including the current dependence of the exchange bias.

References


Towards dipolar quantum magnetism in ultracold atoms

Mark Brannan, Anna Kowalczyk, Kai Bongs
MUARC, University of Birmingham, Edgbaston, B15 2TT, UK

Abstract
Within ultracold gases and Bose-Einstein Condensates (BECs), atomic dipole-dipole interactions are normally dominated by interactions with an external field. In an ultralow magnetic field regime, interactions with the external field become negligible and we can study the interaction of the individual atomic dipoles. We intend to achieve this by using a combination of active and passive magnetic shielding, where we aim to reduce the ambient field by around 8 orders of magnitude. Many theoretical studies of these dipole-dipole interactions exist, but so far there is little experimental verification. Such a system would allow a very controlled study of rich dynamical systems such as interacting spin systems on a lattice (spin ice), exotic ground state behaviours (persistent mass and spin currents), interesting spin textures as well as tests of fundamental physics.

References
MUON SPIN ROTATION AS A PROBE FOR MULTIFERROIC MATERIALS

Authors: Carlos Aristizabal, Donna C. Arnold, Laura Nuccio, Nicola A. Morley, Francis L. Pratt, Sean Giblin, Finlay D. Morrison, Michael Carpenter, Alan J. Drew.

ABSTRACT

Multiferroic magnetoelectrics are materials that exhibit both, ferromagnetic and ferroelectric ordering in the same phase. Thus, they have a spontaneous magnetization that can be manipulated with an applied magnetic field, a spontaneous ferroelectric polarization that can be switched by an applied electric field, and in some cases, there exist some form of coupling between the two order parameters. Such coupling is of great technological importance as it offers the possibility of new multifunctional devices such as transducers, actuators, sensors and memories [1].

Muon spectroscopy (MS) [2] has shown itself to be an extremely versatile and powerful probe of magnetic properties of materials as well as a flexible technique in terms of experimental set up to be able to show magnetic behavior under an applied electric field. By means of MS and other complementary techniques, I will present, in an entirely new tetragonal tungsten bronze (TTB) class of multiferroic material, a direct coupling in the form of an internal magnetic field that varies hysteretically with an applied electric field as shown in the figure below.

Time resolved scanning Kerr microscopy study of a synthetic antiferromagnet writer yoke excited by a bi-polar pulse

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Abstract

A partially built hard disk writer structure with a NiFe/CoFe/Ru/NiFe/CoFe synthetic antiferromagnetic (SAF) yoke was studied by time and vector resolved scanning Kerr microscopy. All three time dependent components of the magnetization were recorded simultaneously as a bi-polar pulse with 1 MHz repetition rate was delivered to the coil. The component of magnetization parallel to the symmetry axis of the yoke was compared at the pole and above a coil winding in the centre of the yoke. The two responses are in phase as the pulse rises, but the pole piece lags the yoke as the pulse falls. The Kerr signal is smaller within the yoke than within the confluence region during pulse cycling. This may indicate a higher permeability of the pole piece under such driving conditions. Dynamic images acquired at different time delays showed that the yoke relaxes faster than the confluence region, perhaps due to the different magnetic anisotropy in these regions. Although the SAF yoke is designed to support a single domain to aid flux conduction, no obvious flux beaming was observed, suggesting that a more complicated domain structure forms at the top of the yoke. The SAF yoke writer hence provides relatively poorer flux conductivity but good control of rise time compared to single layer and multi-layered yokes studied previously.


Novel morphology magnetic FePt clusters and elucidation of the mechanism of formation

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We report the controlled synthesis of novel morphology magnetic FePt clusters composed of platinum rich FePt nanocrystals within an iron rich FePt alloy. Cluster size increases with increasing total surfactant amount. Polycrystalline clusters up to 54 nm composed of crystals of 4 nm in diameter are observed. Clusters of 44 nm in diameter exhibit magnetic saturation ($M_S$) of 30 emu.g\textsuperscript{-1} not previously observed in the literature. With a decrease in the amount of oleic acid, increased size and monodispersity of clusters up to 54 nm is observed, while excess oleic acid promotes monocrystalline NPs in the order of 8 nm. Coordination of Fe and Pt atoms with OA and OLA respectively hinders deposition of each respective metal in NP growth. The use of aromatic bulky dibenzyl ether over aliphatic linear dioctyl ether resulted in clusters with improved monodispersity. Transmission electron microscopy, dynamic light scattering, X-ray diffraction, super-conducting quantum interference device magnetometry, scanning transmission electron microscopy, energy dispersive X-ray spectroscopy, inductively coupled plasma atomic emission spectroscopy, X-ray photoelectron spectroscopy and Fourier transform infra-red spectroscopy analyses are presented and discussed.

Nguyen TK Thanh would like to thank the Royal Society for her University Research Fellowship, Luke Green would like to thank UCL for his PhD stipend.
Abstracts (Posters)
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Ferromagnetic Resonance of Exchange Coupled Bilayers

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Ferromagnetic resonance (FMR) is a mature technique that is currently used to study a wide range of effects from magnetic anisotropies to interface damping and spin transfer torque. The recent development of x-ray detected ferromagnetic resonance (XFMR) has added element selectivity, and allows us to study the magnetodynamics of individual layers in magnetic tunnel junctions and other multilayer structures. A selection of recent results will be presented, including time-resolved precession of a NiFe/Cr/CoFe trilayer, measured at Diamond Light Source.

![Precession of magnetisation of each element in a NiFe/Cr/FeCo trilayer, measured using XFMR.](image)

Micromagnetic simulations have been developed in parallel with these experiments, using fourier transforms to computer the power spectrum of normal modes supported by thin films. Confinement effects lead to the formation of demagnetisation-driven edge modes not observed in macroscopic samples. These are strongly dependent on sample geometry and alignment of the static bias field about which the moments precess. Simulations of coupled bilayers have also been performed, and demonstrate qualitative agreement with XFMR experiments, where NiFe resonances generate precession of CoFe layers through exchange coupling, but not the other way around.

![Resonance modes of a NiFe thin film in x,y,z for uniform precession at 4.9GHz (a,b,c) and 10.1 GHz (d,e,f). Elevation denotes amplitude, colour denotes phase](image)
Bose-Einstein condensation of magnons in the dimer system Cu(pyz)(gly)ClO$_4$

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The compound Cu(pyz)(gly)ClO$_4$ consists of dimers of Cu$^{2+}$ coupled by pyrazine (pyz) ligands. These dimers are tethered with glycine (gly) bridges that connect the dimers to form corrugated sheets. We have used magnetization measurements, heat capacity and µSR to study the phase diagram of this system and demonstrate that a long-range ordered phase is stabilised between 1.7(1) T and 5.8(1) T (as T→0) that is suggestive of Bose-Einstein condensation of magnons.

Figure 1: Cu-(gly)-Cu dimers (shaded) viewed along the a-axis (left) and c-axis (right) in Cu(pyz)(gly)ClO$_4$ (ClO$_4$ ions omitted for clarity).
Spin-orbit Coupling Induced Cancellation of Magnetic Moments in the Double Perovskite Ba$_2$YWO$_6$

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The cubic rocksalt-ordered double perovskite Ba$_2$YWO$_6$ has been previously synthesised, but not studied in detail$^1$. We have analysed X-ray and neutron diffraction patterns (below left) of the powder, to confirm an $Fm\bar{3}m$ structure: this results in the 5$d^1$ electron occupying the triply-degenerate $t_{2g}$ orbital set of the octahedrally co-ordinated W$^{5+}$ ion.

Magnetic susceptibility measurements have also been carried out on the sample. These show a very small magnetisation: such a phenomenon has been predicted previously$^2$, and is said to arise from the strong spin-orbit coupling which results in the $J = 3/2$ quadruplet being favoured, despite Hund’s third rule. Consequently, the spin and orbital angular momentum quantum numbers are projected onto this quadruplet, which theoretically results in complete cancellation of the magnetic moment for the electron.

Heat capacity measurements (below right) show no sharp peak which would indicate a structural phase transition. Comparison of data from Ba$_2$YWO$_6$ with that of the diamagnetic analogue Ba$_2$YTaO$_6$ allows determination of the magnetic contribution to heat capacity. From this, the magnetic entropy can be determined (below right, inset).

Ba$_2$YWO$_6$ thus shows cancellation of magnetic moments to a degree previously unreported. The related compound Ba$_2$YMoO$_6$ is also a cubic double perovskite, and investigations of that material have shown it to have a lower magnetic moment than expected$^3$. Dielectric measurements have also been carried out on that material, showing a glassy freezing of spins.

References

MUON SPIN ROTATION AS A PROBE FOR MULTIFERROIC MATERIALS

Authors: Carlos Aristizabal, Donna C. Arnold, Laura Nuccio, Nicola A. Morley, Francis L. Pratt, Sean Giblin, Finlay D. Morrison, Michael Carpenter, Alan J. Drew.

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Ferromagnetic-organic interfacial states detected by transient conductivity and their role on low voltage current injection in organic spinvalves

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In recent years, there has been an increasing interest in utilising organic materials as spin transport layers as they have very long spin-coherence times due to low spin-orbit and hyperfine coupling present in these materials\(^1\)-\(^4\). Whilst there has been considerable research into organic spinvalves, with devices demonstrating magnetoresistances of up to 300% there is a fundamental unsolved problem of how spin injection occurs. All organic spinvalves have been found to operate best at exceptionally low voltages, in the order of millivolts, where our traditional understanding of the injection mechanism suggest that there should be no carrier injection\(^5\).

In this work we investigate the role of hybrid interface states (HINTS) between a ferromagnetic contact (FM) and an organic semiconductor. Using transient conductivity measurements on a variety of devices, the presence of these HINTS in a real device but only in the presence of a FM contact. We then consider the consequences that these filled HINTS will have on the electrical properties of devices. We argue that the filling of these HINTS introduces a large electric field at the interface between the FM contact and the OSC layer, which causes an effect analogous to “band-bending” in conventional semiconductors. This explains the Ohmic injection seen in organic spinvalves which results in significant hole injection even at very low (e.g. millivolt) applied voltages.