MONDAY MORNING

SPIN-ORBITRONICS

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Spintronics can be described as a new type of electronics based on the propagation of spin-polarized currents. In classical spintronic devices one uses the exchange interaction between the spin of conduction electrons and local spins in magnetic materials to create spin-polarized current or to manipulate nanomagnets by spin transfer from spin-polarized currents. A novel direction of spintronics exploits more the spin-orbit coupling than the exchange, either to generate spin-polarized currents with only nonmagnetic materials or to create new types of magnetic objects like skyrmions. I will review recent advances in two directions of this field.

a) Magnetic skyrmions induced by interface-induced Dzyaloshinsky-Moriya interactions in thin films and current-induced motion of skyrmions in magnetic tracks.
b) Spin Hall, Rashba, Edelstein-Rashba effects and their use for current-induced motion of domain walls (or skyrmions).

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Spintronics and Spin Caloritronics of Ferromagnetic Insulator | Metal Heterostructures

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In the past years magnetic insulators in contact with normal metals such as Yttrium Iron Garnett (YIG)|Pt bilayers [1,2] have emerged as a novel material systems that displays unique phenomena due to the coupling between spin, charge, and heat transport on one hand and lattice and magnetization dynamics on the other.

In this talk I will address selected theoretical issues for this system, such as spin Seebeck effect [2], current-induced magnetization dynamics [3], spin pumping and AC spin Hall effect [4], and the spin Hall magnetoresistance [5,6].

The reported results have been obtained in collaboration with Mathias Althammer, Yanting Chen, Adam Cahaya, Sebastian Gönnenwein, Hujun Jiao, Hiroyasu Nakayama, Eiji Saitoh. Saburo Takahashi, Oleg Tretiakov, Ke Xia, Jiang Xiao, and Yan Zhou.

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NICKELATE-BASED HETEROSTRUCTURES

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Transition metal oxides display a wide range of physical properties arising from the complex interplay between their spin, charge, orbital and lattice degrees of freedom. Strain, reduced dimensionality and/or interfacial interactions allow further tuning of their already outstanding properties and even access to hidden phases and possibly to new functionalities.

Here, we study nickelate thin films and heterostructures. Perovskite nickelates (RNiO$_3$, R=rare earth), with the exception of LaNiO$_3$, display a bandwidth-controlled metal insulator transition (MIT) and antiferromagnetic order in the low temperature phase. We demonstrate tuning of the MIT in nickelate thin films using strain, electric field and light [1], and that ultrathin LaNiO$_3$ films undergo a MIT as the thickness is reduced [2]. We also report how interface engineering can induce magnetism in non-magnetic LaNiO$_3$. This behaviour is observed in (111)-oriented LaNiO$_3$/LaMnO$_3$ superlattices [3] (Fig.1). The properties of NdNiO$_3$/LaMnO$_3$ heterostructures will also be presented.

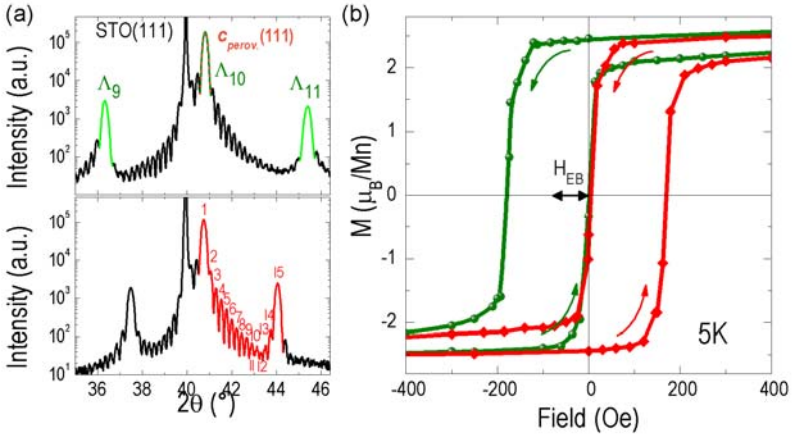

Fig.1: (a) *X-ray diffractograms for (111)-oriented (5LaNiO$_3$/5LaMnO$_3$)$_{20}$ (top) and (7LaNiO$_3$/7LaMnO$_3$)$_{15}$ (bottom) superlattices.(b) Magnetization–field loops at 5 K for a (7LaNiO$_3$/7LaMnO$_3$)$_{15}$ superlattice after field-cooling from room temperature in a +4000 Oe field (green circles) and in a -4000 Oe field (red diamonds).*

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SYMPOSIUM 5.1

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STRESS CONTROLLED MAGNETISM IN OXIDE-MAGNETIC HYBRIDS

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The properties of oxide-magnetic hybrids are very interesting particularly when ferromagnets (FM) are in proximity to materials that undergo a metal-insulator (MIT) and structural phase transition (SPT). The stress associated with the SPT produces a magnetoelastic anisotropy in proximity coupled FM films that allows controlling the magnetic properties without magnetic fields. Canonical examples are the vanadium oxides; VO_2 and V_2O_3. VO_2 undergoes a metal/rutile to an insulator/monoclinic phase transition at 340 K. In V_2O_3 the 160 K transition is from a metallic/rhombohedral to an insulating/ monoclinic phase. We have investigated the magnetic properties of different combinations of ferromagnetic (Ni, Co and Fe) and vanadium oxide thin films. The (0.32%) volume expansion in VO_2 or the (1.4 %) volume decrease in V_2O_3 across the MIT produce an interfacial stress in the FM overlayer. The coercivities and magnetizations of the FM grown on vanadium oxides are strongly affected by the phase transition. The coercivity change can be as large as 170 % and occur in a very narrow temperature interval. These effects are controlled by the thickness and deposition conditions. For VO_2/Ni bilayers the large coercivity change occurring above room temperature opens the possibilities for technological applications.

The oxide research supported by the US-AFOSR and the magnetism by the US-DOE .

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IMAGING MAGNETIZATION REVERSAL PROCESSES IN COBALT ANTIDOT ARRAYS

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Understanding the effect of geometric confinement in magnetization processes of magnetic antidot arrays would contribute to their application in ultrahigh density storage [1]. We report the analysis of magnetization reversal in cobalt antidot arrays by in-situ Lorentz microscopy upon magnetic field as a function of the geometry (hole size and periodicity). For certain geometric parameters (i.e. 160 nm period with,40 nm hole diameter), magnetic superdomains separated by stripes of magnetic contrast (superdomain walls) has been observed (see Fig 1). The magnetization switching along the easy axis occurs in two stages: switching of horizontal magnetic stripes, and then switching of vertical magnetic stripes (see Fig. 2). These results will be correlated to micromagnetic simulations and macroscopic magnetization.

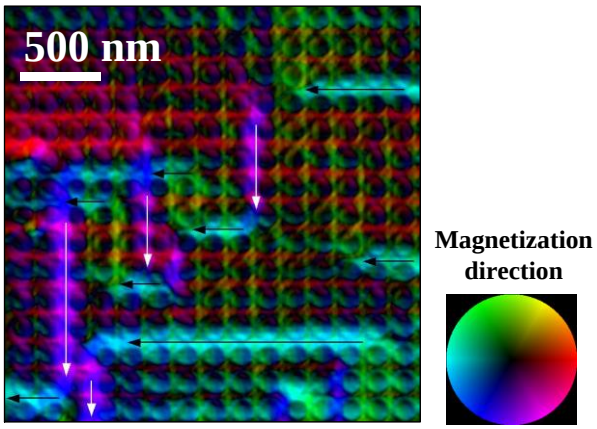

Figure 1. Local reconstruction of the array magnetic state by the Transport-of-Intensity Equation.

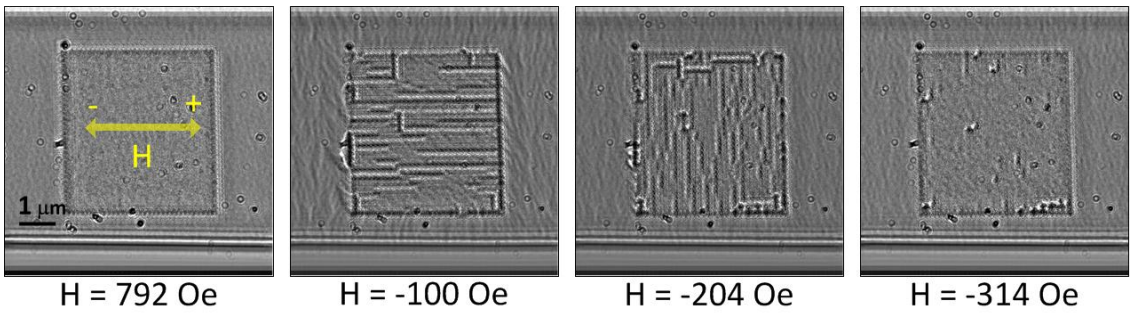

Figure 2. Lorentz images of the magnetization reversal process in a Co antidot array.

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STRUCTURE AND MAGNETIC PROPERTIES OF CoFe NANOWIRES

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Nanowires magnetism is determined by shape and crystalline anisotropy terms. Tailored magnetization reversal is thus essential to design and develop advanced devices.
CoFe nanowire arrays were produced by template-assisted electroplating into self-assembled anodic alumina pores. The present study aims to the correlation between structure and magnetic properties looking for optimizing the hard magnetic properties.
Properties of CoFe alloys nanowires are tuned by adjusting the alloy composition, adding other elements and by suitable thermal treatments [1]. Structure studies by x-ray diffraction and particularly by TEM in individual nanowires, conclude a shift from polycrystalline *bcc* phase to a single crystal *fcc* as Co content increases. That results in a significant modification of the magnetic properties. Enhanced coercivity (~0.5 T) and remanence (~0.98 Ms) are obtained for nanowires with smaller diameter (< 20 nm) and after annealing (500ºC). Micromagnetic simulations indicate a transition from vortex to transverse domain wall propagation for the harder nanowires.

Financial support from EU- Contract REFreePerMag is acknowledged.

[1] D.-H. Qin *et al*, Chem. Phys. Lett. 374, 661 (2003); C. Bran *et al*, IEEE Trans Magn. (in press).

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PREPARATION AND MAGNETOTRANSPORT CHARACTERIZATION OF NANOPATTERNED $La_{2/3}Ca_{1/3}MnO_3$ NANOWIRES

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In this work we report a new approach to fabricate single-crystal nanowires from epitaxial $La_{2/3}Ca_{1/3}MnO_3$ thin films by combining optical and focused ion beam lithographies in order to produce large aspect-ratio nanowires of a maximum of 50 μm in length, 30 nm of thickness and widths ranging from 5 μm down to a minimum of 150 nm. The method successfully preserves their bulk physical properties, such as the metal – insulator transition (T_{MI}) and low residual resistivity (see Figure 1). We have observed that T_{MI} increases upon decreasing the nanowire width. Remarkably, we have obtained an enhanced value of magnetoresistance at low applied magnetic field in the narrowest nanowire (thickness = 150 nm, aspect ratio = length-to-width ratio > 300) at T_{MI}. A combination of both a strain release at the edges of the nanowire with decreasing width together with a destabilization of the insulating regions due to finite size effects around T_{MI} is proposed to account for the observed behavior. The results obtained in this work open new strategies to implement these structures in functional spintronics devices.

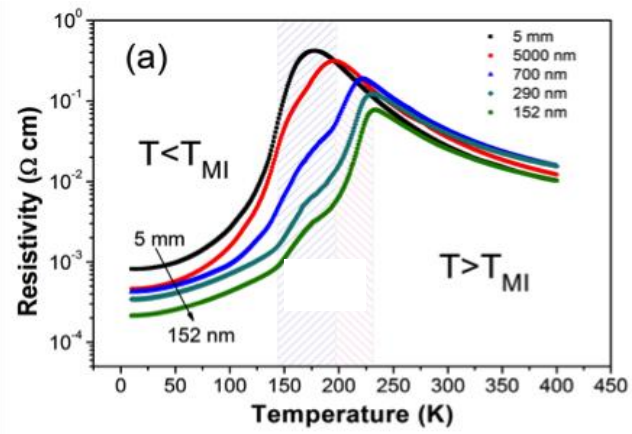

Figure 1.- Temperature dependence of the zero-field resistivity ρ(T) as a function of width of the nanowire.

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INTERFACE PROPERTIES OF $LaNiO_3/LaMnO_3$ SUPERLATTICES INVESTIGATED BY XMCD

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Transition metal oxides present a wide range of interesting properties as metal-insulator transitions (MIT), superconductivity and colossal magneto-resistance. The fabrication of superlattices (SL) composed of these complex systems has proved to be an interesting route to modify or create new properties.

We present x-ray magnetic circular dichroism measurements in $LaMnO_3/LaNiO_3$ (LMO/LNO) superlattices. LNO is a paramagnetic metal and the only system in the nickelate series to show neither antiferromagnetic ordering nor MIT in bulk. It is therefore surprising that LMO/LNO SL exhibit an exchange bias effect [1]. Motivated by this discovery, we have investigated LMO/LNO SL with XMCD in order to shed light on the magnetic interface interaction.

Our measurements show that these systems have a mixed valence (Ni^{2+}/Ni^{3+} Mn^{4+}/Mn^{3+}) coming from charge transfer at the interface. In addition Ni exhibits an average magnetic moment ferromagnetically aligned to Mn, as evidenced by element specific hysteresis curves. XMCD temperature dependence shows that both Ni and Mn moments are coupled manifested by the fact that both go to zero at T_C. Sum rule analysis shows that the Ni moment is small, in agreement with an induced moment at the interface.

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FOCUSED ION BEAM FABRICATED MAGNETIC ANTIDOT ARRAYS: MAGNETIC STRUCTURE DEPENDENCE ON LATTICE SYMMETRY

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Magnetic antidot arrays with hole diameter in the μm and sub-μm scales have been extensively studied as candidates for data storage [1] and logic devices [2] applications. However, very few works have dealt with nanometer-scale antidots [3,4].

In our work, a NanoFIB is used to pattern hexagonal or square lattice arrays on Co films (Figure). The hole diameter is 40 nm and the lattice parameter is in the 150 nm to 300 nm range.

The arrays where studied by means of local magneto-optic Kerr effect measurements and Magnetic Force Microscopy (MFM) imaging. The results were understood with the help of micromagnetic simulations.

MFM reveals that different lattice symmetry, hexagonal or square, gives rise to different magnetic structure in remanence (see Figure). This opens a route to tailor the magnetic properties of the films.

Funding from MINECO (MAT2011-29194-C02-01, MAT2010-20798-C05-01 and CSD2008-00023), CM (S2009/MAT-1726) and EU (PIEF-GA-2010-272470) is acknowledged.

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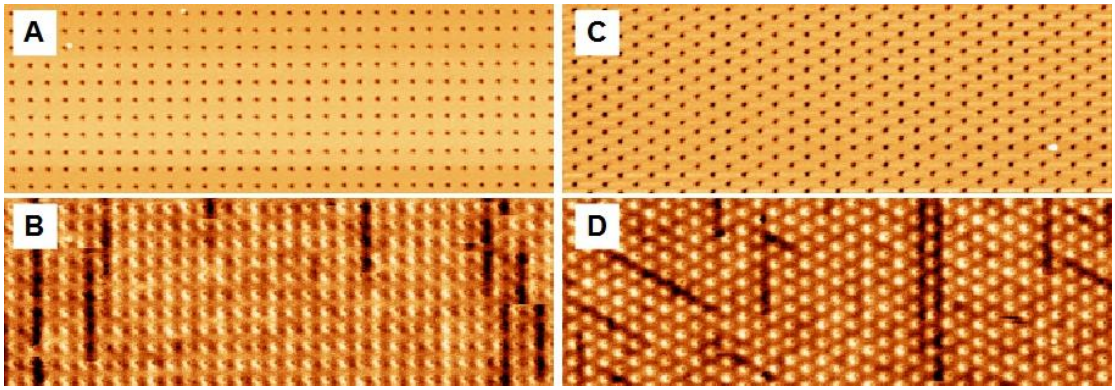

Figure. MFM images. Square array (a) topography (b) magnetic contrast. Hexagonal array (c) topography (b) magnetic contrast. Lattice parameter 250 nm. Image size 2 by 8 μm^2.

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MEMORY EFFECT ON THE MAGNETIC BEHAVIOUR OF ASSEMBLIES OF NANOPARTICLES WITH FM/AFM INTERFACE

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Monte Carlo simulations of the dynamic magnetic behaviour of an assembly of ferromagnetic (FM) core/ antiferromagnetic (AFM) shell nanoparticles are reported. We use a mesoscopic model of six spins that describes efficiently the complex structure of the nanoparticles in the assembly. Intra-particle nearest neighbours exchange interactions and inter-particle dipolar interactions are considered. Memory effects on low field Zero-Field-Cooled (ZFC) magnetisation curves have been investigated after stop and wait for a certain time in a selected temperature below the freezing temperature (T_f) (Fig. 1). Our simulations show that the memory effects increase with the concentration and that both the interface exchange coupling and the dipolar inter-particle interactions contribute to the observed dynamic behaviour. In particular the interface exchange interaction provides an additive source for the frustration of the system resulting in an enhancement of the memory effect. The numerical data reproduce well the experimental results on a system of Co nanoparticles in Mn matrix [1] (Fig. 1), confirming the glassy behaviour of the investigated nanoparticle systems.

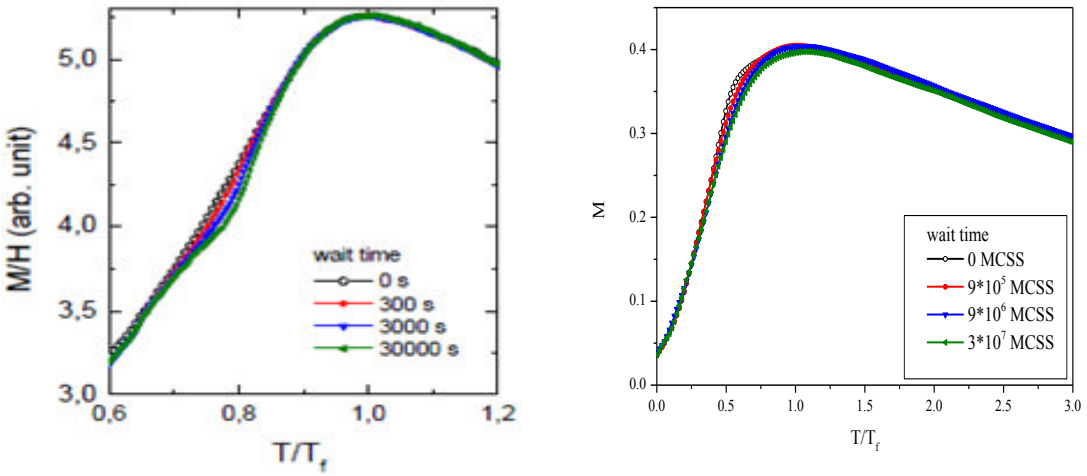

Figure 1 (left) Experimental ZFC-reference curve (open circles) and ZFC-memory curves (filled symbols) for a stop-and-wait of 300, 3000, and 30000 s at T=55 K ~ 0.8 T_f for CoMn nanoparticles concentration 9.8% [1] (right) Monte Carlo ZFC-reference curve (open circles) and ZFC-memory curves (filled symbols) after stop-and-wait for $9*10^5$, $3*10^6$, $9*10^6$, $3*10^7$ Monte Carlo Steps per Spin (MCSS) at T =0.5 T_f for 10% concentration of the FM/AFM nanoparticle assemblies.

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SYMPOSIUM 1.1

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Domain-wall depinning governed by the spin Hall effect

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Current induced domain wall motion (CIDWM) in perpendicular materials has caused much excitement over the last few year years due to the discovery of unexpected DW driving mechanisms. Recently, we have shown that the Spin Hall Effect (SHE) [1,2] provides a radically new mechanism for CIDWM in these systems [3]. Essential for this work was the ability to create and pin DW's at well-defined positions in a Pt /Co / Pt nanowire. By studying the depinning of these DW's as function of applied field directions and current we were able to disentangle different contributions. This allows us to unambiguously identify the SHE as the driving mechanism.

In the first part of this talk we will discuss the SHE mechanism and introduce an DW depinning experiment that allows us to disentangle different contributions to CIDWM. This will be supported by data obtained on different Pt / Co / Pt and Pt / Co / Ta stacks where we test the SHE symmetry properties. This is further explored by studying the effect of the SHE on stabilized Neel or Bloch DWs. The presented results show that we can directly tune the strength of the SHE by simply changing the relative thickness of the non-magnetic Pt layers sandwiching the Co layer. The recent discovery and theoretical support for dyaloshinsky-moriya interactions in similar materials which stabilize Neel DWs with a well-defined chirality opens up the use of the SHE for technological DW applications such as racetrack memory.

In the second part of this talk we will discuss potential applications of the SHE for magnetization manipulation in synthetic multiferroic heterostructures. This allows to tune the SHE effect by switching the order parameter of the underlying substrate.

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MANIPULATION OF SPIN-TRANSPORT BY DISORDER

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INTRODUCTION

In the perspective of contemporary material science, especially within the field of electronic transport, disorder is treated as a severe destructive mechanism, which should be reduced or prevented by all means. In contrast, here we show the constructive use of disorder by its straightforward application in band structure engineering: the electronic properties connected with a certain group of bands can be enabled or disabled by introducing specific disorder, which selectively affects particular bands, or changes the rest of the band structure, leaving the selected bands unperturbed. In particular, we demonstrate how to manipulate the spin-transport characteristics by applying random disorder as a constructive agent. This approach paves the way for the construction of novel systems with a surprising combination of properties, as topological insulators [1], or those which are either extremely rare or even entirely absent within the known classes of the ordered materials: half-metals with arbitrary magnetization and magnetic semiconductors [2].

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TEMPERATURE DEPENDENCE OF SPIN POLARIZATION IN CO/NI NANOWIRES DETERMINED FROM CURRENT-INDUCED MAGNETIC DOMAIN WALL DYNAMICS

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INTRODUCTION

Current-induced magnetic domain wall (DW) motion has been widely investigated due to its potential application. DW dynamics in perpendicularly magnetized Co/Ni nanowires is well explained by adiabatic spin transfer model, which allows us to determine the spin polarization of current (P). Here we report the temperature dependence of P in the nanowires with different Co and Ni thicknesses (t_{Co} and t_{Ni}).

RESULT

As shown in Fig. 1, P decreases more rapidly than M_s with increasing temperature, suggesting the magnon scattering in the temperature dependence of P. In contrast to the systematic dependence of M_s on t_{Ni}/t_{Co} ratio [Not shown], temperature dependences of P are almost independent of t_{Ni}/t_{Co} ratio.

Acknowledgement

This work was partly supported by a Grant-in-Aid for Scientific Research (S) from JSPS, the Collaborative Research Program of ICR, Kyoto Univ., JSPS through FIRST program, and Research Fellowships of JSPS for young scientists.

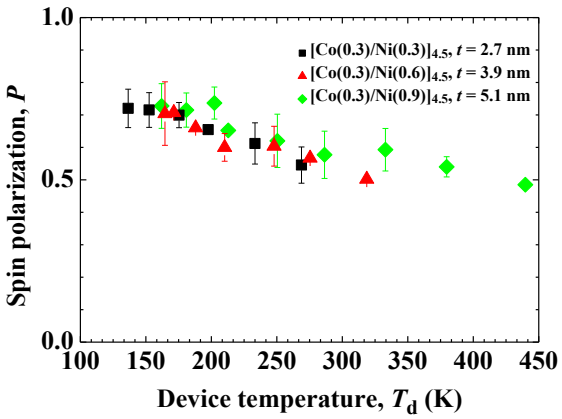

Fig. 1 Temperature dependences of P for Co/Ni nanowires with various total thicknesses (t).

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SPIN SEEBECK EFFECT IN EPITAXIAL FE_3O_4(001) FILM ON $SRTIO_3$(001)

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We report the observation of the spin Seebeck effect in magnetite film. We measured the transversal voltage developed upon application of a thermal gradient and a sweeping magnetic field. Above the metal-insulator transition (Verwey transition) the signal is a contribution from both the anomalous Nernst (ANE) and spin Seebeck effects (SSE) of Fe_3O_4 layer. Nevertheless the ANE contribution to the SSE is found to be negligible due to the resistivity difference between Fe_3O_4 and Pt layers. Below the Verwey transition the SSE is free from the ANE of the ferromagnetic layer and it is found to dominate over the ANE due to magnetic proximity effect on the Pt layer.

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SPIN TRANSFER TORQUE EFFECTS IN $La_{2/3}Sr_{1/3}MnO_3$ MEASURED BY RESISTIVE DETECTION AND XMCD-PEEM IMAGING

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$La_{2/3}Sr_{1/3}MnO_3$ (LSMO) is a metallic magnetic oxide with relatively high Curie Temperature ($T_C \approx 370$ K) and high spin polarisation, promising a high spin transfer torque (STT) efficiency. We will report on our investigations of STT effects in LSMO nanowires evaluated by (i) direct imaging of magnetic domain walls using Photoemission Electron Microscopy with X-ray Magnetic Circular Dichroism magnetic contrast (XMCD-PEEM) after consecutive current pulse injections (Figure 1(a)) and (ii) low temperature current assisted domain wall depinning detected by resistive measurements (Figure 1(b)). Although heating effects, due to higher resistivity and lower Curie temperature compared to 3d metals, limit the applicable current densities, both experiments indicate a high STT efficiency in LSMO so that even at low current densities effects are observed.

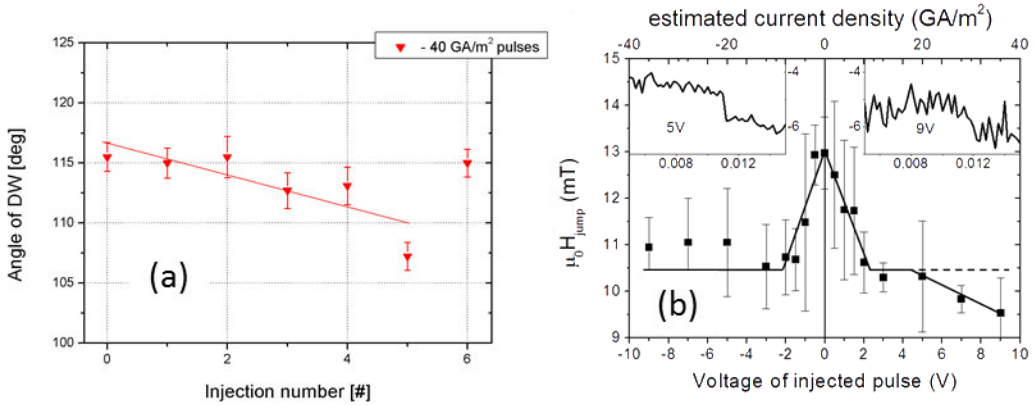

Figure 1: Spin torque effects in LSMO nanowires: (a) Position of a magnetic domain wall in a LSMO nanowire after consecutive current pulse injection, determined by XMCD-PEEM imaging. Domain wall creep in direction of the current is observed. (b) Depinning field of a domain wall in a LSMO nanowire measured in low temperature transport experiment with inject current pulses. Apart from a low current symmetric reduction attributed to heating effects, at higher positive currents a further reduction is observed, which is related to STT. Similar combinations of heating and STT effects have been observed in Permalloy [1].

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SPIN HALL EFFECT IN SWITCHING OF THREE TERMINAL MAGNETIC TUNNEL JUNCTION WITH CuIr CHANNEL

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We investigate switching of three terminal magnetic tunnel junctions (MTJs) having a Cu channel, a common interconnection material in VLSI, with Ir doping (Cu:Ir). Figure shows that with the application of a current pulse to the channel, current direction dependent switching of MTJ takes place. We show that the relationship between the direction of the switching current and magnetization configuration as well as its switching current density are well explained by the combination of spin transfer torque induced by the spin Hall effect in Cu:Ir [1] and current-induced fields.

This work was supported by JSPS through FIRST program.

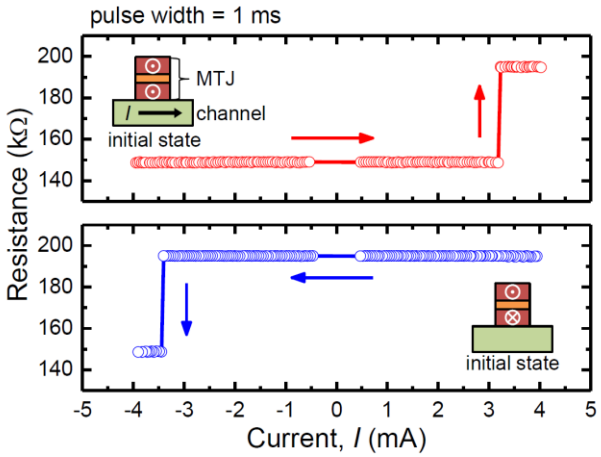

Figure: Resistance of a MTJ as a function of current pulse *I* with the width of 1 ms. The arrows show the direction varying amplitude of *I*.

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IMPACT OF INTERFACE HYBRIDIZATION ON SPIN INJECTION IN MOLECULES

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Molecular spintronics is an emerging research field at the frontier between organic chemistry and the spintronics concept of adding non-volatility and spin degree of freedom to electronics. Compared to traditional inorganic materials molecules are flexible and can be easily tailored by chemical synthesis. However, due to their theoretically expected very long spin lifetime opportunity, they were first only seen as the ultimate media for spintronics devices and it was only very recently that new spintronics tailoring opportunities, unachievable or unthinkable with inorganic materials, and that could arise from the chemical versatility brought by molecules and molecular engineering were unveiled.

We will show that the molecular structure, the local geometry at the molecule-electrode interface and more importantly the ferromagnetic metal/molecule hybridization can strongly influence interfacial spin properties going from spin polarization enhancement to its sign control in spintronics devices [1]. Spin dependent transport measurements on ferromagnet/molecules/ferromagnet magnetic tunnel junctions where molecules are organic semiconductors (Alq3) or self-assembled monolayers [2,3] highlighting the crucial role of the interface will be presented.

This work is funded through the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n◦ 263104

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SYMPOSIUM 4.1

CERAMIC MAGNETIC MATERIALS : TARGETTED DESIGN FOR NEW EMERGING APPLICATIONS

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INTRODUCTION

The appearance of new emerging applications as well as new demands on energy consumption or larger information transfer rates require the development of new ceramic magnetic materials with optimum and tailor made performance. Concrete examples include: i) the need for wireless power transport (i.e. wireless electric car charging) requires new materials high saturation induction at high temperatures ii) the need for low energy consumption (i.e. renewable energy inverter components) requires new materials with low power losses as possible independent of temperature iii) the need for larger information transfer rates requires new materials with high permeability, stable with frequency up to as possible higher frequencies iv) new satellite weather forecasting and cloud imaging techniques require low insertion loss materials for non-reciprocal components at ~95 GHz.

In this presentation the basic principles along which the development of new magnetic materials with optimum properties (*materials with power losses of 210 mW cm^{-3} at 100kHz, 200mT, 90^{o} C or materials with relative initial magnetic permeability of 12500 with 100kHz (25^{o}C) losses of tan(δ)/μ=25x10^{-6}, or materials with saturation induction of 550 mT at 10kHz, 1200 A/m, 100^{o}C, or hexagonal materials with insertion losses of 0.2 dB at 94 GHz*) has taken place will be described.

In addition, emphasis will be given on the fundamental material related problems encountered, when large scale industrial production and real shape products takes place.

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RECORD ENERGY DENSITIES ABOVE 450 kJ/m^3 IN EXCHANGE COUPLED $SmCo_5$/Fe MULTILAYERS

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INTRODUCTION

Exchange coupled hard/soft magnetic nanocomposites have long been in the interest of research for improving the energy density of the best hard magnetic materials. However, only recently values significantly above the theoretical hard phase limit have been realized in epitaxial $SmCo_5$/Fe/$SmCo_5$ trilayers [1]. For these films the total hard layer thickness was kept constant at 50 nm and the Fe layer thickness was varied. Optimum $(BH)_{max}$ of 312 kJ/m^3 is obtained for a Fe thickness of about 13 nm (20 vol-%).

To investigate the influence of a reduced $SmCo_5$ layer thickness a series of [$SmCo_5$(17nm)/Fe(x)]$_2$/ $SmCo_5$(17nm) 5-layers was prepared by UHV pulsed laser deposition. Two Fe layers of thickness 3 to 15 nm were deposited in between three $SmCo_5$ layers of thickness 17 nm each. Due to the reduced $SmCo_5$ layer thickness all multilayers possess a square shaped hysteresis. For an individual Fe thickness of 10 nm, the now larger volume fraction of 35% soft phase drastically increases the maximum energy density to above 450 kJ/m^3 (see Figure 1). The results are discussed with respect to predictions from three-dimensional micromagnetic calculations.

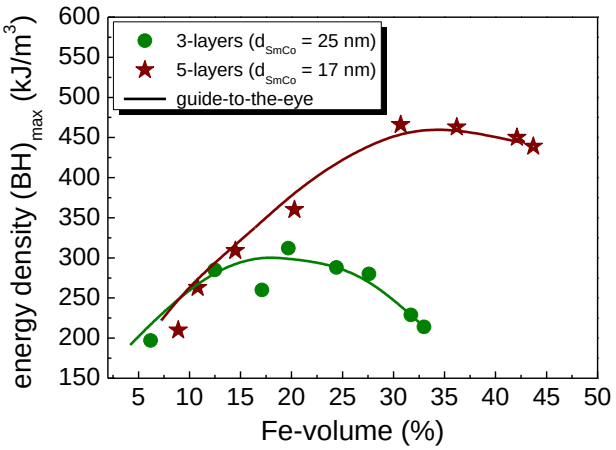

Fig. 1 $(BH)_{max}$ for 3-layer and 5-layer samples as a function of Fe-volume fraction

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UNDERSTANDING COERCIVITY IN ND-FE-B SINTERED MAGNETS: MULTISCALE CHARACTERISATION AND MODELLING

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INTRODUCTION

High performance Nd-Fe-B sintered magnets are critical for clean energy technologies such as hybrid electric vehicles. Greater understanding of the coercivity mechanisms in such materials will enable radical new approaches to the production of Dy-free Nd-Fe-B magnets [1]. Coercivity is dependent on the intrinsic magnetic properties of $Nd_2Fe_{14}B$ and microstructural features ranging in size from ~ 1 nm Nd-rich grain boundary phases to ~ 5 μm $Nd_2Fe_{14}B$ grains. A multiscale approach to characterisation is therefore vital. Atomic resolution STEM images of interfaces and composition profiles with approximately 1 Å spatial resolution have been measured using STEM-EELS. Atomistic models, based on the structure and composition data obtained experimentally have been used as input in atomistic simulations of the interfaces. On a larger length scale, data from experiments has been added to finite element models of ensembles of $Nd_2Fe_{14}B$ grains surrounding a Nd-rich grain. Finite element micromagnetics predicted different coercivity values for the ensembles with different Nd-rich phases in the centre, thus helping to identify potential microstructural weak points.

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SOFT MAGNETIC OBLATE SPHEROIDS IN A HARD MAGNETIC MATRIX

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We use finite element micromagnetics simulations to investigate changing hysteresis properties for varying arrays of soft magnetic ellipsoids ($Fe_{65}Co_{35}$) in a hard magnetic matrix ($Nd_2Fe_{14}B$). The oblate spheroids' major axis is in the x,y-plane, the minor axis is parallel to the z-axis. The external field is applied parallel to the easy axis of the magnet and parallel or perpendicular to the major axes of the ellipsoids as symbolized by the arrows in Figure 1. We notice a significant difference in the nucleation field of approximately 28.5 % between the two orientations of the applied external field. There are two main reasons for this effect: (1) In perpendicular oriented soft spheroids a Neel wall has to form to initiate magnetization reversal. This requires more energy than the formation of a Bloch wall for parallel aligned inclusions. (2) Magnetostatic interactions between the ellipsoids stabilize the soft phase in addition to the exchange hardening.

We will show that it is possible to enhance the nucleation field by up to 45 % through rearranging of the soft inclusions (splitting into smaller ellipsoids with different aspect ratio and reorientation) while the ratio of magnetically soft to magnetically hard material is kept constant.

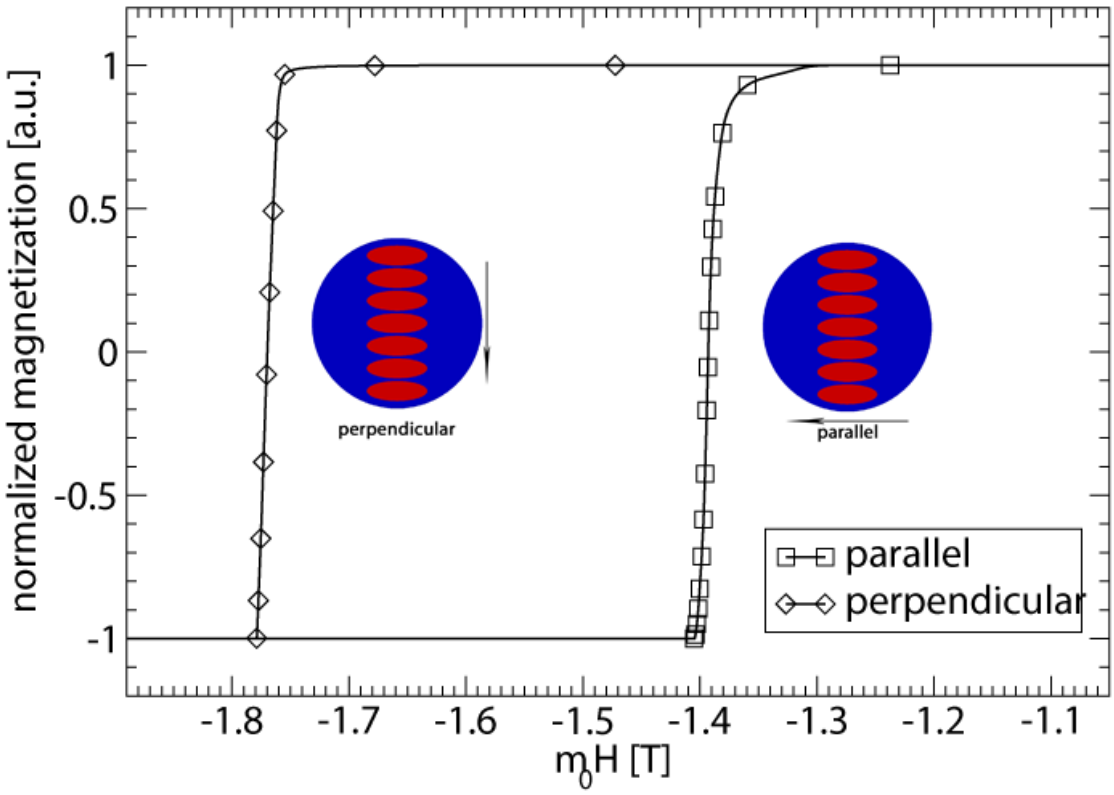

Figure 1: Magnetic reversal of the nanocomposite magnet. If the major axes of the soft inclusions are perpendicular to the hard magnetic easy axis the coercive field is increased by about 30 percent as compared to the parallel alignment.

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DEVELOPMENT OF HYSTERESIS IN BALL-MILLED $La(Co_{5-X}Fe_X)$

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There is an increasing demand for new hard magnets with reduced content of strategic rare earths. Lanthanum has a similar crustal abundance to Nd or Y, but it is not used for manufacturing permanent magnets. It has no 4*f* electrons and contributes little to the anisotropy. The cobalt sublattice provides substantial c-axis anisotropy in $LaCo_5$ ($K \approx$ 6.1 MJ/m^3) It should be possible to increase the magnetization by iron substitution for cobalt, while retaining enough anisotropy to make a good permanent magnet.

Here we report the synthesis and magnetic characterization of a series of $La(Co_{5-x}Fe_x)$ alloys with $0 \leq x < 1$. The bulk alloys were arc melted, annealed for a week at 900°C in evacuated quartz tube and subsequently quenched in air. The Mössbauer spectrum of the x = 1 sample shows a hyperfine field of 30.6 T, corresponding to an iron moment of 2.0 μ_B, which is significantly greater than cobalt and increases the magnetization of the alloy, However, the as-quenched compounds contain a proportion of the cubic LaM_{13} phase, which increases with x.

Following a report of 1.7 T coercivity in La-rich La-Co alloys [1], we have prepared a series of ball-milled, iron-substituted La-Co materials in order to optimize their magnetic properties. These will be discussed together with influence of Ca additives on the structure and magnetic properties.

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COMPARISON OF GLOBAL TEXTURE MEASUREMENTS BY XRD AND AN EBSD STOCHASTIC SAMPLING METHOD IN (ND,DY)-FE-B SINTERED MAGNETS

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INTRODUCTION

The $Nd_2Fe_{14}B$ grains in Nd-Fe-B magnets must have a strong uniaxial texture in order to maximise the remanence. To study the global texture, i.e. the texture on the scale of a bulk magnet, magnetic or x-ray measurements are commonly used. Electron backscattered diffraction (EBSD) mapping is typically used to study the local texture, i.e. texture on a length scale of a few grains. For example, EBSD local texture results suggested that the Nd oxide phases in Nd-Fe-B sintered magnets were randomly oriented [1] and this result was subsequently confirmed by synchrotron global texture measurements of far larger numbers of grains [2]. In order to obtain a global texture measurement from EBSD, mapping can be carried out over large areas but there is much redundancy in the data because diffraction patterns are collected at many different positions in each grain. Instead of mapping, an alternative, stochastic EBSD method can be used to obtain orientation information from large numbers of grains without this redundancy, the results of which approach a measurement of the global texture (*e.g.* by XRD). In the current work, the results of such EBSD global texture measurements are verified by comparison to conventional XRD and magnetic texture measurements.

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ANISOTROPIC TWO-PHASE COMPOSITE MAGNETS WITH SINGLE-PHASE HARD MAGNETIC BEHAVIOR

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ABSTRACT

Anisotropic NdFeB-Fe composite magnets draw much interest due to their theoretical potential of exhibiting significantly higher energy densities than those of currently existing magnets [1]. In these composites, NdFeB provides high anisotropy for a high coercivity, whereas Fe contributes a high saturation magnetization for a higher remanence. Both parameters – coercivity and remanence – are key points in improving the energy density of a permanent magnet. One major necessity is the introduction of a texture within the hard magnetic phase to achieve high energy products. Hot plastic deformation of consolidated melt-spun R-Fe-B alloys is one of the common techniques used to induce texture and thus fabricate anisotropic magnets with the easy axis of magnetization parallel to the pressing direction [2]. We adapted this process in order to produce textured composite magnets containing hard magnetic NdFeB and soft magnetic α-Fe. The particle size of the precursor materials was less than 10 microns. Powders with varying compositions were blended to obtain samples with NdFeB:Fe weight ratios of 100:0 to 70:30. The microstructure of the hot-pressed and hot-deformed magnets was studied with scanning electron microscopy. A layered structure of hard and soft magnetic phases with the layer normal parallel to the pressing direction was observed. Magnetic measurements were carried out by using a vibrating sample magnetometer (VSM). The samples show a single-phase magnetic behavior when measured along the nominal easy direction of magnetization.

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SYMPOSIUM 6.1

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GIANT MAGNETOELECTRIC EFFECT IN THIN FILM COMPOSITES

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Magnetoelectric (ME) composite materials show ME coefficients that are larger than that of natural multiferroics by several orders of magnitude. These ME composites have high potential for applications, e.g. as very sensitive ac magnetic field sensors. Special features are their passive nature, their high sensitivity, and their large dynamic range with linear response. By a suitable combination of magnetic shape anisotropy and field annealing it is possible to obtain a sensor element that has a pronounced sensitivity in only one dimension being a component of a 3-dimensional vector field sensor, which is highly desirable for applications like magnetoencephalography or –cardiography as a replacement for today's sensors based on liqiud He cooled SQUIDs.

The thin film ME 2-2 composites of this work consist of AlN or ferroelectric piezoelectrics and different magnetostrictive layers. Upon magnetic field annealing of amorphous magnetostrictive Metglas layers these ME composites with AlN as the piezoelectric layer show an uniaxial magnetic anisotropy (1) and an extremely high ME coefficient of up to 9.6 kV/cmOe at mechanical resonance in air which is enhanced by a factor of 4 in vacuum.

However, these composites require in general the presence of an external d.c. magnetic bias field, which is detrimental to their use as sensitive magnetic-field sensors. Composites consisting of piezoelectric AlN and multilayers with e.g. the sequence Ta/Cu/Mn70Ir30/Metglas serving as the magnetostrictive component rely on intrinsic magnetic fields arising from the induced exchange bias (2). The thickness of the different ferromagnetic layers and angle dependency of the exchange bias field are used to adjust the shift of the magnetostriction curve in such a way that the maximum magnetoelectric coefficient occurs at zero magnetic bias field. These self-biased composites show high sensitivity to a.c. magnetic fields with a maximum magnetoelectric coefficient of approx. 3 kV/cmOe at mechanical resonance.

In this presentation different thin film composites will be discussed in view of their piezoelectric material, different concepts of the magnetostrictive component and different electrode concepts in view of their use as very sensitive magnetic field sensors in the pT range (3).

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Funding via the DFG Collaborative Research Center SFB 855 is gratefully acknowledged.

CHARACTERIZATION OF INTEGRATED INDUCTORS WITH ONE AND TWO YIG LAYERS FOR LOW-POWER CONVERTERS (1W)

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INTRODUCTION

These last years, the miniaturization of electronic components allows to increase the number of equipment [1-2]. Consequently, the realization of integrated inductors with high inductance and low-cost manufacturing is highly desirable. The objective of our work is the characterization of inductors with one or two magnetic layers (Fig. 1) in order to integrate these components in low-power converters (1W).

Extracted parameters show a strong increase of the inductance either by simulation or by measurement (Fig. 2) according to the magnetic thickness layer. For inductance with two magnetic layers, the increasing factor is equal to the magnetic permeability (Fig. 2b).

In the final paper, the inductor characterization process will be presented and results are completed by studies according to frequency.

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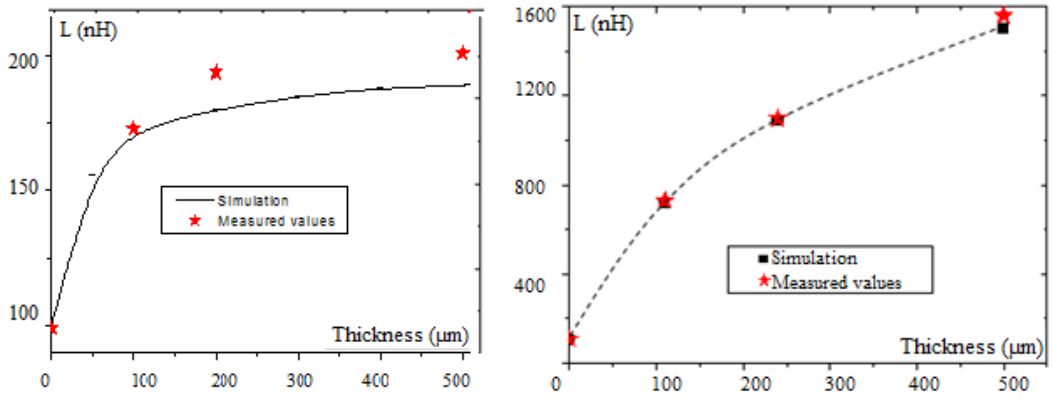
(a) **(b)**

Fig. 1. Pictures of realized inductors (a) one magnetic layer and (b) two magnetic layers.



(a) **(b)**

Fig.2. Simulated and measured inductance value versus magnetic thickness layers (a) inductors with one magnetic layer (b) inductors with two magnetic layers

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HIGH-FREQUENCY PERMEABILITY CHANGES IN FE-CO-HF-N/TI-N MULTILAYER COATINGS FOR MECHANICAL STRESS CHARACTERIZATION

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$Fe_{32}Co_{44}Hf_{12}N_{12}/Ti_{50}N_{50}$ multilayer coatings are realized as wear resistant coatings with an integrated sensor function, in order to detect external mechanical stress. Magnetic sensor functions based on the inverse Villari effect can be realized by detecting changes in hysteresis or resonance frequency. In this study, mechanical stress in the ferromagnetic Fe-Co-Hf-N layers induced by deformation is measured by a shift of the cut-off frequency.

$Fe_{32}Co_{44}Hf_{12}N_{12}/Ti_{50}N_{50}$ multilayer films were grown by a sequential deposition of seven $Fe_{32}Co_{44}Hf_{12}N_{12}$ and seven $Ti_{50}N_{50}$ individual layers plus one $Ti_{50}N_{50}$ top layer by means of reactive RF and DC magnetron sputtering, respectively. A uniaxial anisotropy field of 5 mT was induced after annealing the multilayer films for 1 h at 400 °C in vacuum in a static magnetic field. As a result, magnetic softness ($\mu_0 H_c$ = 0.6 mT) and cut-off frequencies above 2 GHz were observed. Compressive stress induced by a four point bending test increases the cut-off frequency whereas tensile stress causes its decrease. The change of the cut-off frequency is described by an effective in-plane anisotropy field which accounts for a thermally induced uniaxial anisotropy field and a biaxial magnetoelastic anisotropy field . The possibility of detecting mechanically induced stress in a ferromagnetic layer was demonstrated by the shift of the cut-off frequency with a resolution of 1.0 MPa.

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THIN-FILM MICROTRANSFORMER FOR HIGH FREQUENCY POWER APPLICATIONS

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INTRODUCTION

A permanent increase of a switching frequency of an electronic power circuit sets new requirements for inductive components. Inductors and transformers should provide smaller inductivity and smaller size [1, 2]. For a switching frequency range between 10 MHz and 30 MHz a proposed inductivity of transformers should be between 100 nH and 300 nH and for inductors between 20 nH and 200 nH. Decreasing of inductivity causes a decreasing of the inductor size and of the inductor profile height. However, small device sizes like 1008, 0805, 0603, are needed. Also the device profile becomes less as 0.5 mm or 0.3 mm. Only the new fabrication technology as thin-film technology allows a fulfillment of all these requirements.

DESIGN

A design of the developed microtransformer is shown in the Fig. 1. The microtransformer consists of a closed NiFe magnetic core and six coils. Three coils are on the primary and three coils are on the secondary transformer side. The design was simulated using Finite Element Method (FEM). The software tool Ansys Maxwell® was applied.

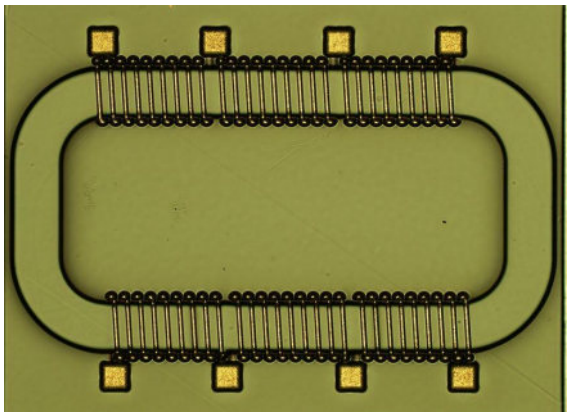

Fig. 1: Design of microtransformer

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A THIN FILM PASSIVE MAGNETIC FIELD SENSOR OPERATED AT 425 MHZ

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INTRODUCTION

A passive, magnetic field sensor consisting of a 425 MHz surface acoustic wave (SAW) transponder loaded with a giant magnetoimpedance (GMI) element is developed. The transponder, consisting of two interdigital transducers (IDTs) and the GMI element, a multilayer structure composed of $Ni_{80}Fe_{20}$/Cu/$Ni_{80}Fe_{20}$, are fabricated on a 128° Y-X cut $LiNbO_3$ substrate as shown in Fig. 1. The GMI component is characterized up to 500 MHz, showing a large impedance change (Fig. 2). The integrated sensor is characterized with a network analyzer through an S-parameter measurement (Fig. 3). Upon the application of a magnetic field, a maximum amplitude change and phase shift of 2.7 dB and 20 degree, respectively, are observed (Fig. 4). Within the linear region, the magnetic sensitivity is 3870 dB/T and the resolution is 1.3 μT.

FIGURES AND TABLES

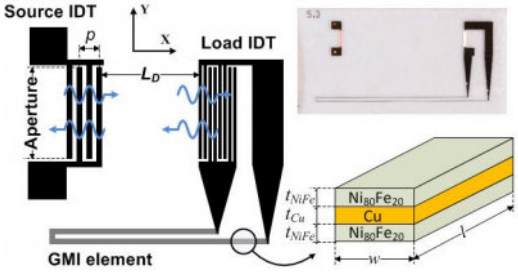

Figure 1: Schematic of the thin film SAW-GMI sensor; Inset: Fabricated device.

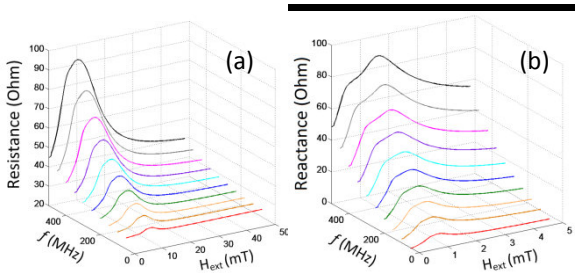

Figure 2: Resistance (a) and Reactance (b) of the GMI element as a function of the magnetic field applied in the longitudinal direction of the sample for frequencies from 10 MHz to 500 MHz.

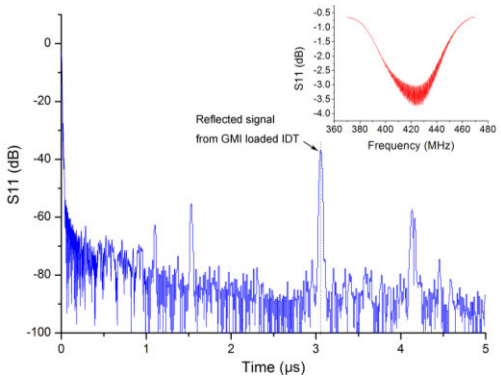

Figure 3: Time domain response of the S11 parameter. Inset: S11 frequency response.

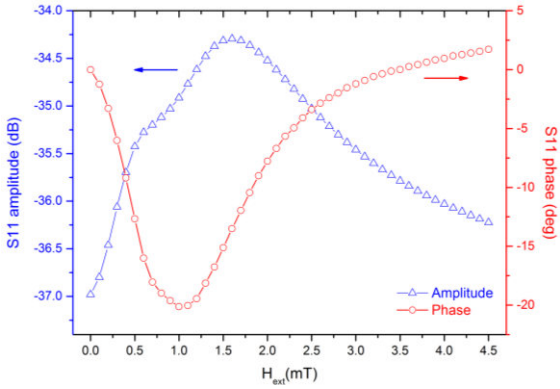

Figure 4: Phase and amplitude of the reflected signal as functions of the magnetic field H_{ext}.

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REALIZATION OF UNBIASED FERRITE COBALT NANOCOMPOSITES FOR NON-RECIPROCAL MICROWAVE COMPONENTS

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INTRODUCTION

In telecommunication systems, heavy bulky magnets are used to establish the proper functioning of a circulator by ensuring the uniform orientation of the ferrite material's magnetic moment.

Thus to develop an unbiased coplanar microwave circulator, the approach based on "ferromagnetic nanowired composite substrates" was promising. The idea was to do a magnetophoretic deposition of nanocoloidal cobalt ferrite nanoparticles into porous alumina membranes and permanently orient them uniformly. Therefore, in order to check the orientation possibility of the nanoparticle, samples of magnetic thin films on glass substrates were synthetized from $CoFe_2O_4$ nanoparticles dispersed in a silica sol-gel matrix using the dip-coating technique with and without a uniformly applied magnetic field. To investigate the magnetic behavior of the prepared samples, the Faraday rotation as a function of the applied magnetic field was measured using a spectral polarimeter. The unambiguous qualitative difference between the Faraday rotation hysteresis loops shows a large variation of coercitivity ($\mu_0 H_c$) and remanent field (—) values, thus proving the orientation of the nanoparticles.

Such nanocomposite is a promising candidate for future miniature microwave circulators fabrication.

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SIMULATION AND MEASUREMENT OF THE MAGNETIC FIELD RADIATION FOR A PLANAR INDUCTOR

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INTRODUCTION:

Reducing the size of electronic components (passive components in particular) has become a major goal since the electronic circuits are minimized. Among these components, we can mention an essential component in radiofrequency applications, high frequencies applications and power electronics: the planar inductor, a most disruptive component.

The aim of our work is the characterization of radiation and shielding. So in this paper we compare simulation results of magnetic radiation for a planar inductor with measurements results. For that, two structures have been fabricated: planar inductors with and without magnetic layer (Fig. 1). Measurements of the magnetic field radiation have been carried out. These two structures have been simulated and compared with measurement results. Results are illustrated in Fig. 2 and Fig. 3.

FIGURES:

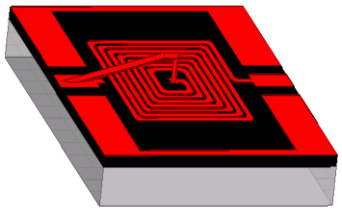

Fig. 1: Planar inductor with one magnetic layer.

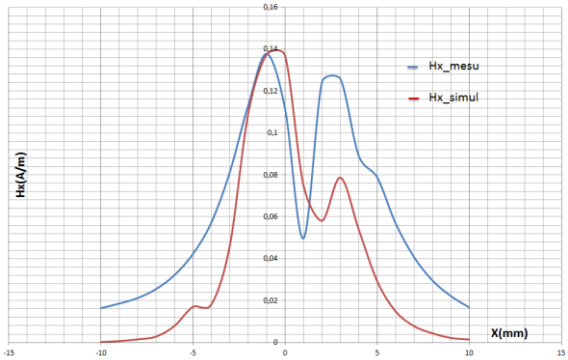

Fig. 2: Magnetic field Hx.

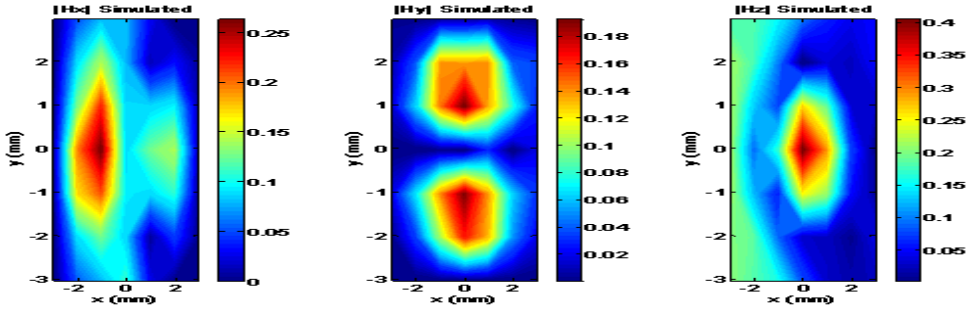

Fig. 3: Magnetic field.

MONDAY AFTERNOON

SYMPOSIUM 5.2

Novel Phenomena in High-Anisotropy Nanomagnets*

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Department of Physics and Astronomy
University of Nebraska

High-anisotropy nanomagnets are important in several areas of magnetic materials and applications [1]. Current topics of high interest are the search for new phases that are rare-earth free or rare-earth lean for permanent magnets [2], the nanostructuring of hard-soft composites to achieve effective exchange coupling [3,4], the fabrication of granular and/or patterned recording media with bit sizes below 10 nm [5,6], and perpendicular nanostructures with high polarization for spintronic applications [7]. In this talk we present selected recent results Mn- and Co-based compounds including high transport spin polarization in MnBi [8], spin correlations and Kondo phenomena in MnBi:X alloys (X = Pt, Au, Fe) [9], and magnetism of Mn_xGa alloys [10]. In addition, new results on Co-rich Co-Hf and Co-Zr nanoparticles and nanocomposites may be discussed.

*Research supported by NSF-MRSEC (DMR-082052), NSF (DMR-0960110), US DOE (DE-FG02-04ER46152), US DOE/BREM (DE-AC02-07CH1), US DOE (DE-AR 0000046), and NCMN.

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ELECTRICAL READ-OUT OF INDIVIDUAL NUCLEAR SPIN TRAJECTORIES

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ABSTRACT

Key problems in spin-based quantum electronic devices are the long-term information storage on single spins and the non-destructive retrieval of the latter. Moreover the ability to perform all operations electrically is advantageous to interconnect classical and quantum electronics. To overcome the problem of short spin lifetimes while using electron-spin based devices, the exploitation of nuclear spins was suggested. Its excellent intrinsic isolation leads to very long relaxation (T_1) and coherence times (T_2) but at the same time impedes high fidelity manipulation.
Here we present a complete electronic read-out of a single nuclear spin using a single-molecule magnet based device (Fig. 1). The quantum non-destructiveness of the measurements together with high read-out fidelities of 95% allowed for the recording of the nuclear spin-trajectory (Fig. 2). We deduced the individual relaxation times T_1 and compared them with quantum Monte Carlo simulations. Based on these results the dominant relaxation mechanism was revealed enabling the electrical tunability of T_1.

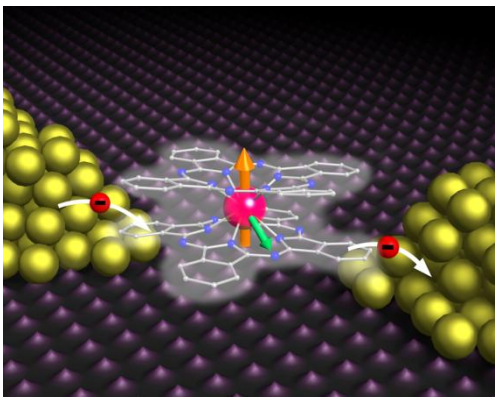

Figure 1 Molecular spin-transistor. A $TbPc_2$ molecular magnet is connected to source and drain gold electrodes and a back-gate underneath.

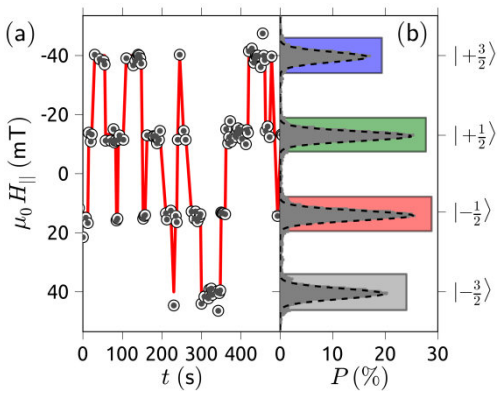

Figure 2 Nuclear spin trajectory. (a) Conductance jumps (grey dots) reveal the nuclear spin state. (b) Histogram of all detected jumps.

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EFFECTIVE SPIN MERON PAIRS IN FERROMAGNETIC MULTILAYERS

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We report on pairs of diverging/converging spin vortices in Co/Rh/$Ni_{81}Fe_{19}$ trilayer disks. The lateral magnetization distribution of these effective spin merons [1] is imaged directly by means of element-selective x-ray microscopy. By this method, both the divergence and circulation states of the individual layers are identified as antisymmetric [2] (cf. Figure 1). Reversal measurements on corresponding continuous films reveal that biquadratic interlayer exchange coupling is the origin for the formation of effective meron pairs. Furthermore, their three-dimensional magnetization structure is determined by micromagnetic simulations. Interestingly, the magnetic induction follows a kind of flux-closing torus. This toroidal topology enforces a symmetry break, which ties the core polarities to the divergence configuration.

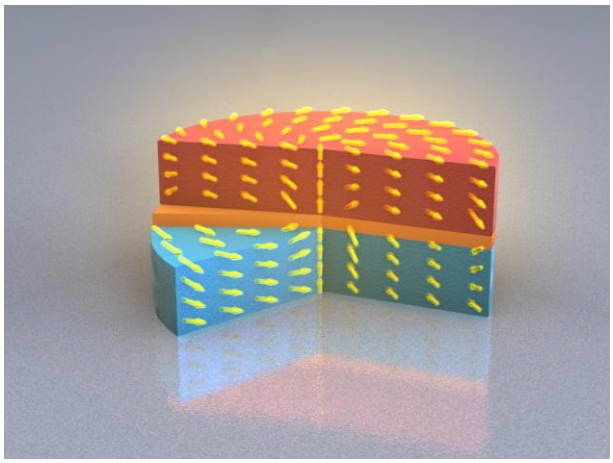

Figure 1: Effective spin meron pair (schematic).

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ELECTRON SPIN RESONANCE IN $LA_{0.25}CA_{0.75}MNO_3$ MANGANITE

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$La_xCa_{1-x}MnO_3$ electron doped manganites , among others, increased their interest due to the possibility to study the exchange bias effect in the nanometric format [1]. In this work, polycrystalline nanogranular powder of $La_{0.25}Ca_{0.75}MnO_3$, was prepared by sol-gel method as described in [1]. Magnetic characterization shows its Néel transition temperature. As well, hysteresis cycles measured at 5 K in 3 T FC and ZFC processes present exchange bias effect.

Electron spin resonance (ESR) was also measured in 1 T FC process, in the range of temperatures between 5 K and 250 K. Experimental results coincide with the theoretical expressions for ESR in spin-glass systems [2,3] and consequent fitting of the results has allowed us to obtain their uniaxial and unidirectional anisotropy constants, with the help of the hysteresis cycle measurements at those temperatures in 1 T FC process. With these measurements, calculation of the time attempt $\tau_0 \approx 2.9 \cdot 10^{-9}$ s and crystallographic structural distortion through g-factor were possible.

Moreover, the performed ESR measurements suggests an interface spin freezing at low temperatures.

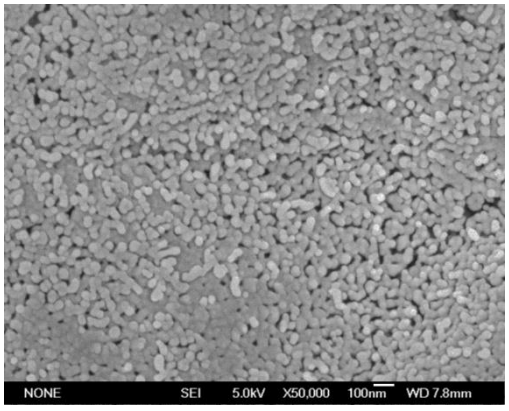

Fig 1**:** SEM picture of $La_{0.25}Ca_{0.75}MnO_3$ polycrystalline nanograins.

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SPIN-DEPENDENT SMOLUCHOWSKI EFFECT

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INTRODUCTION

The spill-out of electron charge density above atomically sharp surface corrugations has been described by Smoluchowski [1]. The Smoluchowski effect focuses on the total electron charge density and it neglects that electrons also carry a spin. In spin-polarized materials, it is a priori not clear how majority and minority states contribute to the spin-dependence of the Smoluchowski effect.

METHODS AND RESULTS

We perform spin-polarized scanning tunneling microscopy at the step edge of a bilayer high Co island on Cu(111) at 8 K [2]. We measure maps of the differential conductance (dI/dV) for states of parallel (P) and anti-parallel (AP) orientation between tip and sample magnetization. From these maps we extract the asymmetry A of the differential conductance A = (dI/dVAP − dI/dVP) / (dI/dVAP + dI/dVP). This quantity is proportional to the spin polarization of the sample. We reveal striking spatial variations of the spin-polarization at the transition between the Co step and the Cu substrate with sub-nm spatial resolution and investigate its energy dependence. We find a variation of the tunnel magneto resistance ratio of more than 20% on a length scale of few Angstroms. We discuss our results on the basis of ab-initio calculations, spin-dependent electron charge flow supports our findings [3].

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RESONANT SOFT X-RAY SCATTERING ON ARTIFICIAL SPIN ICE

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Artificial spin ice comprises coupled dipolar magnetic nanoislands placed at the sites of a square or kagome planar lattice [1,2]. These particular geometries prevent the dipolar interactions to be simultaneously satisfied at the vertices where the islands meet, making the system magnetically frustrated. Microscopy techniques (magnetic force microscopy [3], photoelectron microscopy [4], Lorentz microscopy [5]) are usually employed to investigate such systems and to directly resolve the magnetic configuration of the islands. In contrast, scattering is a complementary method which provides information on magnetic correlations over length and time scales not accessible with microscopy [6].

In the present work, we employ soft x-ray resonant magnetic scattering with circularly-polarized light to study the organization of the magnetic configurations in artificial square spin ice. The scattering patterns are recorded by a CCD camera, providing an extended picture of the reciprocal space in two dimensions. By varying the applied magnetic field, we track the variations of the Bragg peaks intensity using the dichroic contrast.

Pure magnetic Bragg peaks observed in as-grown samples indicate the presence of a long-range antiferromagnetic ordered phase [3], which is subsequently destroyed by orienting the magnetic moments with an applied field. Numerical simulations based on the kinematical approach can correctly reproduce the experimental scattering patterns, allowing us to estimate the number of reversed moments along the two directions of the square lattice.

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INELASTIC SPIN SCATTERING WITH INDIVIDUAL KONDO IMPURITIES INVESTIGATED BY STM SPECTROSCOPY

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The magnetism of atoms on metals is inherently connected with many-body interactions between the localized magnetic moment and the metal host. The most frequently found is the Kondo effect, by which the host electrons screen the impurity spin forming a spin-singlet. It is unclear whether the absence of time averaged total spin disables magnetic scattering at all with this sort of impurities [1]. The energy scale of a Kondo ground state (k_BT_K) depends strongly on the host local density of states at the Fermi level (LDOS). By means of atomic lateral manipulation with a scanning tunneling microscope (STM), we have constructed quantum resonators on the Ag(111) surface that allow us to fine tune the LDOS of adsorbed Co Kondo impurities. Subsequent STM spectroscopy reveals that a magnetic inelastic scattering channel of the impinging electrons against the Kondo state opens up for particular values of the LDOS and T_K, i.e., designated positions of the Co atom within the resonator. This result demonstrates that spin-scattering processes at magnetic atoms on metal surfaces can be exploited for spin-based devices on the atomic scale, even at temperatures well below T_K.

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SYMPOSIUM 1.2

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Experimental identification of extrinsic and intrinsic contributions in the AHE

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The anomalous Hall effect is one of the most prominent phenomena existing in magnetic materials. It has remained unsolved for more than a century because its rich phenomenology defies the standard classification methodology, prompting conflicting reports claiming the dominance of various processes. Working with epitaxial films of Fe, Ni, Co, Ni_xCu_{1-x}, we succeeded in independent controls of different scattering processes through temperature and layer thickness. The resulting data allows an unambiguous identification of the intrinsic mechanism as well as the extrinsic mechanisms of the anomalous Hall effect.

Related recent Publications:

1. J.L. Xu, Y.F. Li, D.Z. Hou, L. Ye, and X.F. Jin, Appl. Phys. Lett. 102 (2013) 162401
2. L. Wu, Y.F Li, J.L. Xu, D.Z. Hou, and X.F. Jin, Phys. Rev. B 87 (2013) 155307
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SINGLE ELECTRON SPINTRONICS STUDIED IN INDIVIDUAL NANOMETRE-SCALE MAGNETIC TUNNEL JUNCTIONS

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Single electron spintronics studied with magnetic nanoparticles, takes the idea of spintronics - looking at large ensembles of spins in a current - and brings it down to the level of the single spin. Restricting current flow through a nanoparticle linked by tunnel barriers to source and drain electrodes leads to single-electron Coulomb blockade effects; if the materials are magnetic, spin accumulation in the nanoisland can occur. We have pioneered a new technique for examining such tunnel junctions with a single 2-12nm diameter particle inside. Crystalline bcc CoFe nanoparticles are grown by gas aggregation technique onto a sputtered MgO barrier CoFeB stack, they are then characterised both topographically and electronically with STM at 25 K. The data obtained is modelled with existing theory [1] and it is found to accord well with the Coulomb steps modified by spin accumulation (Figure 1). Using these fits we find spin relaxation time on the CoFe nanoparticle is enhanced by more than a million times the bulk CoFe value.

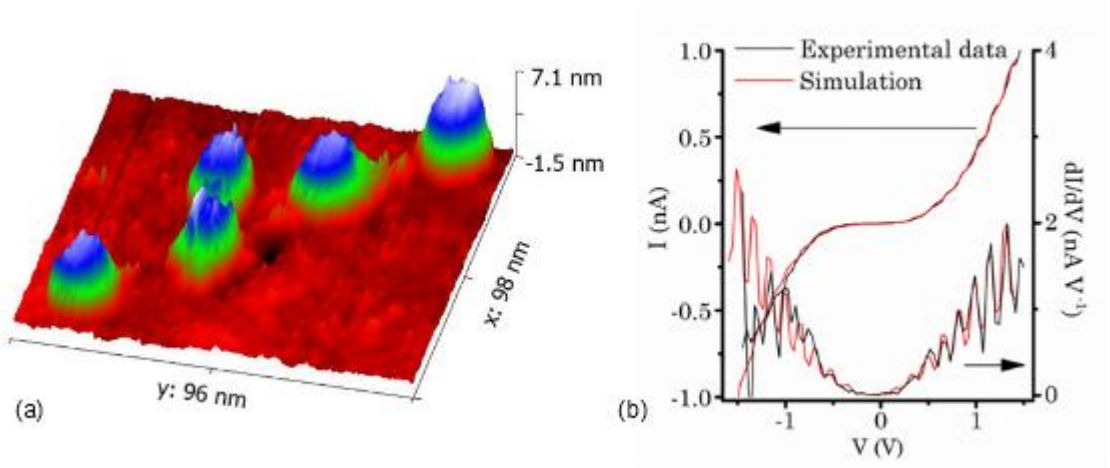

Figure 1 (a) STM topographical characterisation of nanoparticles, (b) I-V data from an MTJ with a single 11 nm nanoparticle taken using STM at 25K. The red lines show fits to existing theory which imply a spin relaxation time more than 10^6 greater than bulk.

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ELECTRIC-FIELD CONTROL OF DOMAIN WALL NUCLEATION AND PINNING IN A METALLIC FERROMAGNET

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The electric (E) field control of magnetic properties, recently demonstrated in metallic magnetic systems [1], opens the prospects of an alternative to magnetic field or electric current activation to control magnetization. Multilayers with perpendicular magnetic anisotropy have proven to be particularly sensitive to the influence of an E-field due to the interfacial origin of their anisotropy. In these systems, E-field effects have been recently applied to assist magnetization switching [2] and control domain wall (DW) velocity [3]. We will report on two new applications of the E-field in a similar material : controlling DW nucleation and stopping DW propagation at the edge of the electrode [4].

We have studied Pt/Co/AlOx sample where the surface anisotropy could be varied in two ways : charging the metal/dielectric interface and modifying its oxidation. We demonstrate that charging and oxidizing the interface affect the magnetic properties in some equivalent manner in this system. The E-field effect is characterized by monitoring the magnetization reversal for different anisotropy values using magneto-optical Kerr microscopy. For weak anisotropy, we observed a nucleation-dominated reversal and we demonstrate that the thermally activated DW nucleation can be electrically controlled via the modulation of the involved energy barrier. In addition to this E-field control of nucleation, we will present in the high anisotropy region of the sample the reversible pinning of a DW at the edge of the electrode. Such E-control over magnetic domains both in the propagation and nucleation regimes is of major interest for applications in magnetic storage and logic.

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THEORY OF FERROMAGNETISM DRIVEN BY SUPEREXCHANGE IN DILUTE MAGNETIC SEMICONDUCTORS

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Dilute magnetic insulators, is an emerging class of magnetic semiconductors [1] where ferromagnetic superexchange [2] accounts for spin-spin coupling. Because of its compatibility with III-nitrides, particularly attractive is $Ga_{1-x}Mn_xN$. After a decade of contradicting reports, recent progress in epitaxy and extensive characterization [1,3,4] allowed to prepare $Ga_{1-x}Mn_xN$ with randomly distributed Mn^{3+} up to x = 10% showing Curie temperatures T_C up to ≈13K [4].

Our extensive tight binding and Monte Carlo studies of ferromagnetism in $Ga_{1-x}Mn_xN$ led to theoretical T_C values (Figure, circles) in quantitative agreement with available experimental data [3-5]. This agreement substantiates the conclusion about the origin of ferromagnetism in this system.

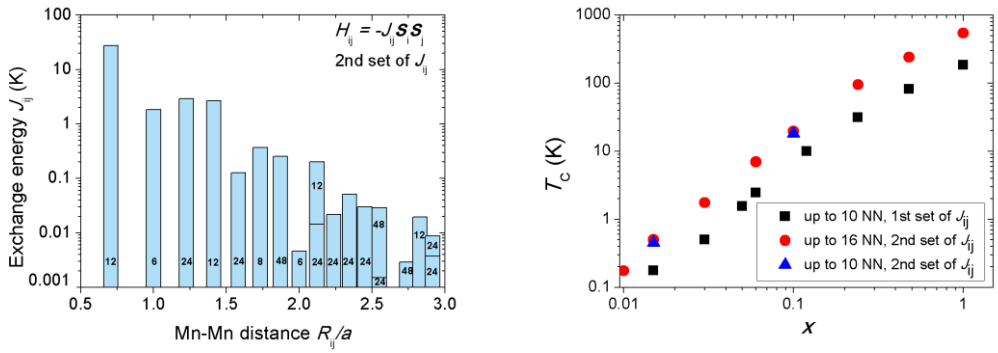

Figure. (a) Tight binding J_{ij} for zincblende GaN vs. Mn-Mn distances R_{ij} per lattice parameter a, and relevant cation sites numbers. (b) Circles (triangles) represent $T_C(x)$ by Monte Carlo simulations for J_{ij} of (a) taking into account 16 (10) nearest neighbors [NN]; squares represent 10NN and another set of J_{ij} [3].

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DIFFUSIVE RASHBA SPIN TORQUE IN FERROMAGNETIC HETEROSTRUCTURES

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Spin-orbit torques in ultrathin ferromagnetic layers are of great interest to manipulate the orientation of nanomagnets without the need of non-collinear magnetic layers or external magnetic fields [1]. As a model system, we consider a ferromagnetic 2-dimensional electron gas possessing both Rashba SOC and ferromagnetic exchange. In such a heterostructure, the interplay between a Rashba spin-orbit coupling and an exchange field gives rise to a current-driven spin orbit spin torque. Using Keldysh technique, we derive a spin diffusion equation that provides a coherent description to the diffusive spin dynamics in a realistic device element [2]. The obtain diffusion equation unveils the rich physics underlying the Rashba torque involving spin Hall effect, spin precession, dephasing and anisotropic relaxation.

First, we show that the relative magnitude of the two components of the Rashba torque depends non-linearly on the relative strengths between Rashba spin-orbit coupling and the ferromagnetic exchange. It is found that the optimal magnitude of the in-plane torque is achieved when the exchange energy is about of the same order of magnitude of the Rashba splitting. Second, we uncover a significant spatial distribution of the torque in the sample, as well as a complex angular dependence with respect to magnetization direction. We demonstrate that a non-vanishing spin torque exists at the edges of the device even when the magnetization and effective Rashba field are aligned. Furthermore, in agreement with recent experiments [3], anisotropic spin relaxation rates driven by the Rashba spin-orbit coupling assign the spin torque a more complex expression than the usual in-plane and out-of-plane components given in previous works [4]. These results open new avenues for the development of device based on Rashba spin-orbit coupling by enabling a flexible design of the system.

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QUANTUM INTERFERENCE EFFECTS IN $[Co/Bi]_n$ THIN FILMS

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Magneto-transport measurements in polycrystalline $[Co/Bi]_n$ films, grown by magnetron sputtering, revealed [1] that the Hall coefficient R_H exhibits a critical scaling close to a percolation threshold p_c=0.3 of Co concentration. To understand this effect, we analyze here magnetoconductance measurements, $\Delta\sigma(B)=\sigma(B)-\sigma(0)$, using a two-band model to account for bulk-like Bi-layer contributions [2] and a weak-anti-localization (WAL) formula [3] for the surface states of Bi lying in the direct energy gap at the L-point (electron pocket) of the Brillouin zone. Fig.1 shows $\Delta\sigma(B)$ loops, with the field perpendicular to film plane, in a 15 nm thick Bi film and one trilayer of Bi(10nm)/Co(1nm)/Bi(10nm). The WAL contribution (between $\pm$0.4T), is enhanced in the trilayer, indicating an electron transfer from Co interface layer to surface states of Bi. The WAL formula cannot be replaced with an anisotropic magnetoresistance model to fit the data. These results indicate that there is no need of a Dirac-point from surface states of a topological insulator [3] (as a starting point) in order to succeed a controllable modification (with doping) of surface states in Bi.

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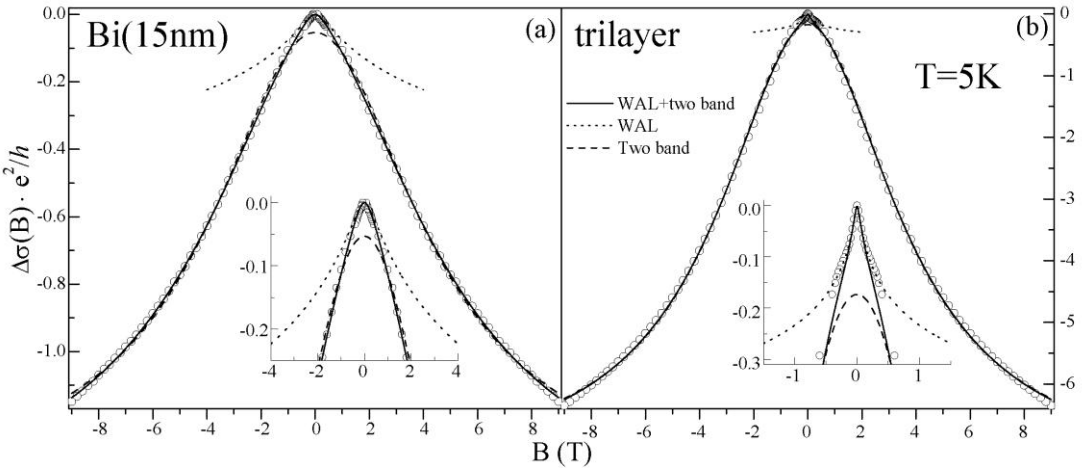

Fig.1 $\Delta\sigma(B)$ loops. Note the different scales in two films

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PIEZOELECTRIC-STRAIN CONTROL OF PERPENDICULAR MAGNETIC ANISOTROPY IN Pt/Co/Pt FILMS

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Materials with perpendicular magnetic anisotropy (PMA) have potential for use in spintronic devices due to properties derived from their high anisotropy, such as stability against thermally activated magnetization switching and narrow domain walls [1][2]. Here we investigate piezoelectric-strain as a method of controlling PMA.

Thin films composed of Ta[4.5nm]\Pt[2.5nm]\Co[t]\Pt[1.5nm] (t=0.9,0.95,1.0nm) were sputtered onto 150μm thick glass substrates and patterned into 50μm wide Hall bars by optical lithography. The substrates were bonded to piezoelectric stressors with epoxy resin. Applying a voltage to the stressors causes an in-plane uniaxial strain in the thin films of up to ~10^{-3}. The anisotropy field of the films was found from extraordinary Hall effect measurements.

We find that uniaxial strain modifies the strength of the PMA and also induces an in-plane magnetic anisotropy. The anisotropy changes are larger in films with thicker Co, with the largest changes of 12kJm^{-3} out-of-plane (Figure 1b) and 18kJm^{-3} in-plane (Figure 1a) for Pt/Co[1nm]/Pt.

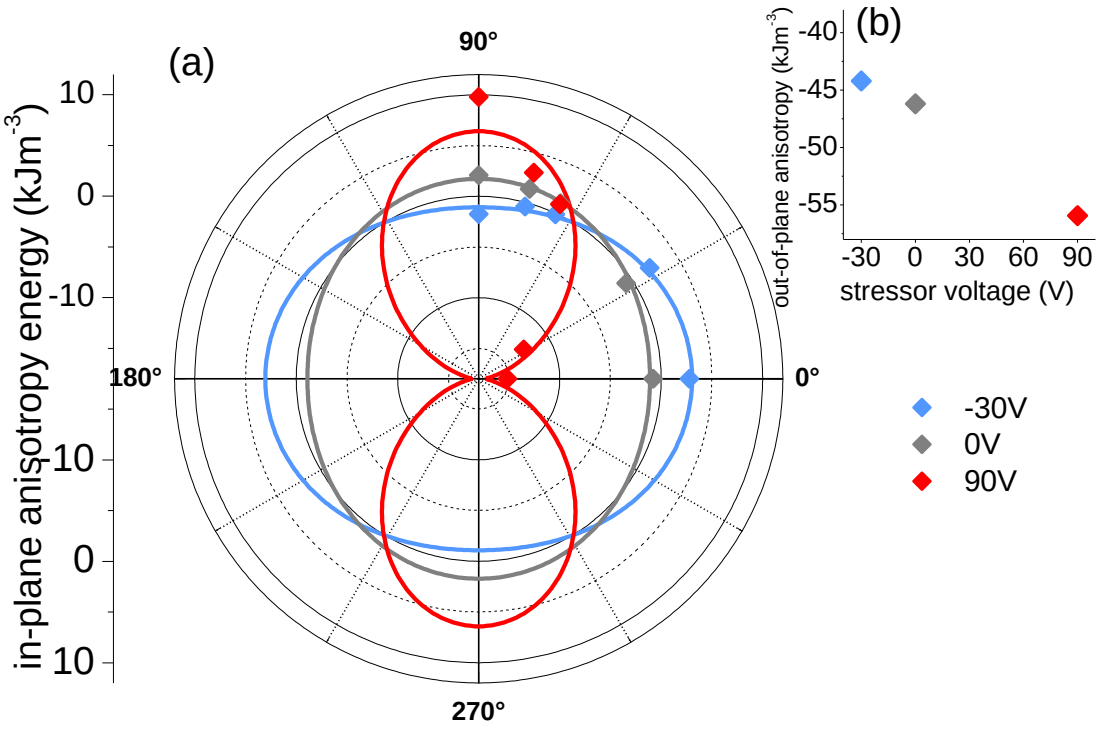

Figure 1 – Changes to (a) in-plane and (b) out-of-plane anisotropy energy of Pt/Co[1nm]/Pt under voltage-induced piezo-strain. The lines show in-plane anisotropy energy calculated from anisotropy constants extracted from the data.

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SYMPOSIUM 4.2

Model Abstract

GAINING INFORMATION OF PHASE TRANSITIONS AND CRITICAL PHENOMENA VIA MAGNETOCALORIC STUDIES

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The increasing concern of modern societies about energy efficiency, together with the fact that temperature control accounts for a large portion of the energy consumption at homes and commercial buildings, has fostered research on the applicability of magnetocaloric materials for magnetic refrigeration [1]. But in addition to the studies on magnetocaloric materials for the optimization of their properties for room temperature magnetic refrigeration, in this talk we will show that MCE can be used for characterizing magnetic phase transitions, showing examples of how critical exponents can be determined, evidencing that the magnetocaloric response can be used to determine the order of a phase transition or to infer the presence of impurity phases in the samples. We will also show how tailoring the microstructure of a material at the nanoscale can lead to magnetocaloric responses which are qualitatively different from the bulk. This deeper understanding of the phase transitions giving rise to MCE should create paths along which new applications of these materials should be found.

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GENERALIZED MAGNETOCALORIC PROPERTIES OF NI-MN-IN AND NI-MN-IN-CO SYSTEMS

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INTRODUCTION

The benchmark material of the magnetocaloric community, Gadolinium, warms up when magnetized due to a pure magnetic transition. Larger magnetocaloric effects are observed when the character of the magnetic state change is accompanied by a structural conversion which is referred as magnetostructural transition. In the Heusler-typed Ni-Mn-In and Ni-Mn-In-Co system the low temperature antiferromagnetic martensite phase transforms endothermically into the high temperature ferromagnetic austenite phase. An external magnetic field shifts the martensitic transition to lower temperatures. This field dependence of the transition temperature is of great importance, acting as the driving force of the magnetocaloric effect[1]. We found that this physical quantity is well determined, which leads to a new description of the entropy change ΔS. Comparison with direct measurements of the adiabatic temperature change ΔT_{ad} reveals that the consideration of ΔS alone leads to a misjudgment of the suitability for magnetic refrigeration. We conclude that the determination of both, the adiabatic temperature change ΔT_{ad} AND the entropy change ΔS, related to the maximum available magnetic field, is necessary for a comprehensive study of the magnetocaloric properties and the potential cooling power of the material[2].

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COMPARATIVE ANALYSIS OF MAGNETIC AND CALORIC DETERMINATIONS OF THE MAGNETOCALORIC EFFECT IN $Mn_{0.99}Co_{0.01}As$

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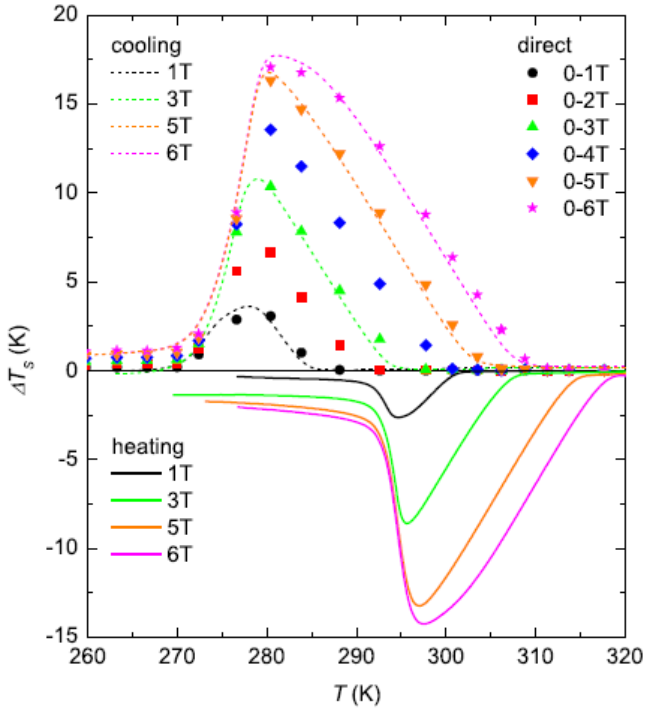
Intermetallic compounds $Mn_{1-x}M_xAs$ with M=Cr,Fe,Co,Cu have been reported to show huge magnetocaloric properties derived from magnetization measurements [1]. For low x concentrations, they have a first-order magnetostructural transition around room temperature between a hexagonal ferromagnetic phase and an orthorhombic paramagnetic phase. We made an experimental study of the magnetocaloric parameters of $Mn_{0.99}Co_{0.01}As$ with magnetic and calorimetric measurements.

Magnetization data up to 9 T show metamagnetic transitions with intermediate plateaus in a narrow temperature range. A blind application of the Maxwell relation gives a "colossal" maximum isothermal entropy change $-\Delta S_T$=138 J/kg·K for a field increase to 6 T.

Heat capacities up to 6 T have been measured on heating and cooling, giving sharp transitions for every field. The transition temperature at zero field, T_t=294.7 K, has a large thermal hysteresis, 17.1 K, and a field dependence dT_t^h/dB=3.7 K/T on heating and dT_t^c/dB=4.7 K/T on cooling. From the derived heating and cooling entropy curves, maximum values of $-\Delta S_T$=26.9 J/kg·K and 32.1 J/kg·K, respectively, have been obtained for a field change of 6 T.

Direct measurements of $-\Delta S_T$ reproduce the results obtained from the entropy curves. The adiabatic temperature change, ΔT_S, has also been measured, giving a perfect match with the values derived from the entropy curves and having a maximum of 17.7 K for 6 T.

The different results have been analyzed discussing the origin of the spurious huge results from isothermal magnetization [2]. The smaller differences between the heating and cooling entropy results have been deduced as coming from the irreversible entropy contributions in the first-order transitions.



Adiabatic temperature change. Symbols: Direct measurements. Dotted and solid lines: From cooling and heating entropies, respectively.

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MAGNETISM AND MAGNETOCALORIC EFFECT IN MULTICOMPONENT LAVES PHASE COMPOUNDS

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The magnetocaloric effect (MCE) manifests as the change in temperature of a material in response to magnetic field. This effect is particularly pronounced at temperatures and fields corresponding to magnetic phase transitions.

In this work we present a comparison of the Gd influence on some physical properties of $(R_{0.9}R`_{0.1})_{1-x}Gd_xCo_2$ multicomponents, where R = Dy, Ho and R` = Er, Ho and x varies from 0.05 to 0.15. Powder X-ray diffraction analysis revealed that all measured samples solidify with the formation of a Laves-phase structure. Magnetic experiments were performed using SQUID and VSM magnetometer in an applied field of up to 14 T. The specific heat was measured using a Quantum Design PPMS. The magnetization behaviour and the magnetic transition are analyzed in terms of Landau theory.

The magnetic and heat capacity studies revealed that a relatively small Gd addition significantly increases T_C of measured samples. The magnetocaloric effect has been estimated both in terms of isothermal magnetic entropy change and adiabatic temperature change. The highest adiabatic temperature change (ΔT_{ad} = 3.1 K) was observed for $(Ho_{0.9}Er_{0.1})_{0.95}Gd_{0.05}Co_2$ at 89 K. The relative cooling power and the effect of increasing Gd content on their magnetic and magnetocaloric properties for all solid solutions will be presented.

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ON THE BAROCALORIC EFFECT IN RARE EARTH BASED COMPOUNDS

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INTRODUCTION

The magnetic barocaloric effect, which is characterized by the isothermal entropy change (ΔS_{iso}^{bar}) and adiabatic temperature (ΔT_{ad}^{bar}) change upon pressure variation can be a very useful to improve the performance of magnetic refrigerator. In this work, we discuss the magnetic barocaloric effect in rare earth based compounds whose magnetism comes from localized electrons. To this end we use a model of interacting localized magnetic moments[1].

RESULTS AND DISCUSSION

In the first part of the work we make a systematic analysis in terms of the model parameters. For this purpose, we consider the simplest case whose angular momentum is 1/2. Our calculations show that the behavior of the barocaloric quantity ΔS_{iso}^{bar} can be normal (negative values) inverse (positive values) or anomalous (a change of sign).

In the second part of the work, we apply the model to describe the barocaloric effect in the compounds RCo_2, $Gd_5Si_2Ge_2$ and $Tb_5Si_2Ge_2$. Our theoretically calculated quantity ΔS_{iso}^{bar} [2] for $Gd_5Si_2Ge_2$ is in a reasonable agreement with the available experimental data [3]. Our calculations for the other compounds, need experimental data to be confirmed.

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MAGNETIC PROPERTIES AND MAGNETOCALORIC EFFECT IN LAYERED $NdMn_{1.9}V_{0.1}Si_2$

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INTRODUCTION

Magnetocaloric effect (MCE) around T_C ~ 22.5 K is found in layered $NdMn_{1.9}V_{0.1}Si_2$ associated with first order magnetic transition from antiferromagnetic to ferromagnetic. The magnetic entropy change $-\Delta S_M$= 21.5 Jkg/K and adiabatic temperature change ΔT_{ad} = 7.2 K have been determined using magnetization and specific heat measurement under 0-8 T field applied.

The study of MCE has become an interesting area of research in the field of magnetic materials as magnetic refrigerant especially in first order transition material [1]. However first order transition behaviour normally accompany with thermal and magnetic hysteresis issue [2]. This compound belongs with the small thermal ~ 0.8 K and magnetic ~ 0.6 T hysteresis characteristic providing potential material for magnetic refrigerator in low temperature region.

FIGURE

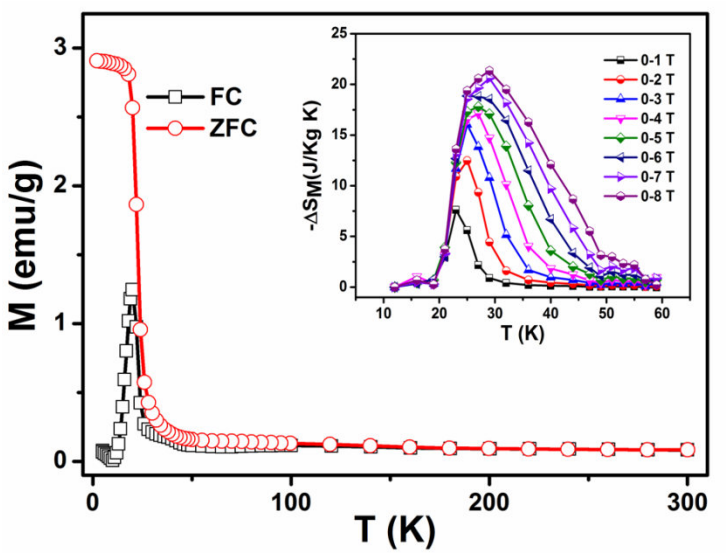

Figure 1. Temperature dependence of magnetization of $NdMn_{1.9}V_{0.1}Si_2$ compound as measured in a field of 0.01 T and (inset) The isothermal magnetic entropy change, $-\Delta S_M$, for $NdMn_{1.9}V_{0.1}Si_2$ as determined from the magnetization isotherms for ΔB = 0-1 till 8 T.

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MICROSCOPIC THEORY OF MAGNETISM IN MAGNETOCALORIC MATERIAL $FE_2P_{1-X}T_X$ (T=B AND SI)

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INTRODUCTION

Di-iron phosphide (Fe_2P) is a prototype compound for a family of promising magnetocaloric materials [1-4] obtained by partial substitution of Fe and P. Fe_2P shows a sharp first-order type transition from a paramagnetic (PM) to a ferromagnetic (FM) state around 215 K [5]. The first order nature of the magnetic phase transition is attributed to a metamagnetic behavior of the one of the two iron sublattices [6]. Landau phenomenological theory in combination with first-principles calculations was used to reveal the origin of the metamagnetic nature and the unusually strong dependence of the ordering temperature with doping of the Fe_2P compound. We show that the magnetism of the two sublattices occupied by Fe atoms has an entwined codependency, which is strongly influenced by alloying. We furthermore demonstrate that a constrained disordered local moment approach combined with Monte Carlo simulations can reproduce the experimental ordering temperatures in these technologically important prototype alloys for magnetocaloric refrigeration.

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SYMPOSIUM 3.1

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MAGNETIC DEFLAGRATION: MATERIALS AND RELATED PHENOMENA.

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Magnetic relaxation is a process that can develop instabilities and leads to a *magnetic deflagration*. Unlike many other systems (e.g., chemical or biological reactions), magnetic deflagration is controllable, reversible, non-destructive, and its energy and time scales are easily controlled in a lab. In my talk I will review the main results on magnetic deflagration –from its pioneering discovery in 2005 [1,2] to the most recent results [3]. I will overview the process of magnetic deflagration in different magnetic materials and focus on associated phenomena: i) quantum detonation of the magnetization in molecular magnets [4] ii) colossal variation of mgnetoresistance in manganites [5] iii) structural crystalographic and speed anisotropic changes in intermetallic compounds [6]. Magnetic deflagration processes might be present in many more magnetic systems during magnetic relaxation and its study might bring new insights to the understanding of spin dynamics.

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LOCAL ORBITALS APPROACH TO THE ANOMALOUS HALL AND NERNST EFFECTS IN ITINERANT FERROMAGNETS

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INTRODUCTION

Quantum transport theories are traditionally formulated to give expressions containing velocity matrix elements only to allow standard analysis of the scattering events. In the case of ferromagnetic systems except of such term, so called Fermi surface term, there appears the additional contribution, Fermi see term [1]. To include the effect of scattering into this term by a consistent way is not easy task. For this reason an alternative compact form of the Hall conductivity formula has been used [2].

LOCAL ORBITALS APPROCH

The tight-binding model of the energy bands representing ferromagnetic systems has been used. Hopping between the nearest neighbor atomic sites has only been considered which excludes the effect of the skew scattering. Two bands representing states having opposite spins and local orbital momenta has been considered. In the limit of the perfect crystal the resulting expression for the Hall conductivity coincides with the standard formula given by the Berry phase curvatures. Crystal disorder has been introduced by assuming fluctuation of the local-orbital energies.

RESULTS

Resulting scaling of the Hall conductivity with the longitudinal conductivity coincides with the observed scaling covering the scattering-independent and a bad-metal regimes. It has been predicted that the low-temperature transverse Peltier coefficient scales with the longitudinal conductivity by the same way.

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BENEFIT OF (CU/PT) INTERMIXING DUAL BARRIER FOR THE BLOCKING TEMPERATURE DISTRIBUTION OF CO/(CU/PT)/IRMN

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INTRODUCTION

Exchange bias based devices involve ferromagnetic/antiferromagnetic interfaces and concomitant layers intermixing [1]. Consequently, interfacial spin-glass-like phases with reduced properties and increased dispersions form [2] and lower devices performances. It is therefore necessary to limit intermixing by introduction of diffusion barriers [3]. One of the major difficulties is that the barrier must be inert [4].

METHODS

Cu and Pt based barriers were inserted at Co/IrMn interfaces. The interfacial quality and exchange bias potential improvements were recorded via measurements of the low-temperature contributions to the blocking-temperature distributions [2].

RESULTS AND DISCUSSION

The use of (Cu/Pt) dual barriers led to blocking-temperature distributions reductions. All at once, (Cu/Pt) limited Co-Mn, Co-Pt and Cu-Mn mixing, which took place when using either no or single Pt and Cu barriers. Although inserting (Cu/Pt) was beneficial for the distributions, it weakened the loop shift amplitude by taking the ferromagnet away from the antiferromagnet. However, some encouraging data suggested that the benefits of intermixing limitations can overcome the disadvantages of spacing augment.

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Reversibility in the magnetocaloric effect at the antiferromagnetic-ferromagnetic spin-flop transition in Mn_3GaC

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INTRODUCTION

In Mn_3GaC, a first order antiferromagnetic-ferromagnetic transition is accompanied by a volume-change and a 5 K thermal-hysteresis. We study the reversibility of the magnetocaloric effect in the transition region by direct adiabatic temperature-change measurements. We find that the system exhibits a temperature-change of 3.1 K in the virgin state, and all subsequent cycling leads to a 2.8 K warming and cooling when the field is decreased and increased, respectively [1]. Neutron diffraction studies of the magnetic-field-evolution of the transition show that ferromagnetism is stabilized at the expense of antiferromagnetism as a progressive spin-flop process rather than a continuous process of the antiferromagnetic alignment into a ferromagnetic one [2].

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ANGULAR DEPENDENCE OF THE XMLD IN REFLECTION AT THE 3P EDGES OF THE 3D FERROMAGNETS – THEORY AND EXPERIMENT

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The full angular dependence of the x-ray magnetic linear dichroism (XMLD) in reflection spectra on the orientation of the magnetization in the crystal was investigated for ferromagnetic bcc Fe, fcc Ni and fcc Co by means of the single electron picture within the framework of the DFT. The excitation stemming from semicore 3p levels were considered. The calculated results show similarities as well as differences between $L_{2,3}$ and $M_{2,3}$ edges, where at the latter spin-orbit interaction is of the same order as the exchange interaction [1]. The XMLD signal is strongly dependent on the magnetization direction with respect to the crystal axes. The effect of the substrate, capping layer, layer thickness on reflection coefficients as well as different models of the surface and interlayer roughness were considered. The calculated data show very good agreement with recently recorded spectra of bcc Fe, fcc Ni and fcc Co. The influence of the spin-orbit coupling and exchange interaction at the 3p states is emphasized.

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EXPLORATION OF THERMALLY ACTIVATED FLUX FLOW IN THE $Y_3BA_5CU_8O_{18}$ AND $Y_3BA_5CA_2CU_8O_{18}$ SUPERCONDUCTORS

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Abstract

This work is related to the influence of adding Ca atoms into the $Y_3Ba_5Cu_8O_{18}$ superconductor explored by employing the electrical resistivity measurements done under various magnetic fields. $Y_3Ba_5Cu_8O_{18}$ (Y-358) and $Y_3Ba_5Ca_2Cu_8O_{18}$ (YCa-358) compounds were prepared by the so called sol-gel method. The thermally activated flux flow (TAFF) model has been used to do a systematic analysis of the magnetoresistances of the Y-358 and the YCa-358 compounds. The TAFF activation energy, U_0, is field dependent and obeys a power law, $U_0=cH^{-\alpha}$, where α increases whereas c decreases with the addition of Ca. Furthermore, U_0, and the calculated upper critical field, H_{c2}, decrease with the addition of Ca.

Keywords: YBCO, magnetoresistance, thermally activated flux flow, activation energy, upper critical field.

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Structural and Magnetic Properties of Fe Doped Mn-Ga Ribbons

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Heusler compounds is a large family of materials containing more than 1500 members. Most of them are ternary materials with XYZ (Half-Heusler) or X_2YZ stoichiometry (Full-Heusler) where X,Y are transition metal elements and Z main group element. These compounds have a broad potential for applications due to the extended range of electric and magnetic properties they exhibit [1]. Among them the Fe-Mn-Ga system has recently attracted attention for being a candidate for future functional magnetic materials due to the tunability of its interesting magnetic properties[2].

In the present work we study the effect on structural and magnetic properties due to the introduction of Fe in Mn_2Ga system. $Mn_{0.7-x}Fe_xGa_{0.3}$ (x = 0.1 to 0.3) alloys are prepared with Ar arc-melting as base materials which were subsequently converted to ribbons using melt-spinning technique with velocity ranged from 20-35 m/s. Some of the materials were heat treated in a temperature range from 550 to 850 °C and for different time span, from 10 minutes to 1 hour. Alloys were studied by various characterization techniques (EDX, X-ray diffraction, magnetization versus temperature and field). The magnetic properties are improved with the increase of Fe content, Ms rises almost an order of magnitude from 0.05 μ_β per formula unit to 0.5 while low temperature coercivity reached 3.5 kOe. The temperature and time of the thermal processing also plays a significant role in the alloys and two phases were detected, the one being stable above 700 °C. The materials present two main Curie temperatures, one above 500 K and one transition below room temperature.

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TUESDAY MORNING

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ARTIFICIAL SPIN ICE: FRUSTRATION, EMERGENT MAGNETIC MONOPOLES AND THERMAL BEHAVIOUR

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Artificial spin ice, consisting of 2D arrays of dipolar coupled nanomagnets with specific arrangements, allows the study of frustration by tailoring the array geometry and observation of the magnetic configurations with various microscopy techniques.

We focus on artificial kagome spin ice with elongated monodomain nanomagnets forming an array of hexagonal rings and employ synchrotron x-ray photoemission electron microscopy (PEEM) to characterize the magnetic states. Starting with the basic structures with one, two and three hexagonal rings [1, 2], we found that demagnetization did not lead to the ground state for larger structures [1]. Observation of magnetization reversal in infinite artificial kagome spin ice has allowed real space observations of emergent magnetic monopoles with their associated Dirac strings [3].

Recently we have realized a method to create artificial spin ice with fluctuating moments and observed the evolving magnetic configurations with PEEM [4], which can be understood by considering the dipolar energy landscape. These thermally active systems open the door to microscopic studies of relaxation processes and provide a controlled route to the lowest-energy state.

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Heat Assisted Magnetic Recording: Progress and Challenges

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The recent 1.0Tbit/in^2 technology demonstration [1] with heat assisted magnetic recording (HAMR) has shown this technology to be viable and promising for further capacity growth of future magnetic data storage products. In this presentation, we will examine HAMR technology progress and challenges.

The coercivity of the recording media must be increased to maintain thermal stability as the magnetic recording bit volume decreases for increased storage density. As coercivity increases it becomes impossible to write data to the media using a standard magnetic recording head. HAMR technology elevates the media temperature during the recording process to reduce the coercivity, which provides a solution to the fundamental constraint of "writability versus thermal-stability" [2].Once the "writability versus thermal stability" constraint is broken, magnetic recording density is expected to grow as grain size scales down. The magnetic recording media must provide an anisotropy strong enough for stable storage at room temperature. At the same time, the HAMR head must provide an sufficiently small thermal spot size and an efficient heating mechanism to be a viable candidate to extend hard disk drive performance. Near-field plasmonics technology provides a viable solution for HAMR head design and energy transfer. Near field transducer (NFT) based recording achieves writing resolution far below the diffraction limit and efficiently elevates the media temperature.

In order to apply HAMR principles to storage products many practical technology challenges will need to be overcome. To further increase recording bit densities, the media grain size, the storage layer's magnetic anisotropy distribution, the head-to-disk spacing, and the thermal spot size in the media must be reduced. For a successful product, the largest challenge is the lifetime of the recording subsystem (HAMR writer, head–disc interface (HDI), and media). With peak media temperatures exceeding the recording layer Curie temperature (600 to 750 K) and the optical losses heating the head and HDI, the recording subsystem degrades due to thermal stress. Solutions include improved optical efficiency through new designs, more robust NFT materials, better management of the thermal energy in the head, more robust HDI materials, and novel recording schemes such as pulsed recording[3]. With these challenges addressed, HAMR provides the capability to continue areal density growth.

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MAGNETORESISTIVE SENSORS AND MAGNETIC NANOPARTICLES APPLIED TO BIOMEDICAL DIAGNOSTICS

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Recent progress in fabrication and characterization of magnetic nano-objects like rods and beads has triggered possible applications in biomedical diagnostics. Magnetic nano-objects provide the unique possibility to actively manipulate biomolecules in solution and on-chip fluidic channels which paves the way to an integrated magnetic Lab-on-a-Chip combining detection and manipulation. Advancing this idea, a unique magnetic Lab-on-a-Bead is presented which is based on highly sensitive plasmon-optical detection of the rotational dynamics of anisotropic magnetic nanoparticles immersed in the sample solution. On the specific binding of analyte molecules to the antibody functionalized nanoparticle surfaces, their hydrodynamic volumes increase, which translates into a change in their rotational dynamics. A suitable nanoparticle type consists of an elongated core-shell structure with magnetic core and noble metal shell. Compared to existing nanoparticle-based homogeneous immunodiagnostic methods, this approach promises to combine ease of use, minimum sample preparation and a simple setup with femtomolar analyte sensitivity.

Additionally to the diagnostics, such magnetic Lab-on-a-Chip platforms are capable for on-chip cell analysis. Phagocytosis of human fibroblast (NHDF) and human prostate cancer (DU145) cells are studied in-vitro by magnetic beads. By varying bead size and surface modification as well as cell physiology (i.e. drug or metabolic inhibition), we mimic cellular responses to changes in the environment. Compared to existing end-point detection methods, this chip-based approach allows real-time measurements of the kinetics of cellular uptake mechanisms.

SYMPOSIUM 5.3

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TOWARDS COMPUTATION WITH SINGLE SKYRMIONS AND SINGLE SPINS

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Based on the development of atomic-resolution spin-polarized scanning tunneling microscopy (SP-STM) [1], we have recently discovered nanoskyrmion lattices in single atomic layers of transition metals on particular substrates exhibiting a large spin-orbit coupling [2]. In this case, skyrmionic lattices can be stabilized by Dzyaloshinskii-Moriya interactions combined with the breaking of inversion symmetry at surfaces and interfaces. Following this approach, the direct observation and manipulation of individual skyrmions of ultimate small size has recently been demonstrated [3], offering great potential for future nanospintronic devices [4].

By using SP-STM with single-atom and single-spin sensitivity, we have established the novel method of single-atom magnetometry [5,6] which allows the measurement of magnetization curves and the determination of magnetic moments on an atom-by-atom basis. While the sensitivity level of single-atom magnetometry is below one Bohr magneton, it can easily be combined with the atomic-resolution imaging and manipulation capabilities of conventional STM, thereby offering a novel approach towards a rational material design based on the knowledge of the atomic-level properties and interactions within the solid state [7,8]. Moreover, an atom-by-atom fabrication and a successful operation of all-spin logic devices [9] have recently been demonstrated by our group based on the combined knowledge derived from surface physics, nanoscience, and magnetism.

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SEGREGATION PHENOMENA IN Fe-Nd-B NANOMAGNETS

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INTRODUCTION

$Nd_2Fe_{14}B$ is a comparably hard magnet as $L1_0$-ordered FePt, however, with a smaller Curie temperature [1]. $Nd_2Fe_{14}B$ nanomagnets are thus interesting for HAMR media. It was recently reported that such particles prepared by ball milling have smaller coercivities than bulk $Nd_2Fe_{14}B$ [2,3]. To investigate the origin of the reduced magnetic hardness and the phase stability of $Nd_2Fe_{14}B$ at small sizes, inert gas condensation was used to prepare Nd-Fe-B nanoparticles which could be rapidly annealed in-flight for thermal equilibration.

EXPERIMENTS AND RESULTS

HR-(S)TEM, EELS and VSM were used to determine the atomic structure, chemical composition and magnetic properties of the particles, respectively. All these properties are found to be different for the annealed as compared to the as-prepared Nd-Fe-B particles. Whereas the latter are largely amorphous, annealing leads to (partial) (re)crystallization. Due to a segregation of Nd towards the particle surface, the annealed particles exhibit core-shell structures, and no indications of the formation of the hard-magnetic $Nd_2Fe_{14}B$ phase were found. This segregation reduces both the coercivity and the saturation magnetization of the particles.

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$(SM,PR)_2(CO,FE)_{17}$ AND $ND_2FE_{14}B$ ANISOTROPIC PARTICLES BY MECHANOCHEMICAL SYNTHESIS

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Polydispersed single crystal particles of the $(Sm,Pr)_2(Co,Fe)_{17}$ compound in the range of 80-300 nm and $Nd_2Fe_{14}B$ compound with a short axis in the 60 - 140 nm range were prepared by high-energy ball milling and subsequent annealing of Co, rare-earth oxides, iron oxide and boron oxides in the presence of a calcium reducing agent and a calcium oxide dispersant. The particle size can be tuned by controlling the excess Ca metal and the annealing temperature. The Sm-Co particles showed coercivities up to 14 kOe which didn't change much after washing. The as-made Nd-Fe-B particles embedded in the CaO/Ca matrix exhibit coercivity in the range of 14.7-18.9 kOe. However, washing of the by-products resulted in a lower coercivity (1.4 kOe) because of interstitial modification of the 2:14:1 compounds with hydrogen. After desorption of the hydrogen through vacuum annealing, the H_c increases, but only to 4.6 kOe. This incomplete recovery of coercivity is attributed to local anisotropy defects caused by loss of the Nd atoms from the particle surfaces.
Work supported by DOE.

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LOW-TEMPERATURE THERMOMAGNETIC PROPERTIES OF THE BUTTERFLY $\{Fe_3LnO_2\}$ SINGLE-MOLECULE MAGNETS

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The intramolecular exchange interactions within the single-molecule magnet (SMM) "butterfly" molecule $[Fe_3Ln(\mu_3\text{-}O)_2(CCl_3COO)_8(H_2O)(THF)_3]$, where Ln(III) represents a lanthanide cation, are determined in a combined experimental [x-ray magnetic circular dichroism (XMCD) and vibrating sample magnetometer (VSM)] and theoretical work [1]. SMM behaviour has been observed by us in this kind of molecules [2]. Compounds with Ln = Gd and Dy, which represent extreme cases where the rare earth presents single-ion isotropic and uniaxial anisotropy respectively, on one hand, and with Ln = Lu and Y(III) as pseudolanthanide substitutions that supply a nonmagnetic Ln reference case, on the other hand, are studied. Low-temperature ($T \approx 2.5$ K) hard x-ray XMCD at the Ln $L_{2,3}$ edges and VSM measurements as a function of the field indicate that the Ln moment dominates the polarization of the molecule and that the Ln-Fe_3 subcluster interaction within the $\{Fe_3LnO_2\}$ cluster is determined to be antiferromagnetic. Very low-temperature ($T << 1$ K) ac susceptibility and heat capacity measurements reveal the existence of frequency dependent components and magnetic interaction between the clusters.

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TRANSPORT PROPERTIES OF GOLD NANOPARTICLES LINKED BY SINGLE-MOLECULE MAGNETS

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Single-Molecule Magnets (SMMs) are intensively investigated as core components for new molecule-based spintronics. A particularly critical step is grafting SMMs on metal substrates. The aim of this work was to create an unprecedented SMM-nanoparticles (SMM-NPs) hybrid nanostructure, as model system to investigate the interactions between SMMs and conducting substrates.

Hexadecylamine (HDA)-functionalized gold NPs have been successfully functionalized via ligand exchange using a tetrairon(III) SMM containing two 1,2-dithiolane end groups, named Fe4thioctic [1] and deposited on interdigitated gold electrodes in order to study the transport properties of the SMM-NPs nanostructures.

Electronic transport properties of these nanostructures and results of conductance experiments will be discussed.

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3D MAGNETIC NANOSTRUCTURES FABRICATED BY SPOT ELECTRON-BEAM LITHOGRAPHY

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We demonstrate novel magnetic nanostructures produced by the author's method of 3D nanofabrication with high resolution and small shape defects using electron-beam lithography (EBL) technique. Our method of the spot EBL is extremely fast, highly scaleables and capable of sub-20 nm resolution.

The results of the study of Py square rings by magnetic force microscope (MFM) are represented in Fig.1a. At an applied magnetic field H=100 Oe the single domain state is observed on the side walls of square rings. At H=0 the two magnetic configurations are realized: the four domain state (FDS) having a weak magnetic contrast (Fig.1b) and diagonal state (DS) with a vivid black and white contrast (Fig.1c). The hysteresis loops demonstrate the anisotropy of magnetization processes in external magnetic fields applied along walls of square rings (axis [10] or [01]) and its diagonals (axis [11]), Fig.1d.

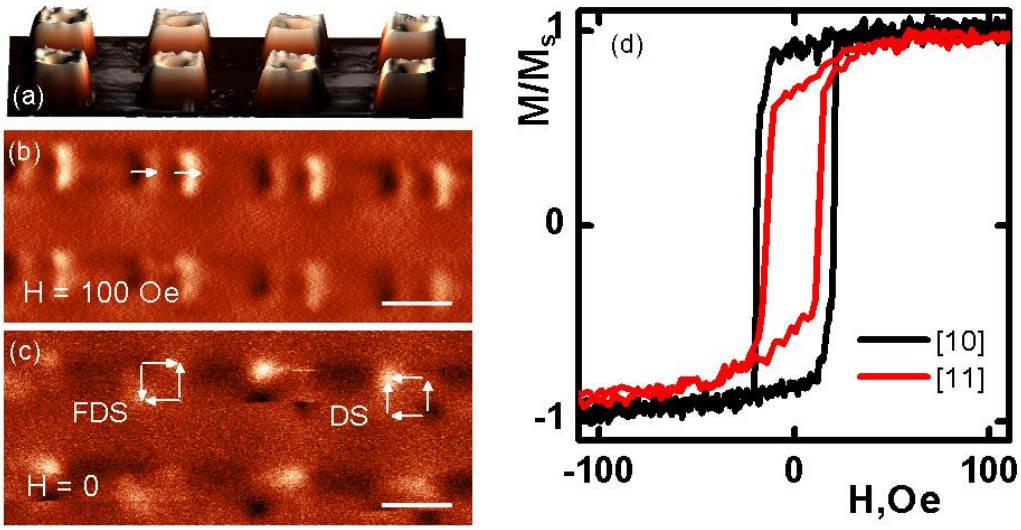

Figure 1. (a) The quasi-3D image of the ring array observed by MFM. The image of magnetic structure for square rings at saturation (b) and at remanent magnetization (c). Hysteresis loops measured at different directions of an applied magnetic field relatively to the selected axis of the array. The scale in figures (b) and (c) is 500 nm. Magnetic field is applied along [10] axis.

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1-BIT FULL ADDER IN PERPENDICULAR NANOMAGNETIC LOGIC USING A NOVEL 5-INPUT MAJORITY GATE

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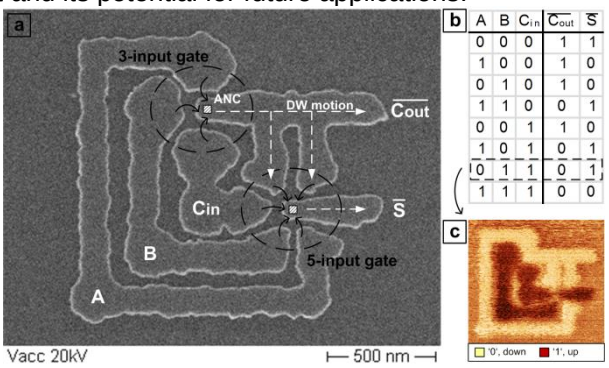
Nanomagnetic Logic (NML) is an emerging technology using non-volatile, field-coupled nanomagnets to combine logic and memory functionality [1]. Partial FIB irradiation reduces locally the anisotropy of the Co/Pt nanomagnets and creates artificial nucleation centers (ANCs) [2].The domain wall (DW) nucleation at the ANC is supported or constrained by the coupling fields of the surrounding input dots, which superimpose with the clocking field and therefore force a dot to switch to the antiparallel state compared to its input majority [3].
In this paper, a 1-bit full adder (2.6 µm²) using a novel 5-input majority gate is experimentally demonstrated (Fig. 1a). 2 majority gates, one 3-input gate and one 5-input gate where $\overline{C_{out}}$ is weighted twice, compute the 2 outputs (inverted carry-out $\overline{C_{out}}$ and sum $\overline{S}$) depending on the configuration of the 3 inputs (A, B, carry-in C_{in}).
$\overline{C_{out}}$ and $\overline{S}$ are computed by two alternating clocking field pulses with constant amplitude $B_{clock} = \pm 50$ mT proving the circuit functionality (Fig.2). Experiments are supported by numerical and compact model simulations to verify the measurements and predict the behavior of the circuit and its potential for future applications.



A	B	C_{in}	$\overline{C_{out}}$	$\overline{S}$
0	0	0	1	1
1	0	0	1	0
0	1	0	1	0
1	1	0	0	1
0	0	1	1	0
1	0	1	0	1
0	1	1	0	1
1	1	1	0	0

Figure 1: a) SEM image of the full adder structure with inputs A, B, C_{in} and outputs $\overline{C_{out}}$, $\overline{S}$. **b)** Corresponding truth table. **c)** MFM image after clocking.

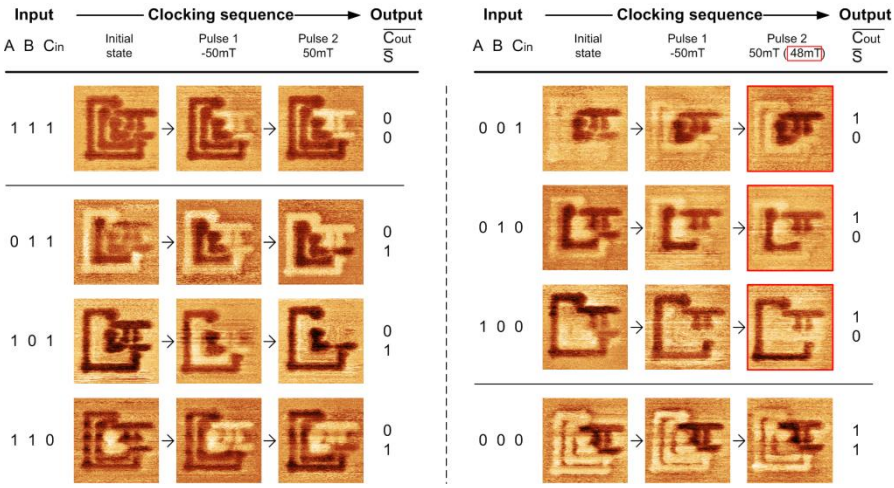


Figure 2: MFM images of the full adder during the clocking sequence. $\overline{C_{out}}$ and $\overline{S}$ are sequentially ordered in the correct state by two clocking pulses with ±50mT.

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SYMPOSIUM 6.2

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IMPROVEMENT OF MICROSTRUCTURE AND MAGNETIC PROPERTIES OF FEPT FILMS WITH NEW INTERMEIDATE LAYERS

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The main challenge to application of $L1_0$ FePt thin films as magnetic recording media is the fabrication of FePt (001) thin films with both high perpendicular anisotropy and small grain size. In this paper, we discussed the microstructure and magnetic properties of FePt films grown on TiN intermediate layer.

With TiN intermediate layer, FePt (001) films with high perpendicular anisotropy was obtained and the in-plane hysteresis loop was almost a straight line. In order to evaluate the dead layer of FePt films on TiN intermediate layer, FePt film with nominal thickness of 2 nm was deposited on TiN (5nm)/CrRu/glass. The film showed very large out-of-plane coercivity and the out-of-plane hysteresis loop was a typical minor loop of hard magnetic materials with S-W mode reversal. With the doping C and SiO_2 into FePt, well isolated grains with grain size of 5.5 nm were obtained on this new intermediate layer, as shown in Fig.1. Most importantly, the magnetic properties such as magnetic anisotropy and opening up of in-plane hysteresis loop were retained with various concentrations of SiO_2 and C co-doping. Therefore, the new intermediate layer is very promising $L1_0$ FePt HAMR media.

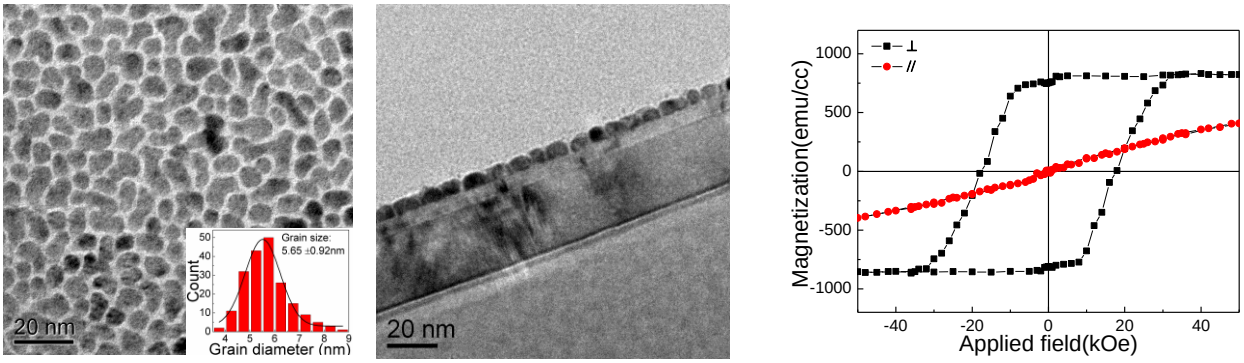

Fig. 1 TEM images and hysteresis loops of FePt-SiO_2-C film grown on the new intermediate layer

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TAILORING THE MAGNETIC DOMAIN PATTERNS OF SPUTTERED TbFeGa ALLOYS

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The control of the domain patterns in systems with perpendicular magnetic anisotropy (PMA) is of great interest because of their applications on magnetic storage or spintronic devices. Amorphous Tb-Fe alloys exhibit a pretty large PMA constant that reaches 10^6 J/m^3. Recently, it has been reported a constant of at least 1×10^5 J/m^3 in TbFeGa alloys [1]. We have deposited TbFeGa films by cosputtering using two targets with a composition of $TbFe_2$ and Fe_3Ga. Two series of samples were obtained by applying a different type of power source (DC or pulsed) in each target. In particular, the evaporation of $TbFe_2$ by means of the DC source enhances the out of plane component of the magnetization (Fig. 1). The results indicate that this can be due to the Tb enrichment of the $TbFe_2$-based phases present in the alloys. Therefore, the magnetic domain pattern can be tailored by means of the composition and the type of power source used in each sputtering target.

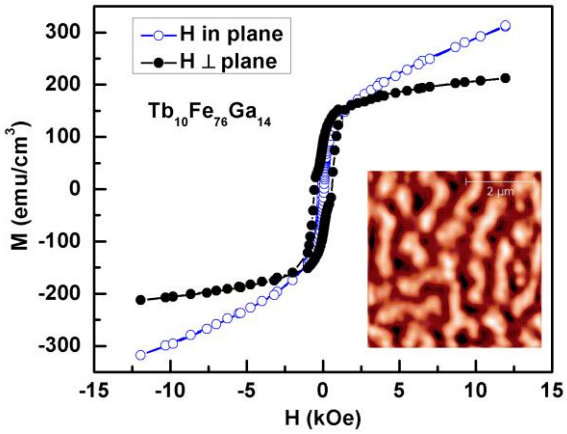

Figure 1. Room temperature hysteresis loops of the $Tb_{10}Fe_{76}Ga_{14}$ measured with the applied magnetic field perpendicular (●) and in the sample plane (○). Inset: MFM signal recorded at remanence.

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CORRELATIONS BETWEEN ATOMIC STRUCTURE AND MAGNETIC PROPERTIES OF GRANULAR FePtX-Y FILMS

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INTRODUCTION

Due to their high magneto-crystalline anisotropy of chemically ordered $L1_0$-FePt granular FePtX-Y films are promising candidates for future heat assisted magnetic recording (HAMR) media.

METHODS

High-resolution transmission electron microscopy (HRTEM) and vibrating sample magnetometry (VSM) are used to correlate the structural and magnetic properties of highly textured granular films of matrix-isolated $L1_0$ ordered FePtX-Y (X: Cu/Ag; Y: C…).

RESULTS AND DISSCUSION

Plan view HRTEM images reveal bimodal distributions of particle sizes = 4 - 6 nm). From cross-sectional images the orientations of the particles' easy axes with respect to their MgO seed crystal and the substrate plane are determined, respectively. The texture spread of the [001] easy axes is roughly 3° and thus larger than the misalignment of the layered MgO crystals. This finding is ascribed to the nucleation of the FePtX growth at MgO step edges. The magnetic remanence analyses reveal only a weak dipolar coupling between the matrix-separated nanomagnets and high anisotropy fields of $\mu_0 H_A = 8 – 9$ T. Surprisingly, the magnetic texture spread is clearly larger than the distribution of easy axis orientations.

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BREAKING THE THERMALLY INDUCED WRITE ERROR IN HEAT ASSISTED RECORDING BY USING LOW AND HIGH TC MATERIALS

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INTRODUCTION

Heat assisted recording is believed as a key future recording technology. In the work of Richter et al [1] it is stated that storage densities will be limited to 15 to 20 Tbit/in² due to thermally induced write errors. We propose a composite structure for heat assisted recording consisting of two materials with different Curie temperature as shown in Fig 1. The material on top has a Curie temperature slightly above the write temperature and the other material below has a significant higher Curie temperature. It is shown that for this composite media the thermally induced write error does not limit the achievable areal density in heat assisted recording. Recording can be performed at lower temperature which has - besides the reduced thermal write errors - several key advantages, such as an increased life time of the plasmonic transducer. Furthermore errors which occur after writing, when the media cools down are reduced. It is shown that transition jitter in heat assisted recording media is dominated by variations of the Curie temperature already for variation of σ_{Tc} = 3%. Write schemes which lower the write temperature significantly below the Curie temperature are beneficial in order to decrease the transition jitter although the thermal effective head field gradient becomes smaller.

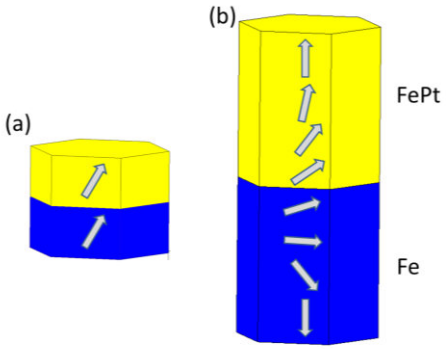

Fig. 1: Two media designs. (a: Fe/FePt - single domain) and (b: Fe/FePt - exchange spring) with a high T_c material at the bottom.

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MAGNETOIMPEDANCE IN AS-PREPARED NiFe/Cu/NiFe MULTILAYER WITH NiFe GRATINGS

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INTRODUCTION

In this work, a new type of thin film magnetoimpedance (MI) sensor with a ferromagnetic grating layer is studied. The sensor consists of a $Ni_{80}Fe_{20}$/Cu/$Ni_{80}Fe_{20}$ tri-layer and a high aspect ratio $Ni_{80}Fe_{20}$ grating layer on the top (Fig 1). The device is fabricated by standard microfabrication methods and without inducing a magnetic anisotropy through, e.g., field deposition or field annealing. The sensor is characterized using a vibrating sample magnetometer and an impedance analyzer. The results show that the magnetic easy axis of the sensor can be controlled through the alignment of the ferromagnetic grating layer (Fig. 2). Due to the effect of the grating layer, the impedance maxima shifts from 0 to 8 Oe at 500 MHz, and the MI ratio is improved from 16% to 22% (Fig. 3). These results show the possibility of tuning the sensor's properties by the help of the grating layer.

FIGURES AND TABLES

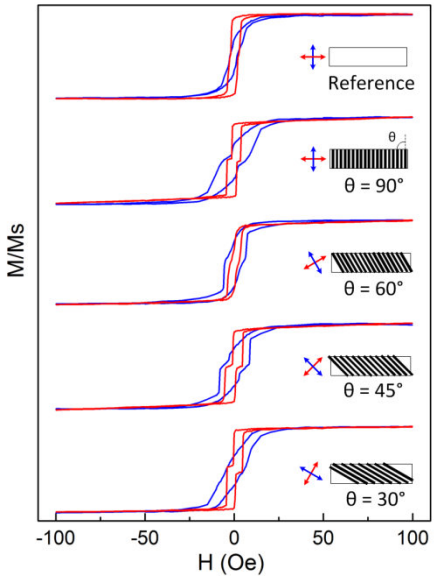

Figure 1: Magnetization curves along the easy (red) and hard (blue) axis of the samples without and with grating layers at different angle θ.

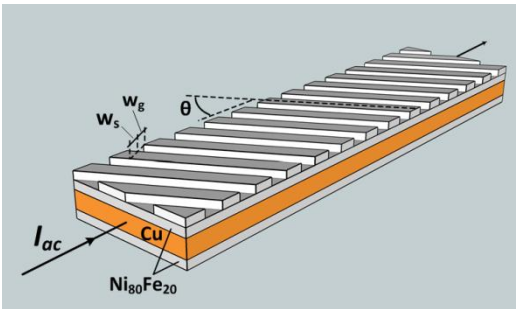

Figure 2: Schematic of the MI sensor: tri-layer $Ni_{80}Fe_{20}$/ Cu/ $Ni_{80}Fe_{20}$ with the thickness of 50/100/50 nm followed by a 50 nm $Ni_{80}Fe_{20}$ grating layer.

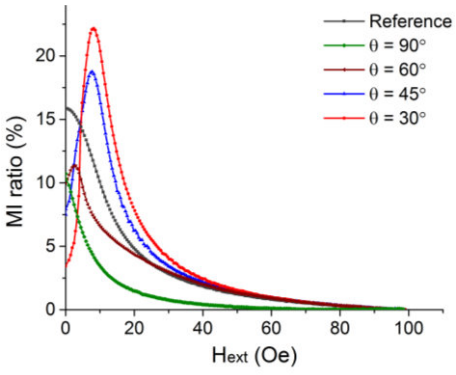

Figure 3: MI ratio of different samples at 500 MHz.

STRUCTURE ANALYSIS OF CoPt FILM WITH METASTABLE ORDERED PHASES OF $L1_1$ AND B_h FORMED ON Ru(0001) UNDERLAYER

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CoPt-alloy with metastable ordered phase of fcc-based $L1_1$ shows K_u greater than 10^7 erg/cm^3 along the direction normal to the close-packed plane [1] and the film has recently attracted much attention to applications like recording media and MRAM devices. In the present study, $Co_{50}Pt_{50}$ (at. %) film is RF-sputter deposited on Ru(0001) single-crystal underlayer at 300 °C. RHEED shows that a CoPt epitaxial film with the close-packed plane parallel to the film plane is formed. Cross-sectional high-resolution TEM [Fig. 1(a)] and pole-figure XRD show that hcp-based atomic stacking sequence, ABAB…, is included in addition to fcc-based sequence, ABCABC… The result indicates that the film consists of a mixture of metastable fcc-based $L1_1$ and hcp-based B_h phases. Fig. 1(b) shows the out-of-plane XRD spectrum. Superlattice reflection of CoPt(111)$_{L11}$+(0001)$_{Bh}$ is clearly observed. The order degree is estimated to be 0.3. The film with metastable phases shows strong perpendicular magnetic anisotropy which reflects the magnetocrystalline anisotropy of $L1_1$- and B_h-CoPt crystals.

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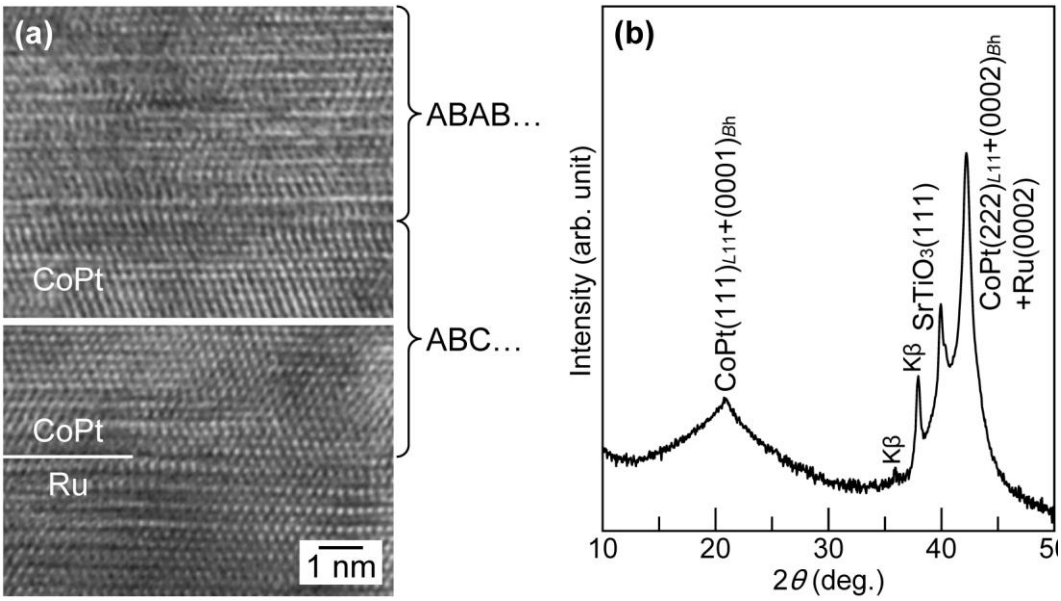

Fig. 1 (a) Cross-sectional HR-TEM. (b) Out-of-plane XRD.

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EFFECT OF MgO BUFFER LAYER AND SUBSTRATE TEMPERATURE ON STRUCTURAL AND MAGNETIC PROPERTIES OF $L1_0$ - FePt THIN FILMS

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FePt compound films with $L1_0$ ordered structure have been intensively studied due to the strong interest for ultrahigh density recording media applications. Nowadays the reduction of the ordering temperature and the achievement of fct (001) preferred orientation of FePt by sputtering technology, are two of the most important challenges for the application in perpendicular recording media. The strain energy arising from thermal stress misfit between CoPt or FePt grains and Ag matrix provide the driving force for the reduction of ordering temperature and the epitaxial growth of FePt-fct films [1]. In the second route the deposition of a CrRu underlayer with Cr (002) texture can be adjusted in such controllable crystalline misfit that results in a generation of strain energy. By this way a tensile stress is produced, expanding FePt *a* axis and shrinking *c* axis, thus leading to the formation of the fct structure [2].
Ordered FePt thin films with face-centered-tetragonal (fct)-(001) preferred orientation have been prepared by magnetron sputtering a FePt layer onto Cr underlayer. The effect of a MgO buffer layer between Cr underlayer and FePt layer, along with the deposition temperature of FePt film effect on the structural and magnetic properties of the FePt were investigated. The long range ordering parameter decreased as the MgO thickness changes from 2nm to 1 nm or 4 nm. The out of plane coercivity also decreases with the above described variation of MgO thickness. For a 2 nm constant MgO buffer layer thickness the effect of deposition temperature of FePt films is presented and a fully $L1_0$ transformation is observed at 325 ^{0}C.

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INTERPLANETARY INSPIRATION: SYNTHESIZING TETRATAENITE FOR PERMANENT MAGNET APPLICATIONS

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INTRODUCTION

It is of interest to develop alloys and process schemes that will facilitate large-scale production of nanostructured rare-earth-free permanent magnets. FeNi compounds with the tetragonal $L1_0$ structure possess high magnetization and high anisotropy that, when properly harnessed via structural optimization, can substitute for rare-earth-containing "supermagnets" in energy-relevant technologies. $L1_0$ FeNi, known to meteoricists as "tetrataenite" has been observed to occur naturally in selected meteorites that form over millions to billions of years. Tetrataenite possesses a large saturation magnetization and a large magnetocrystalline anisotropy that combine to provide a magnetic energy product close to that of the best $Nd_2Fe_{14}B$-based magnets.

Guidance for development of bulk $L1_0$-type FeNi may be obtained from past studies that have indicated its formation under certain conditions in the laboratory. In this presentation, new results concerning naturally-occurring tetrataenite as well as the formation of tetrataenite in laboratory conditions will be presented and discussed. These results demonstrate the potential for production of $L1_0$ FeNi at time and temperature scales suitable for nanostructured bulk magnet production.

ACKNOWLEDGEMENT

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METAL INJECTION MOULDING (MIM) OF NDFEB MAGNETS

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Due to the increased and unstable prices for Rare Earth elements there are activities to develop alternative hard magnetic materials. Reducing the amount of material necessary to produce complex sintered NdFeB magnets can also help to reduce some of the supply problem. Metal Injection Molding (MIM) is able to produce near net shape parts and can reduce the amount of finishing to achieve final geometry.

Although MIM of NdFeB has been patented and published fairly soon after the development of the NdFeB magnets there has never been an industrial production. This could be due to the fact that MIM was very young at that time and hardly developed. Thus, the feasibility of the process needs to be revaluated. This paper presents results of our work on determining the process parameters influencing the magnetic properties of the sintered magnets as well as the shrinkage during processing. The role of binder and powder loading on the alignment of the particles as well as on the carbon and oxygen contamination was examined.

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MANGANESE ALLOYS FOR MAGNETIC REFRIGERATION: MAGNETOELASTIC *VS* MAGNETOSTRUCTURAL PHASE TRANSITIONS

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Magnetic refrigeration is a promising cooling technique which might advantageously replace the gas compression technology. For its development, it is requested to search for new materials presenting a magnetocaloric effect (MCE) as large as possible. But, attention must not only be paid on ΔS and ΔT_{ad} values. For applications, other properties are also relevant: the reversibility of the effect, the mechanical properties, the cost of the starting materials…

Following this spirit, the interest for magnetic refrigeration of Manganese alloys based on a TiNiSi-to-Ni_2In magneto-structural phase transition (compounds derived from the MnCoGe [1]) is compared to a *new* Fe_2P-type material displaying a first order magneto-elastic transition. It appears that even if both kinds of transition lead to a “Giant” magnetocaloric effect, only the latter type is really suitable for applications. These new materials derived from MnFe(P,Si) combine several advantages making them highly desirable for magnetic refrigeration:

- The first order transition is at room temperature and can be easily adjusted

- A large MCE is observed in intermediate field, for instance a ΔT of 2.8 K is obtained for ΔB=1.1 T, *cf.* figure

- The hysteresis of the transition being negligible, the MCE is fully reversible

- There is not any volume change at the transition, which ensures a good mechanical stability (bulk pieces stay intact even after 10 000 magnetization cycles)

- No toxic or critical elements are used

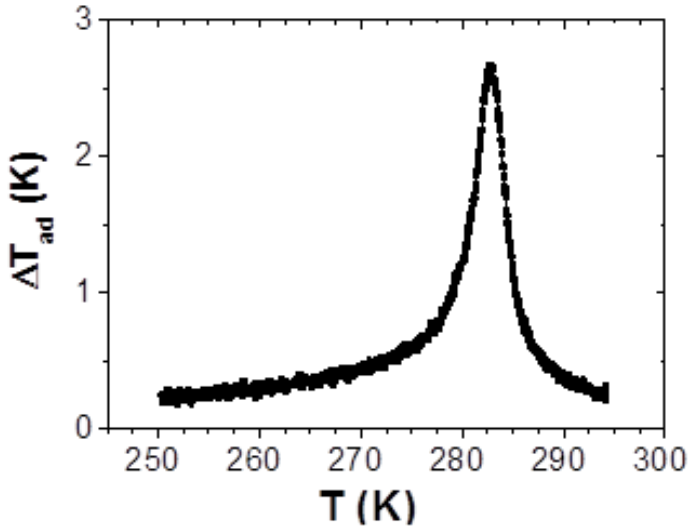

Figure: Direct ΔT_{ad} of a MnFe(P,Si,B) material

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SELECTIVE LASER MELTING OF $La(Fe,Co,Si)_{13}$ REGENERATORS FOR MAGNETIC REFRIGERATION

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INTRODUCTION

This work takes a magnetocaloric material, $La(Fe,Co,Si)_{13}$, and combines it with a three-dimensional prototyping technique called Selective Laser Melting (SLM) to fabricate advanced geometries of magnetocaloric regenerators–the heart of a magnetic cooling fridge [1].

We demonstrate two advanced geometries: a wavy-channel block and an array of fin-shaped rods. These designs maximize heat transfer, minimize pressure loss, or eliminate unwanted heat conduction along the regenerator's length.

To meet the reliability requirements of industry, we show that the regenerators survive more than 10^6 cycles of a rotating permanent magnet. We characterize the magnetocaloric properties (indirect ΔS and direct ΔT_{ad}) and the microstructure and composition (SEM and XRD) of the regenerators. Finally, we summarize the advantages and disadvantages of SLM technique for making magnetic refrigerants.

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MULTISCALE INVESTIGATION OF NiMnGa THIN FILMS AND NANO-DISKS

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Nanostructured ferromagnetic shape memory materials are promising for the realization of,micro/nano-actuators, energy harvester and micro-refrigerators. Most of the activity to date concerns NiMnGa films of thickness ranging from 100 nm up to several hundred of nanometers.

Here we present a multiscale structural and magnetic investigation of NiMnGa thin films of low thickness (10- 100 nm) grown by r.f. sputtering on different substrates (e.g. Figure 1).The occurrence of the martensitic transition and the twin configuration are strongly dependent on thickness and can be explained in terms of lattice constrains imposed by substrate. For instance, thin films (up to 20 nm) grown on MgO are austenitic at all temperatures, while for thickness up to 75 nm they undergo the martensitic transformation to a multivariant structure with the tetragonal c-axis perpendicular to the film plane [1]. In contrast, for films grown on Cr underlayer of t=75 and t=100 nm, the c-axis was found to lye in the film plane. Novel results on nano-disks obtained by patterning NiMnGa thin films (75, 100 nm) by means of the polystirene-nanosphere lithography will also be discussed.

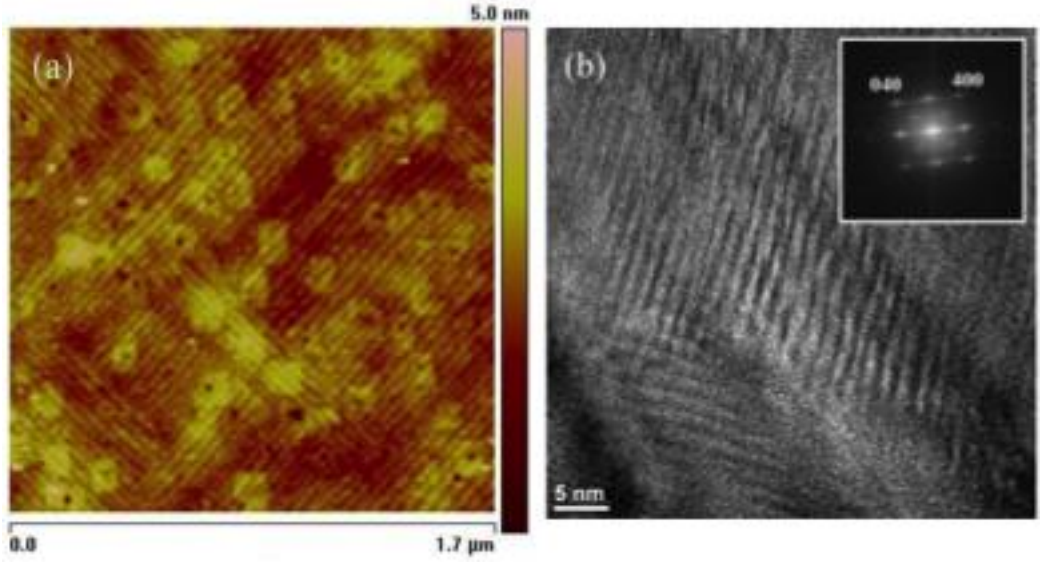

Figure 1: 100 nm NiMnGa film grown on MgO (100): (a) atomic force, (b) transmission electron microscopy images.

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THE ORIGIN OF GIANT MAGNETOCALORIC EFFECT

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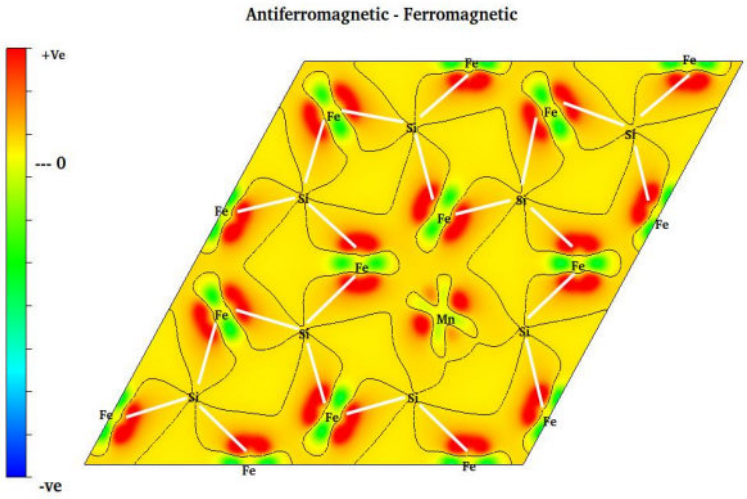
INTRODUCTION

Since cooling at present still relies on old fashioned mechanical devices, large changes are to be expected in this field by the application of 21st century technology. Very recently spectacular results have been obtained by using adiabatic demagnetization near room temperature. Electronic structure calculation revealed the origin of the high efficiency of the materials responsible for the effect: the coexistence of weakly and strongly magnetic layers in one compound [1]. The strong magnetic layer is responsible for the relatively high Curie temperature (room temperature and above), while the weak one controls the size of the effect. The loss of the moments releases degrees of freedom for chemical bonding that induces a phase transition with a giant magneto-caloric effect.

FIGURES AND TABLES



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THE MAGNETIC PROPERTIES OF FE_2P UNDER PRESSURE REVISITED: THE INFLUENCE OF COMPOSITION ON THE T-P DIAGRAM AND MAGNETOCALORIC EFFECTS

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Magnetocaloric-based refrigeration presents itself as an environmentally-friendly energy-efficient technology capable of beneficially replacing the current gas compression-based technology. The most promising magnetocaloric working materials found to date, $(Fe,Mn)_2(P,Si)$, are based on the Fe_2P binary compound. Fe_2P presents a first-order FM-PM magnetoelastic transition around 219K and low magnetic entropy changes spanning large temperature ranges. What makes Fe_2P so unique is the coupling presented by its magnetic and crystal lattices which gives rise to the so-called mixed magnetism[1]. To better understand this coupling in both Fe_2P and Fe_2P-based compounds we have characterized the magnetic and magnetocaloric properties of stoichiometric polycrystalline Fe_2P under hydrostatic pressure. Pressure decreases T_C at a rate of 6.1K/kbar, and at ~8kbar an antiferromagnetic state is achieved that is easily destroyed by field, which induces ferromagnetism above 0.2T. This pressure is much higher than the 5kbar reported in literature[2], emphasizing that stoichiometric deviations play a crucial role in the magnetic properties of Fe_2P.

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SYMPOSIUM 3.2

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APPROACHES FOR THE DISCOVERY AND DESIGN OF NON-RARE-EARTH BASED PERMANENT MAGNETS

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Supply restrictions in the global market for rare-earth metals have spurred interest in the discovery of new compounds with high saturation magnetization and intrinsic coercively as well as ways of optimizing older alloys. Both are daunting tasks given the high energy product of existing rare-earth based alloys. Opportunity exists in developing new alloys for the higher operating temperature regime of traction motors and some generators. These machines require up to 12 wt.% Dy for the Nd to improve its high temperature resistance to demagnetization. Given the high production tonnage projected and the high cost and clear resource limitation of the Dy needed for such applications, new or greatly improved alloys are needed. Discovery of new compounds requires a more sophisticated approach that past brute-force trial and error. Ames Laboratory, in collaboration with a number of universities and laboratories have been embarking on a comprehensive research program to combine a series of integrated computational and experimental efforts to both discover and design new compounds with promising magnetic properties. The computational efforts include both density functional theory and adaptive genetic algorithms to identify new compounds. More importantly we are developing feedback algorithms to identify and solve the crystal structures of new and old compounds which have been identified as promising candidates. More sophisticated computational tools which incorporate more accurate determination of the correlated electrons are being brought to bear on understanding some promising older compounds such as alnico and MnBi and guiding new processing routes and minor alloying agents. Specific examples of materials discovery and new insights into improvements of existing alloys will be presented.

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MODULATION OF EXCHANGE BIAS IN NI-MN-SB HEUSLER ALLOY BY THERMAL CYCLE

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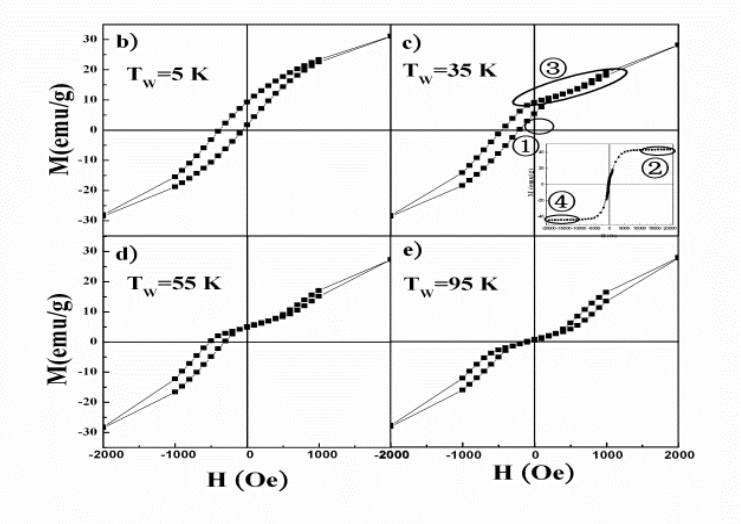
Abstract :

The off-stoichiometric Ni-Mn based Heusler ferromagnetic shape memory alloys (FSMAs) have attracted considerable attentions for their rich and special properties and potential application due to the martensitic transition (MT) and the unique properties of martensitic phase. In this work, the effect of thermal cycle on the interfacial antiferromagnetic (AFM) spin configuration and exchange bias has been investigated for the $Ni_{50}Mn_{36}Sb_{14}$ alloy. The shape of hysteresis loops at 5 K after cooling back can be tuned from a single-shifted loop to a nearly symmetric double-shifted loop gradually together with increasing the exchange bias field to the peak value and then decreasing slowly. The results indicate thermal cycle can induce further martensitic transition from part of arrested FM phase to AFM phase, which results in the reconstruction of interfacial antiferromagnetic spin configuration. The evolutions of exchange bias can be illustrated intuitively by a simple AFM bi-domain model.



Magnetization loops of $Ni_{50}Mn_{36}Sb_{14}$ alloy from -2 kOe to 2 kOe after different thermal cycling procedure.

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EXCHANGE BIAS EFFECT IN HETEROSTRUCTURES OF FERRIMAGNETIC TBFECO AND FERROMAGNETIC [CO/PT]-MULTILAYERS

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The realization of a large exchange bias effect is an important aspect in the miniaturization of prospective spintronic devices. The stack of amorphous ferrimagnetic Tb_xFe_{100-x} thin films on top of ferromagnetic [Co/Pt]-multilayers attracted much attention due to the occurrence of a large exchange bias field up to H_b = 20 kOe [1, 2]. A confinement of the exchange bias field H_b is given by the formation of an interfacial domain wall during the reversal of the softer [Co/Pt]-multilayers. The domain wall thickness depends on the magnetic properties of the ferrimagnetic alloy. By stepwise substitution of Fe- by Co-atoms a change in the coupling conditions will influence H_b.
In the presented study, $Tb_x(Fe_{100-} Co_y)_{100-x}$ (20nm) / $[Co(0.4nm)/Pt(0.8nm)]_{10}$ heterostructures were prepared by magnetron-sputtering at room temperature. The magnetization reversal process at different temperatures and for different compositions of the ternary alloy was investigated.
Furthermore, we analyzed the influence of the cobalt as well as the terbium content on the exchange bias field, revealing the correlation between the uniaxial anisotropy of the ferrimagnetic layer and the exchange coupling at the interface.

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LOW THICKNESS ANTIFERROMAGNETIC THIN FILM OF FERH

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FeRh in the equiatomic alloy has many intriguing properties. It could have many potential applications for magnetic recording[1]. One such property is its metamagnetic transition that occurs around 370 K. At low temperature, FeRh is antiferromagnetic and goes to a ferromagnetic state above 370 K.

In this paper we will present results on FeRh thin films of small thickness grown by molecular beam epitaxy on (001) MgO substrates. Thickness varies from 3 nm to 10 nm. The films are grown at 300 °C and annealed at 800 °C during 30 minutes. After cooling down below 80 °C, all films are capped with 3 nm of Al. X ray diffraction shows a very good chemical ordering for all the layers.

The positions of MgO[113] and FeRh[102] diffraction peaks show a perfect matching between MgO and FeRh. High resolution transmission electron microscopy demonstrates the high quality of the films. SQUID Magnetometry measurements show that films with thickness 4 nm and above show a clear metamagnetic transition (see figure 1). When the thickness is 5 nm and above, the transition occurs at its bulk value. We are investigating the low thickness films to understand their behaviour.

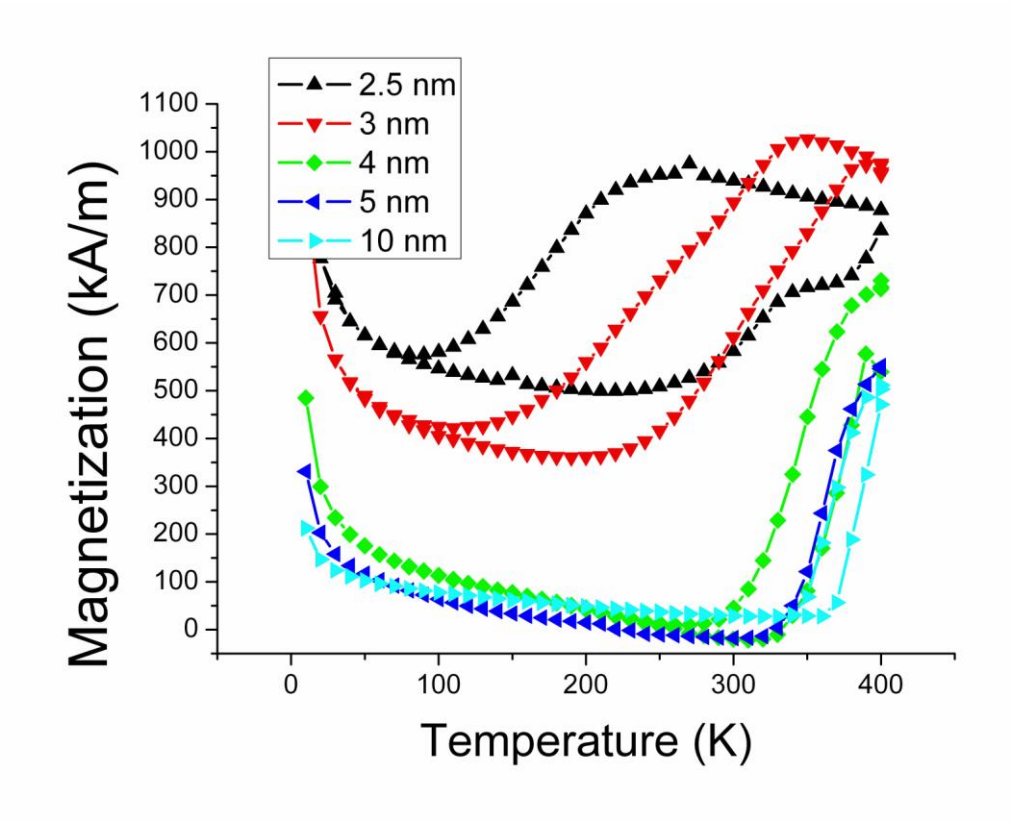

Figure 1 Magnetization as a function of temperature. Applied field is 0.1 T.

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CONTROL OF THE MAGNETIC ANISOTROPY OF AN ANTIFERROMAGNETIC FILM THROUGH GROWTH CONDITIONS

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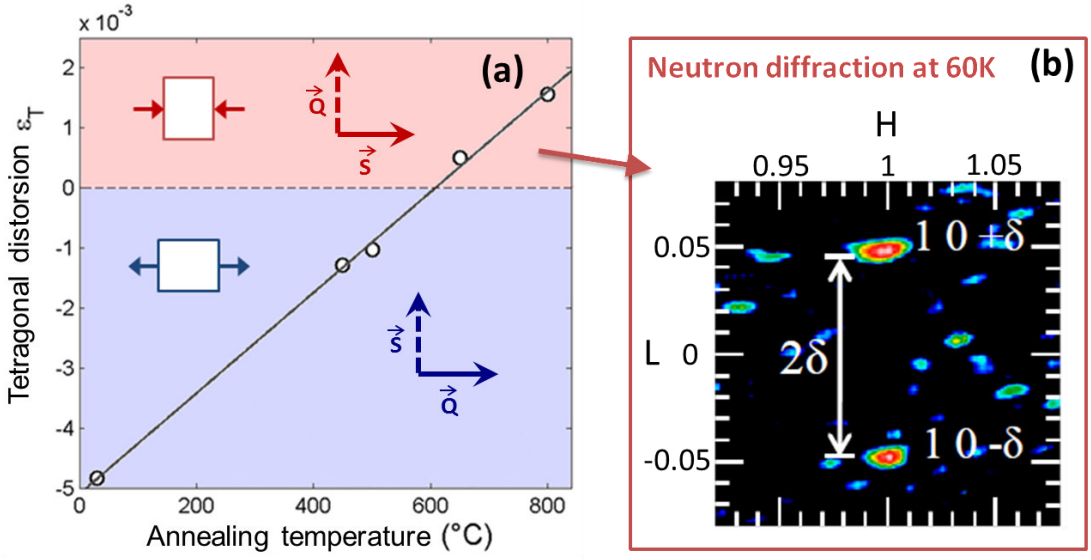
For Cr thin films in heterostructures and multilayers, finite size and interface hybridization effects can trigger a modification of the antiferromagnetism of Cr [1]. Its magnetic phase is a modulated spin density wave order, characterized by a polarization, and a propagation direction. However, like for bulk Cr, strain effect (originating from the epitaxy on the substrate) in thin films can also dictate the orientation of these two parameters. We will show how it is possible by simply adjusting the annealing temperature of the Cr film, to obtain the wanted magnetic anisotropy. We have grown epitaxially 200nm thick Cr films on a MgO substrate and annealed them at different temperatures. X-ray diffraction measurements show that the stress and the tetragonal distortion depend linearly on the annealing temperature (Figure a), because of thermal differential deformation of the substrate and the layer. Neutron diffraction measurements on the thin films show that, depending on the annealing temperature, the phase is either commensurate (not modulated), propagating normal to the surface (polarization in-plane) (Figure b), or propagating in the film plane (spins out-of-plane). This control enables to disentangle strain effects from finer effects like interface coupling phenomena.



a) Tetragonal distortion as a function of annealing temperature and associated phases
b) Neutron magnetic reflections for a spin density wave propagating normal to the surface.

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ANTIFERROMAGNETIC STRUCTURE OF Mn_2Au

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In a recent first-principle LSDA study, Khmelevskyi and Mohn [1] predicted that Mn_2Au, known as an itinerant electron paramagnet [2], should rather be an antiferromagnet with $T_N \approx$ 1600 K.

A polycrystalline sample was prepared by induction melting and annealed 3 days at 650 °C. X-ray diffraction showed that the sample contained almost uniquely the $MoSi_2$–type tetragonal phase, the impurity phases (MnO and MnAu) were below 1%. A neutron diffraction study (λ_n = 1.28 Å) was performed on D1B (ILL-Grenoble) at four temperatures (2K, 20 K, 300 K and 550 K). No peak, additional to the ones found by X-ray, was detected. However, refinement of the peaks intensities revealed that the Mn moments form an antiferromagnetic structure, with a [000] propagation vector, identical to the structure predicted in [2]. The Mn amounts to 3.56 (5) μ_B, to be compared to the theoretical value of 3.64 μ_B. Up to 550 K, the peak intensities remain almost unchanged, thus indicating that the Néel temperature is well above room temperature.

The discovery of a new high temperature antiferromagnet, such as Mn_2Au, is of potential interest for exchange-biased systems or in TAMR (Tunnel Anisotropic Magnetoresistance) devices.

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MAGNETISM IN THE INTERFACE OF Co/CoO

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Magnetic nanoparticles have attracted immense interest due to the huge number of current and anticipated applications in many areas of technology. Co/CoO bilayers and core/shell nanostructures form a ferromagnetic-antiferromagnetic interface and present unusual magnetic properties [1]. The study of the magnetic moments of the atoms of the systems is important, while the magnetic anisotropy energy is a key property that determines whether a magnetic system will be useful in technological applications [2].

In the present study, first-principles calculations were employed to study the magnetic properties of core-shell nanostructures Co/CoO. Three types of calculations were carried out: i. Co-O clusters of 13, 14 and 19 atoms, ii. Co/CoO bilayers, and iii. Co/CoO core/shell nanostructures. The geometrical structures of the clusters were optimized via ab initio collinear and non-collinear calculations. The spin-orbit interaction was also included. For the study of the Co/CoO bilayers and core-shell nanostructures, Co has an fcc and CoO has a rock salt structure. In all cases, the magnetic moments and the magnetic anisotropy energy of the atoms of these systems were calculated.

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TUESDAY AFTERNOON

Spin-Torque Driven Magnetic Nano-Droplet Solitons

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INTRODUCTION

Ivanov and Kosevich showed over 35 years ago that the Landau-Lifshitz equation predicts a family of conservative magnetic solitons in thin films with strong perpendicular magnetic anisotropy (PMA) and zero spin wave damping [1]. While all materials exhibit damping, Hoefer, Silva and Keller, demonstrated analytically, and numerically, the possible existence of the similar *dissipative* magnetic solitons, or magnetic droplets, in nano-contact spin torque oscillators (NC-STOs) with PMA free layers [2]. We present the first experimental results on such droplets, in NC-STOs with Co0.3[Ni0.8/Co0.4]x4 free layers (thicknesses in nm) having strong PMA [3]. Nano-contacts with diameters ranging from 50 to 100 nm were studied as a function of drive current and perpendicular magnetic field. At a field of about 0.65 T the NC-STO frequency exhibits a dramatic drop of about 10 GHz, accompanied by a sharp increase in both the microwave power and the device resistance, and strong modulation sidebands appearing. The transition is also observed as a function of drive current in a fixed field and indicates the formation of a substantially reversed magnetic droplet underneath the nano-contact. The appearance of sidebands can be reproduced by micromagnetic simulations where they arise due to a repetitive motion of the entire droplet about the nano-contact.

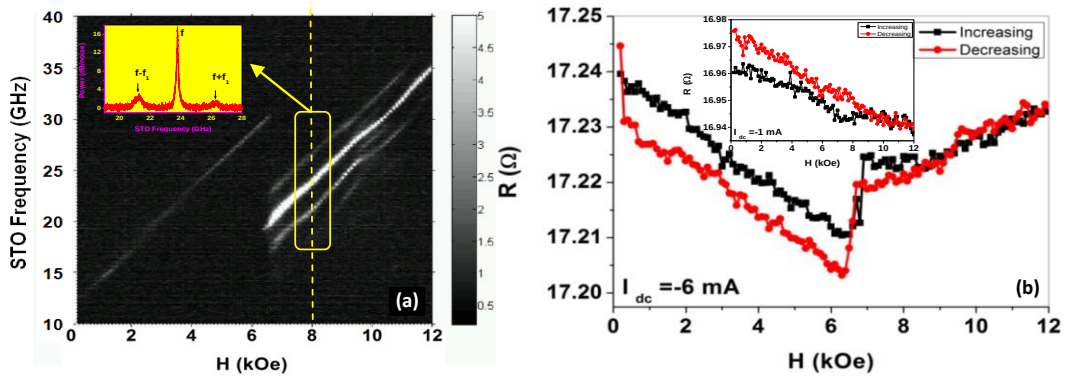

Figure 1: (a): Field dependent NC-STO frequency at I = -6 mA with a dramatic frequency drop at about 0.65 T. Inset: self-modulated dynamics at μ0H = 0.8 T; (b): Resistance vs. field at I = -6 mA showing a jump coincident with the frequency drop. Inset: data for I = -1 mA.

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PHYSICAL PRINCIPLES OF MAGNETIC REFRIGERATION DESIGN

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It is characteristic of the current state of near-room-temperature magnetic refrigeration that there are dozens of prototypes in operation around the world. These are essentially demonstration-of-principle devices, cumbersome and inefficient. Commercially viable magnetic refrigerators are long in coming. The reason is the neglect of basic principles of refrigerator design, which can be deduced from general physical considerations. Thus, it is imperative to use low-porosity ($p << 1$) magnetocaloric beds. Efficiency in the temporal dimension means raising the operation frequency to the theoretical limit, $f << 200$ Hz [1]. This should be accompanied by thinning the refrigerant down to such a thickness that permits heat transfer within a time $\tau << f^{-1}$. To minimize viscous friction, the channels for the heat-exchange fluid should be streamlined. Choosing the right material is a very important issue: a large magnetocaloric effect alone does not suffice. Using $La(Fe,Si)_{13}$ as an example, we discuss the negative role of hysteresis and fatigue. Brittle materials are generally not amenable to fine machining; in the case of $La(Fe,Si)_{13}$ the difficulty can be overcome by means of an ingenious technique [2,3].

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SYMPOSIUM 1.3

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UNDERSTANDING THE ORIGIN OF FERROMAGNETISM IN (Ga,Mn)N

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There are two compounds which arguably demonstrate the highest potential for studying novel spintronics-related phenomena: (Ga,Mn)As, the 'canonical' dilute ferromagnetic semiconductor (DFS) and (Ga,Mn)N, the emerging member of this family [1,2]. Whereas (Ga,Mn)As has become the model material to test semiconductor spintronics concepts, the importance of (Ga,Mn)N stems from a different origin of magnetism and the already dominating role of GaN in photonics and high power electronics. Due to the strong p-d hybridization the $Mn^{2+/3+}$ acceptor level occupies the mid band gap position in GaN precluding the existence of carrier-mediated spin-spin coupling. Interchangeable, either a high p-type doping or high Mn content x is possible. Nevertheless, in uncompensated films, where Mn^{3+} ions prevail, the superexchange interaction becomes ferromagnetic for all Mn-Mn distances resulting in a ferromagnetic order [1] characterized by the Curie temperature T_C = 13 K for x = 0.10 [3]. This finding indicates that (Ga,Mn)N emerges as a model system making it possible to explore properties and functionalities specific to dilute ferromagnetic insulators.

Detailed magnetization studies for MBE-grown films thoroughly characterized by a number of structure-sensitive and element-specific methods will be presented. Experimentally established $T_C \sim x^{2.2}$ dependence will be accounted by theoretical results obtained by combining a tight-binding evaluation of the exchange integrals for short-range ferromagnetic superexchange with Monte Carlo simulations of T_C. Basing on this system a fundamental and long staying question on how disorder influences the critical behavior of continues phase transitions will be discussed. Finally, spin dependent magnetotransport for magnetic tunnel junctions of these dilute ferromagnetic insulators will be presented.

The work has been in part supported by FunDMS Advanced Grant of ERC within the Ideas 7th FP of EC and by (Polish) National Science Centre through project MAESTRO "Quantum phase transitions in magnetic layers driven by an electric field" (Decision 2011/02/A/ST3/00125).

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INFLUENCE OF A METALLIC SPACER ON THE MAGNETIC AND TRANSPORT PROPERTIES OF PERPENDICULAR TUNNEL JUNCTIONS

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The use of Magnetic Tunnel Junctions (MTJs) with perpendicular magnetic anisotropy (PMA) allows enhancing thermal stability of MRAMs. In addition to PMA at CoFeB/MgO interface [1], PMA can be further enhanced by exchange-coupling the CoFeB electrode to a Co/Pt multilayer. However, to obtain high TMR, CoFeB must grow in the bcc structure, which is not possible on Pt. A metallic spacer, often Ta [2], is thus introduced between the Pt and CoFeB layers in order to facilitate the transition from fcc to bcc. When this non-magnetic spacer is thin, exchange-coupling is strong enough to maintain the CoFeB and (Co/Pt) magnetizations parallel. However, when the spacer thickness increases, exchange-coupling decreases, and the magnetization of the CoFeB layer may fall in-plane, leading to zero magnetoresistance.

It has been shown that a window of Ta thickness allows having PMA and a strong magnetic coupling [3]. We will present results on the influence of the Ta thickness on the magnetic and transport properties of full junctions, evidencing a transition from perpendicular to planar anisotropy of the CoFeB layer.

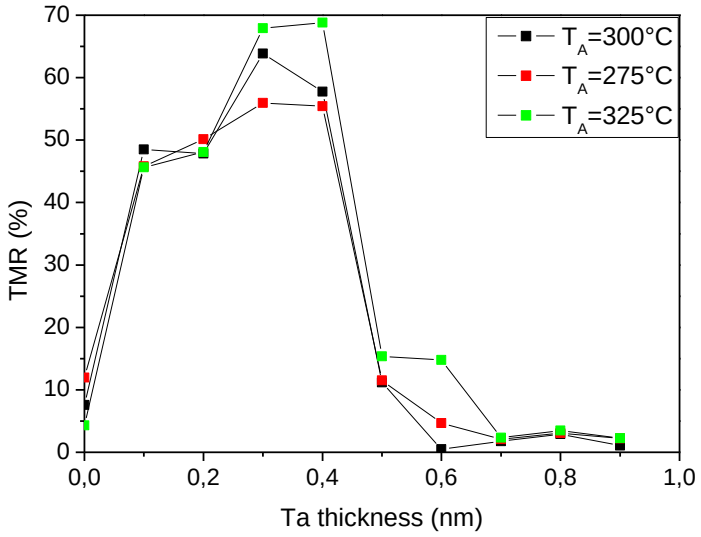

Figure 1: TMR as a function of Ta thickness for different annealing temperatures

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INTER-GRAIN TUNNELING IN HALF-METALLIC DOUBLE-PEROVSKITES WITH HIGH T_c

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We report on electronic transport in polycrystalline Sr_2FeMoO_6 (SFMO), Sr_2FeReO_6 (SFRO), Sr_2CrMoO_6 (SCMO), Sr_2CrWO_6 (SCWO) and Sr_2CrReO_6 (SCRO) with nominal saturation magnetizations M_i between 1 and 4 μ_B/f.u. for SCRO and SFMO, respectively, and T_c between 390 K (SCWO [1]) and 635 K (SCRO). The zero-field conductivities (σ) of polycrystals are governed by inter-grain transport that depends strongly on preparation conditions and often exhibit unusual T-dependence [2]. For all our samples, except for porous SCRO with Berthelot-type σ(T) [3], but including cold-pressed SCRO, σ(T) can be derived from the "fluctuation induced tunneling" (FIT) model [4]. Within the FIT model, the linearity-in-T of σ(T) for all the SFMO samples, sintered or cold-pressed, implies that $2<\pi\chi w/2<3$ (w - the barrier-width and χ - the inverse decay-length of the wave function), consistent with an intrinsic insulating boundary layer with well-defined electronic (and magnetic) structure [5]. In all other samples, $\pi\chi w/2$ varies with preparation conditions indicating less robust boundary layers than those of SFMO.

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ORIGIN OF THE ANISOTROPIC GMR IN MAGNETIC MULTILAYERS

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The GMR found in FM/NM/FM structures consists in a significant change of the electrical resistance depending on the relative magnetization orientation of the FM layers. It is commonly assumed that the MR depends on the magnetic anisotropy of multilayer structures, even though usual experiments just relies in either magnetization or MR curves measured independently for a given applied field angle, normally close to e.a. We present a detailed study of the angular-dependence of both magneto-resistive and magnetization-reversal properties in exchange-biased spin-valve structure [1]. A new experimental set-up allows us to measure simultaneously magneto-resistance and vectorial-resolved-Kerr hysteresis-loops, including MR and in-plane parallel and perpendicular magnetization components, at different applied field angles in the whole angular range.

We advance towards a microscopic understanding of the MR properties by showing that their angular-dependence are directly related to the magnetization-reversal processes. For instance, reversible and irreversible transitions are similar in both MR and vectorial-resolved magnetization curves. Well-defined MR-plateaus are observed around the e.a. whereas just reversible MR transitions are found around the h.a. direction. The MR-plateau value decreases as the magnetic field is misaligned with respect to e.a. and the maximum of MR decreases approaching to h.a. The results directly show that the different magneto-resistive behaviors originate from the magnetic anisotropy of the structure, which ultimately depends on the relative magnetization orientation of the FM layers.

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Antiferromagnetic coupling and temperature-dependent magnetization reorientation in perpendicular CoFeB/MgO/CoFeB

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The down-size scalability of CoFeB/MgO/CoFeB structures with perpendicular anisotropy demands memory elements with reduced dipolar fields. Utilizing antiferromagnetic interlayer coupling can solve this problem.

Here, we present antiferromagnetically and ferromagnetically coupled FeCoB/MgO/FeCoB sputtered structures with coupling strength exceeding $5\mu J/m^2$.

We found that the monolayer-scaled changes in thicknesses of magnetic layers lead to transition of magnetization alignment to out-of-plane orientation for CoFeB thinner than 1.4 nm. For temperatures below T_0~200K, a single-domain state forms showing reorientation from parallel to antiparallel magnetization alignment, which transforms to a multi-domain state or still remains in single-domain state depending on type of coupling.

We quantified effective perpendicular anisotropies and connect transformations of the magnetization alignment with the interplay between interface anisotropy and exchange coupling.

Observed changes in alignment provide an optimal geometry of magnetic electrodes for spin-transfer-torque switching with ultralow critical currents [1].

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MULTIFUNCTIONAL ORGANIC SPINTRONIC DEVICE ACTING AS A MAGNETICALLY ENHANCED MEMRISTOR

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INTRODUCTION

Information and communication technology (ICT) is calling for solutions enabling lower power consumption, further miniaturization and multifunctionality requiring the development of new device concepts and new materials. A fertile approach to meet such demands is the introduction of the spin degree of freedom into electronics devices, an approach commonly known as spintronics. This already lead to a revolution in the information storage (GMR readheads) in the last decades. Nowadays, the challenge is to bring spintronics also into devices dedicated to logics, communications and storage within the same material technology [1].

In this context the electric control of the magnetoresistance represents one of the most promising issues enabling both further miniaturization and multifunctional operation of spintronic devices. Likewise, also the electronics community is committed to follow the Moore's law, and one of the promising approaches is the use of arrays of crossbar memristors capable of information processing and storing ('stateful' logic) [2].

We show that an electrically controlled magnetoresistance can be achieved in organic devices [3] combining magnetic bistability (spin-valve) and resistance switching effects. In such devices the GMR effect can be turned ON and OFF by a programming bias that sets the device in low or high resistance state respectively. The magnitude of the GMR depends on the bias history and can be recovered up to the pristine value [4].

We show [4] that such devices operate like Magnetically Enhanced Memristors (MEM). MEMs can be operated in both memory and logic gate applications merging together spintronic and electronic approaches towards new future device concepts [5].

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ANNEALING STUDY OF SPIN-ORBIT TORQUES IN PERPENDICULARLY MAGNETIZED Ta/CoFeB/MgO LAYERS

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To overcome the bottleneck encountered by the conventional data storage technologies, alternative material systems and mechanisms are needed to improve functionalities and efficiency of memory units. In this context, current-induced spin-orbit torques (SOT) provide interesting solutions to manipulate the magnetization of thin films and nanostructures allowing time and energy efficient, fully electrical write and read out scheme in permanent nanomagnets. Recently, magnetization switching of a single ferromagnetic layer induced by in-plane current injection has been demonstrated in several oxide based heterostructures (e.g. Pt/Co/AlOx, Pt/Co/MgO, Ta/CoFeB/MgO) possessing strong spin-orbit coupling and perpendicular magnetic anisotropy[1-3]. Switching was found to occur due to an effective torque perpendicular to both the current and instantaneous magnetization directions, equivalently to an effective field that rotates with the magnetization.

To shed light on the origin of this torque, we will present a detailed study of the current-induced SOTs and the magnetization switching behavior (with ultrashort current pulses) in perpendicularly magnetized Ta/CoFeB/MgO layers as a function of the annealing temperature. With refined vectorial measurements in the low current regime we will demonstrate that, on a *single* sample, the magnitude of the SOTs strongly depends on the annealing temperature. We will also show that the perpendicular magnetic anisotropy dramatically changes with annealing temperature which consequently has an influence on the switching behavior of the system. Finally, using transmission electron microscope images and x-ray magnetic circular dichroism data, we will comment on the physical and chemical changes occured in the layers by annealing, which might lead to the observed dependencies. We believe that this work will provide useful information for the fundamental understanding of SOTs and optimize their magnitude for technology applications.

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SYMPOSIUM 6.3

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HIGH DENSITY TAPE RECORDING: A MICROMAGNETIC STUDY

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INTRODUCTION

Tape Technology has continued to advance in past few years by introducing new media materials based on Barium Ferrite and increasing the areal storage density and it is expected to retain a very significant share of worldwide stored data. Main advantages include low acquisition and low operational costs, a high data reliability and longevity of the stored data. The classical application for backup and recovery tasks has extended to long term archiving tasks. The importance of tape in cloud storage environment to reduce the storage provider costs is significant.

MICROMAGNETIC MODELING

We have studied the influence of various head field designs (Fig.1a) on the recording behaviour of $BaFe_{12}O_{19}$ (M_s=275emu/cc, K_1=1.3-1.9x10^6erg/cc) nanoplatelets with a diameter ~15 nm and height ~5 nm as candidates for high density recording with an areal density up to 30 Gb/inch^2[1] using an integrated numerical finite element micromagnetic simulation together with the nudged elastic band method for thermal stability calculation. The microstructural media models were prepared by an implementation of the Lubachevsky-Stillinger packing algorithm [2] and the bullet physics library [3]. The track model of the magnetic storage layer consists of about 10000 nanoparticles and has a length of 10000nm, a width of 200nm and a thickness of 30-60nm (Fig.1b). In detail we analysed the signal to noise ratio of the read back signal as a function of the head to media distance (d=20-80nm), head speed and coil current (Fig. 1c) of the ring type write head up to a linear density of 508 kfci (linear bit length 50nm). The bit write simulations on the particulate media models were performed by overlapping the write head field boxes on the finite element media models. Magnetization dynamics of the particles under the head field is calculated using the Landau-Lifshitz-Gilbert equation.

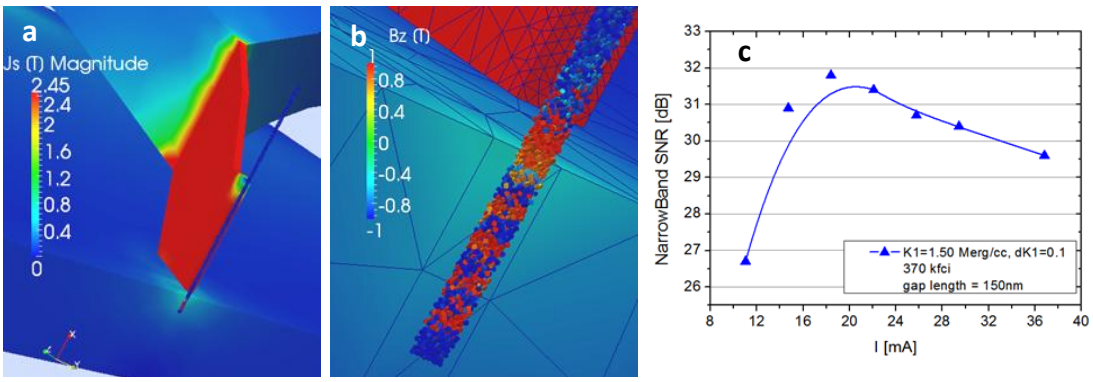

Figure 1: (a) Finite element simulation of ring type head with saturated top yoke at I=20mA.
(b) Written bit structure at 370kfci.
(c) Dependence of signal to noise ratio of the read back signal on the coil current I.

The support of the INSIC TAPE Program is acknowledged.

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LINEAR MAGENTORESISTANCE OF ELECTRODEPOSITED InSb FOR HIGH MAGNETIC FIELD SENSORS

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Classical geometric magnetoresistance (MR) effects in disordered and inhomogeneous materials, and associated mobility fluctuations can lead to high, non-saturating, linear magnetoresistance values [1]. Polycrystalline narrow bandgap semiconductors (like InSb) with doped grain boundaries leading to strong variation of the mobility distribution, can show a high MR, which is linear and not saturating at fields of up to megagauss values [2]. Normally grown from powder mixtures or ground single crystals, we investigate an alternative processing route of wet processed electrodeposited polycrystalline InSb thin films [3]. Electrodeposition allows for quicker and cheaper processing, in addition to adaption, investigation and optimization for different homogeneity regimes. Varying growing conditions, such as: substrate preparation, solution concentration, electrodeposition and annealing conditions, resulted in a wide range of film compositions and microstructures. We characterized the films via scanning electron microscopy and X-ray diffraction to reveal the effects of the different parameters and determine their influence on microstructure and magneto resistance values. We processed InSb thin films which showed a linear MR behavior at high magnetic fields of up to 9T, as shown in Fig 1.

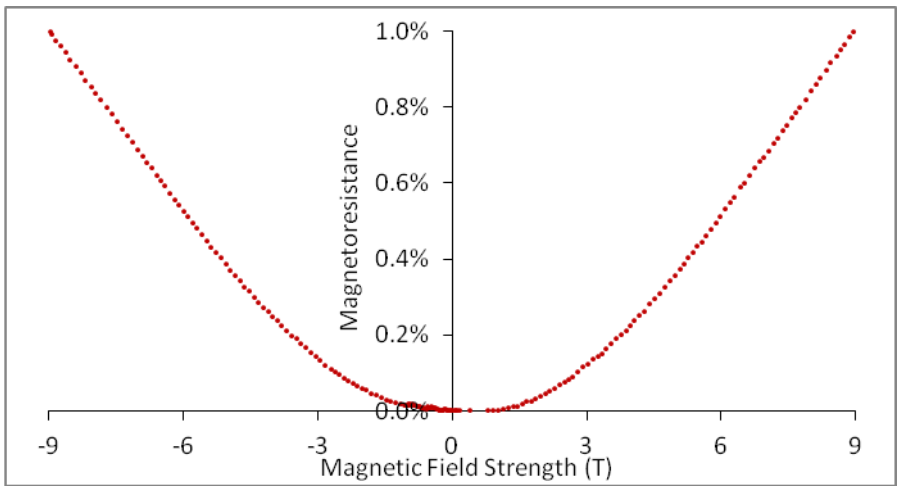

Fig 1 Magnetoresistance measurement of a wet processed electrodeposited InSb film

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$Bi_3Fe_5O_{12}$ ELECTRONIC STRUCTURE AND INDIVIDUAL SUBLATTICE PROPERTIES PROBED BY MAGNETO-OPTICAL SPECTROSCOPY

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Bismuth iron garnet ($Bi_3Fe_5O_{12}$ or BIG) is a novel material with exceptional magneto-optical (MO) properties (ex. giant rotation of the incident light polarization). This compound cannot be synthesized in bulk form as the preparation requires non-equilibrium techniques of growth. BIG is ferrimagnetic with two magnetic sublattices (tetrahedral and octahedral) defined by different oxygen environment of magnetic iron atoms.

In this work, we show that magneto-optical Faraday spectroscopy can be used, on one hand, to study spin-dependent electronic density of states in complex ferrimagnetic BIG near and above the Fermi level. Our work is concordant with independent density of states calculation [1].

On the other hand, we determine the individual magnetic behavior of each iron sublattice as a function of the temperature. We analyze the magneto-optical spectra of BIG in the framework of the model based on two diamagnetic lines associated to tetrahedral and octahedral iron sites [2], successfully reproduce the experimental spectra and extract the individual sublattice contributions from the total MO signal. We show that the different observed MO phenomena are related to the sign of the magneto-optical contribution and the different temperature dependence of the magnetization of each sublattice.

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PERFORMANCE OF THIN FILM GMI MICROSENSORS BASED ON NANOSTRUCTURED MAGNETIC MULTILAYERS

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INTRODUCTION

The Giant Magneto-Impedance (GMI) effect is interesting for weak magnetic fields detection. Thin films are preferred over wires and ribbons for compatibility with the fabrication processes of microdevices. After an intense research to optimize the properties of the materials and to develop an optimum multilayered and sandwiched structure [1], we present here the GMI performance of the microsensor elements fabricated by photolithography.

EXPERIMENTAL

Micro-shaped GMI elements have been prepared by sputtering with a multilayered and sandwiched structure, and patterned by lift-off in the form of stripes with different lengths (0.5 to 2.0 mm) and widths (70-130 μm). A second photolithography process defines contacts at the ends of the samples so they can be inserted in a microstrip line. Impedance is measured as a function of the applied field (up to 150 Oe) and the frequency (up to 150 MHz) using a network analyzer.

RESULTS AND DISCUSION

A maximum value of 150 % for the magnitude of the GMI and 60 %/Oe of the sensitivity to the applied field has been found for the sample 110 μm thick and 1 mm long. Both figures of merit strongly depend on the aspect ratio of the sample through the magnitude of the effective anisotropy [2], the quality of the patterning, and the distribution of current in the sample. A detailed discussion of the influence of these parameters on the results will be presented. The evaluation of the performance of the microsensors is completed with noise analysis.

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ELECTROMAGNETIC PROPERTIES OF Ni DOPED $BaSrCo_2$−Y HEXAFERRITES

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INTRODUCTION

With a view to high frequency applications of magnetic ceramics, we have investigated the Y-type hexaferrites with composition $BaSrCo_{2-x}Ni_xFe_{12}O_{22}$ (x=0, 0.5, 1.0, 1.5, 2.0). These materials were prepared with the conventional ceramic method, including successive milling and double-sintering process at 1250°C for 12h. The fabrication of single phase samples was verified by means of XRD analysis, whereas the microstructural observation through SEM indicated the decrease of average grain size with Ni concentration.

The recorded M-H loops show the progressive decrease of saturation magnetization M_S from 33 emu/gr to 21 emu/gr and of coercive field H_C from 74 Oe to 31 Oe, with the substitution of Co by Ni.

Moreover, the constitutive electromagnetic parameters were measured up to 20 GHz. Specifically, the complex permeability spectra demonstrate that Ni doping shifts the characteristic frequency of domain wall relaxation from 3 GHz to 900 MHz and of the spin rotation resonance from 18 GHz to 8 GHz. Additionally, the wall contribution is increased with Ni content as magnetocrystalline anisotropy is raising, despite the reduced grain size.

Finally, the potential of $BaSrCo_{2-x}Ni_xFe_{12}O_{22}$ hexaferrites as planar microwave absorbers emerges. In fact, by using single-layer configuration we achieve reflection losses above 20 dB, tuned at any frequency between 3-20 GHz with a maximum thickness of 5mm.

NATURAL DOMAIN WALL OSCILLATOR

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We present a novel domain wall (DW) oscillator that consists of a pair of cylindrical nanowires. Our oscillator makes use of the natural DW oscillations in cylindrical nanowires to reduce the operational applied current as compared to other conventional DW oscillators. The nanowires are of 10 nm diameter and are separated by 10 nm. A transverse DW is generated in each of the nanowire, as shown in Fig. 1 (a). In the absence of external magnetic field or current, the two DWs are driven away from each other due to the magnetostatic coupling. The motion is accompanied by a rotation along the cylindrical axis. The DW rotations are self-sustained because of zero intrinsic pinning [1] from the cylindrical nanowires. To maintain the positions of the DWs, spin-polarized current is applied to both nanowires in opposite direction. When the applied current density is in the order of 10^4 A/cm^2, the spin transfer torque and the magnetostatic coupling are balanced. In this range of current density, the two DWs oscillate with a fixed frequency around the centre of the nanowires. The frequency of the DW oscillations is found to be in the range of 150 MHz.

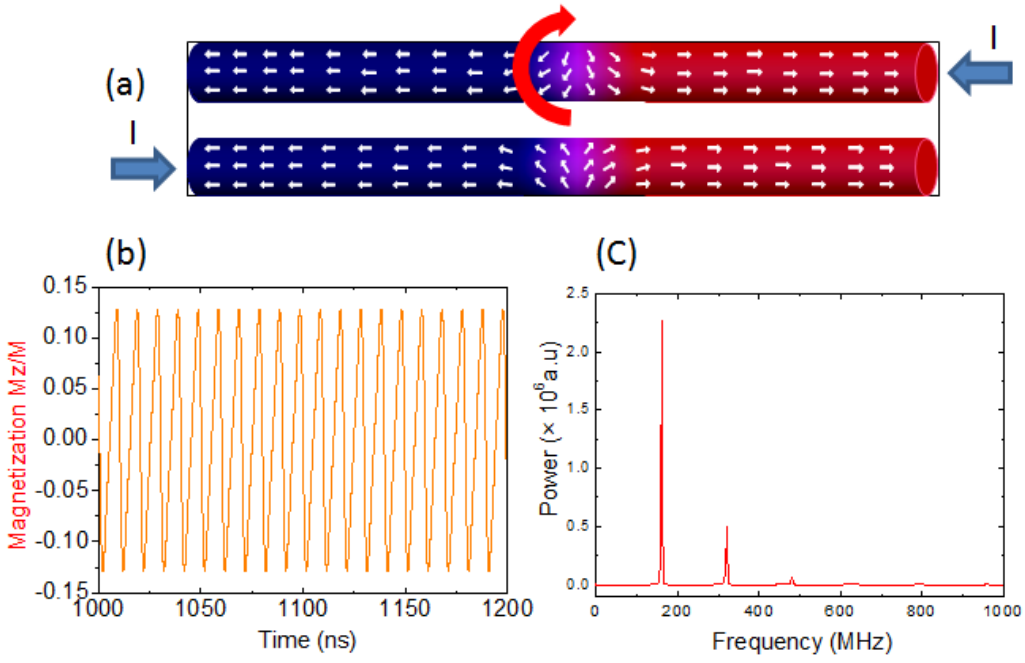

Figure 1: (a) The model employed in the micromagnetic simulations (b) DW rotations due to the magnetostatic coupling (c) FFT spectra of the DW rotations

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ESTIMATION OF PERMEABILITY TENSOR AND DIELECTRIC PERMITTIVITY OF FERRITES USING A WAVE GUIDE METHOD UNDER A DC MAGNETIC FIELD

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The increasing need for novel, small and reconfigurable microwave patch capable to cover the modern design trends, requires materials with novel physical properties. Based on this demand, materials with tensor type electric permittivity and magnetic permeability could offer new design degrees of freedom. In magnetically polarized ferrites with an external dc magnetic field, the magnetic permeability becomes a tensor physical quantity with resonance dispersion behavior. This is a consequence of the ferromagnetic resonance phenomenon. The non- diagonal element of the permeability tensor produce new interesting non reciprocal phenomena. In order, the design task of the patch antennas where the substrate is partially replaced by ferrites, to be optimized, the knowledge of the dielectric permittivity and the parameters which influence the magnetic permeability tensor is necessary. On this context we present our effort to estimate the electric permittivity and permeability tensor parameters under a dc magnetic field, using a wave guide method using garnets and spinels ferrites as samples.

SYMPOSIUM 4.4

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RECENT UNDERSTANDINGS OF GRAIN BOUNDARY MAGNETISM IN ND-FE-B PERMANENT MAGNETS AND THEIR IMPLICATIONS

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INTRODUCTION

$Nd_2Fe_{14}B$ is still the material of choice for the powerful permanent magnets to be used in markedly expanding clean energy technologies such as hybrid vehicles and power generators that require huge amounts of the best-quality, hich-coercivity, grades because Fe is a far abundant ferromagnetic element than any other magnetic-moment-carrying elements and Nd is the most abundant element carrying the 4f magnetism with which a large magneto crystalline anisotropy is readily accessible in non-cubic environments. However, a serious concern about criticality of Dy, which is used to realize the high coercivity, has been addressed and development of Nd-Fe-B magnets free of Dy has become one of urgent issues, recently. Since shortly after the invention of the materials, the majority of the Nd-Fe-B permanent magnets are produced by means of powder metallurgical process [1] and a small portion of the market has also been covered by hot-deformation process using rapidly solidified alloys [2]. These are anisotropic magnets which are composed of oriented fine $Nd_2Fe_{14}B$-type grains. The coercivity develops in these materials when $Nd_2Fe_{14}B$ grains are surrounded by a thin Nd-rich film phase [3- 5]. However, after about 30 years of investigation, it is only recent that the basic belief concerning magnetism of the Nd-rich grain boundaries is seriously reexamined. Namely, the Nd-rich intergranular thin layers between adjacent $Nd_2Fe_{14}B$ grains, which have been believed to be paramagnetic, effectively cutting off exchange-coupling among the grains, are now strongly suspected to be ferromagnetic [5, 6]. If the intergranular thin layers are ferromagnetic, the traditional understanding of the coercivity mechanism in Nd-Fe-B should be reconsidered and, more importantly, a possibility of further improving the intrinsic coercivity in the anisotropic Nd-Fe-B permanent magnets arises for the realization of materials free from the critical element, Dy (and in some cases, Tb). The purpose of this presentation is to give a brief overview on the recent characterization of grain boundary magnetism in the Nd-Fe-B permanent magnets and present a future outlook for development of critical-elements-free permanent magnets for the large-scale applications, which are conducted in the Elements Strategy Initiative Center for Magnetic Materials (ESICMM) [7], a new research center established in 2012 for this purpose in NIMS under the Element Strategy Initiative by Ministry of Education, Culture, Sports, Science, and Technology in Japan.

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Examples of European projects relating to permanent magnets with reduced quantities of, or zero, rare earths.

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Permanent magnets are vital components in an enormous number of domestic and industrial devices, and they are particularly crucial within the rapidly-developing renewable energy sector, where the motors for electric vehicles and the generators in wind turbines require strong magnets with the ability to operate at temperatures well over 100°C. Currently, these magnets are predominantly based on the rare-earth elements neodymium and dysprosium, which are mainly mined in China (>95%). Exports are being restricting as a result of an expanding domestic market and a policy of relocating magnet manufacturing to China, thereby multiplying the costs of raw materials for magnet manufacturers in Europe. The rare-earth crisis is particularly critical for heavy rare earths such as dysprosium that are currently required to assure the high-temperature performance of the magnets. In July 2010, the European Commission's Ad-hoc Working Group on defining critical raw materials identified 41 materials, of which 14 are "critical", based on their high relative economic importance and the high relative supply risk. Of these 14 materials, the rare earths are clearly the most problematic in terms of supply risk. Over the last few years the European Union has begun to fund research into the replacement of some or all of the rare earths in permanent magnets. In this talk we look at some examples of projects that are currently being funded or will start later in 2013.

The rare earth magnet industry and rare earth price in China

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Abstract
In the past four years, The price of rare earth metal fluctuate sharply for many reasons . Currently, It become more stabile and more reasonable. This presentation is focused on the effect about the rare earth metal price . Some motor manufacturer shift from rare earth permanent magnet to ferrite magnet. Many motor manufacturer change the design about the motor cooling system to make the motor working at a lower temperature . Thus the consume about Dy can be markedly reduced. As for manufacturer of NdFeB magnet, we are also try to optimize our process to reduce to dependence about HREE such as Dy and Tb. HS process have been introduced to solve the problem. With more and more people are focusing and engaging on REE industry, The price of REE will be more transparent without too much fluctuate. Considering about the problem in China about environment , energy sources and labor sources. The application field about NdFeB such as wind turbine generator, HEV/EV , FA /OA still can be flourishing.

SYMPOSIUM 3.3

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WHICH HEUSLER ALLOYS DISTORT?

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Modern technology has an insatiable appetite for hard magnets, which at present is satisfied by rare-earth-based compounds. Although rare-earth elements are not particularly “rare”, with abundance similar to lead, due to political/economical reasons there is a limited availability on the market making the price volatile. We therefore need to consider other alternatives and the Heusler alloys family is one of the strongest contenders.

The full Heusler structure consists of four interlaced FCC lattices. This cubic symmetry is not favourable to hard magnets, due to the high symmetry leading to poor anisotropy. However several Heuslers have been reported to undergo a tetragonal distortion, breaking the symmetry making these materials much more promising for the development of new hard magnets and materials for spin torque application. However the mechanism behind the distortion is still unknown.

In this work we use density functional theory to investigate the Rh_2YSn class of materials, where Y spans all the 3d and 4d transition metals. We show that the distortion in this class is driven by the density of states at the Fermi-level, which comes largely from the Y element. Strong hybridization between Y and Rh orbitals results in a Jahn-Teller distortion from the Jahn-Teller active Rh site. By applying our understanding of this “indirect Jahn-Teller” mechanism we are able to predict which other Heuslers will distort.

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MODELLING OF PACKED Co NANOROD STRUCTURES FOR HARD MAGNETIC APPLICATIONS

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INTRODUCTION

High magnetocrystalline and shape anisotropy are preconditions for achieving hard magnetic properties. We have studied the influences of size and shape of densely packed structures and introduced a method to generate realistic structures consisting of cylindrical Co nanorods. The hysteresis properties of these structures have been calculated by finite element micromagnetic simulations.

METHODS AND RESULTS

For the generation of packed structures, we developed a numerical algorithm, which is based on the bullet physics library [1]. We obtain packing densities between 37% and 41% for stiff cylinders with an aspect ratio of 1:7 using realistic alignment forces. Structures with different standard deviation σ_ϕ from the external alignment field can be generated by a tunable torque (Fig. 1a).

The hysteresis properties of Co structures have been calculated with three different methods (Fig. 1b). That makes it possible to differentiate between magnetocrystalline and shape anisotropy contributions. As a result, the loss due to incoherent reversal is 27% and the gain due to shape anisotropy is 59%. Depending on σ_ϕ (10.0° - 57.3°), our simulations yield coercivities $\mu_0 H_c$ between 0.53T and 0.61T. The calculated hysteresis properties are in good agreement with experimental values.

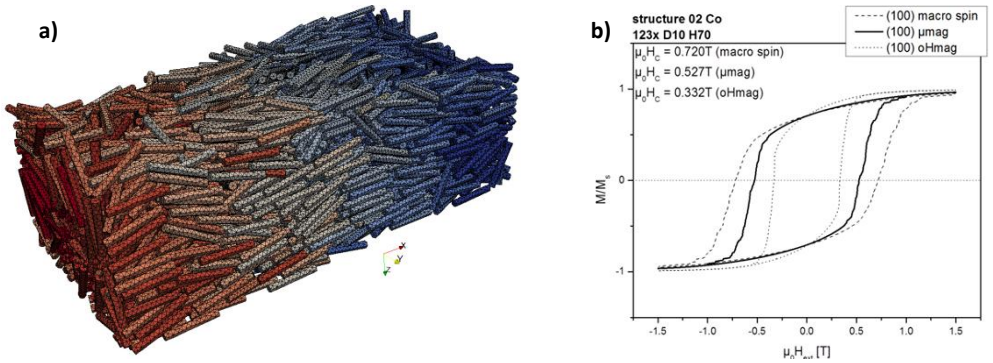

Figure 1: a) Finite element model of a Co structure with 3200 nanorods. b) Calculated hysteresis properties according to the three simulation methods: Full micromagnetics (*μmag)* give the most accurate results, *macro spin* assumes coherent reversal and *oHmag* takes only crystal anisotropy into account.

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TEMPERATURE DEPENDENT PHASE TRANSFORMATIONS AND MAGNETIC BEHAVIOR OF FePt-BASED NANOCOMPOSITE MAGNETS

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Ternary and quaternary FePt-based melt spun alloys show good permanent magnet properties [1,2]. The key for such good magnetic properties lies in the structural phase transformation that occurs in the binary system. FePt undergoes a disorder-order structural phase transformation from a fcc A1 disordered phase that is soft magnetic to a highly anisotropic, ordered, tetragonal $L1_0$ phase that is hard magnetic. The purpose of this work is to study and monitor in-situ the disorder-order structural transformation, to show the co-existence of hard and soft magnetic phases, and to determine the magnetic properties of the nanocomposite magnet after the transformation has occurred. The role of Ag as a partly substitute for Fe in FePtB has been proven to be beneficial for direct formation of the tetragonal $L1_0$ FePt phase in such alloys [2]. Nevertheless, the effects of such addition are still to be studied during the phase transformation. For that purpose, structural phase transformation of as-cast FePtAgB alloys with various Ag contents (3 – 12 at%) has been monitored using temperature-dependent dynamic X-ray diffraction of synchrotron radiation at the Swiss Light Source. The evolution with temperature of the relative proportion of the tetragonal and cubic FePt phases is monitored in situ. The dynamic of the transformation is highly dependent on the Ag content. M(T) studies evidence the different T_C's of the two FePt phases and it is shown that there is an optimum of Ag content for which the hard-soft exchance coupling is maximized.

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ELECTRONIC STRUCTURE CALCULATIONS OF MATERIALS WITH INCREASED MAGNETIC ANISOTROPY ENERGY

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INTRODUCTION

Materials with a large saturation magnetization, as well as large magnetic anisotropy energy (MAE), are required to produce permanent magnets which are important in a wide range of applications. This makes finding new such materials, made from readily available elements rather than, for example, rare earths commonly used today, a task of significant importance. Certain materials, such as FeCo based alloys, with relatively large saturation magnetization, are known to also exhibit large MAE at particular crystal distortions and alloy concentrations [1], potentially making them suitable for the purpose if a method of breaking the cubic symmetry is found.

Here, DFT calculations are used to study MAEs and magnetizations in a variety of materials. Addition of carbon to FeCo is suggested as a way to change the cubic structure into a tetragonal and the affect on MAE is studied. Additional candidates, for which results are discussed, include chemically ordered FeNi and tetragonal Heusler compounds.

RESULTS

Results indicate that compounds of the form $(Fe_{1-x}Co_x)_yC$ with carbon atoms in interstitial positions, causing tetragonal distortion, can reach MAE in order of 119 μeV/atom = 1.7 MJ/m^3 in the case of $(Fe_{0.35}Co_{0.65})_{16}C$.

ACKNOWLEDGEMENTS

This work was supported by ERC project REFREEPERMAG and Swedish Research Council.

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HYSTERESIS MODELING OF ISOTROPIC AND ANISOTROPIC NdFeB MAGNETS

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INTRODUCTION

The coercivity of $Nd_2Fe_{14}B$ magnets is determined by several microstructural factors, as for example crystallographical texture and grain size. It has been found that that the Stoner-Wohlfarth model, which assumes coherent rotation, provides a basis for the hysteresis description in $Nd_2Fe_{14}B$ magnets.

In this study, it is evaluated how the hysteresis curves of $Nd_2Fe_{14}B$ magnets are affected by the texture. In the case of nanocrystalline magnets with soft iron (Fe alpha), effects of exchange coupling on the hysteresis can be evaluated using the CLC (Callen-Liu-Cullen) model [1].

In the case of of NdFeB sintered magnets with grain size of the order of micrometers, the nucleation model [2] points out that reversal of magnetization occurs near to the surface of the grains, due to coherent rotation. The coercive field decreases according to a $D^{-0.5}$ law, where D is the grain size [3], according to a model that takes into account the magnetostatic energy of the system.

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$N_2Fe_{14}B$ PARTICLES PRODUCED BY PLANETARY BALL MILLING OF HDDR POWDERS

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Recent improvements in the fabrication of magnetic nanoparticles open the way to the development of the next generation nanocomposite magnets using the bottom-up approach. However, rare earth materials are highly sensitive to oxygen and that brings challenges to both the fabrication and stability of the nanocomposites. The objective of this study is to prepare $Nd_2Fe_{14}B$ nanoparticles by planetary ball milling, from an HDDR magnet precursor and find the optimum milling conditions in order to obtain particles with submicron size and with magnetic properties comparable to those of the $Nd_2Fe_{14}B$ bulk material.

The precursor HDDR powder consists of grains with a diameter around 200-300 nm. The powder is milled in hexane with BPR 40:1 at different speeds and time periods using a Fritsch planetary mill. Small particles are separated from the slurry using fast sedimentation of the same solution that the particles are milled. For this purpose bigger particles were let to sediment for 30 seconds after 4 minutes of sonication, and smaller particles were collected from the top solution. Characterization of the particles shows that particles collected at lower milling speeds (100 rpm) have an average diameter of 300 nm, coercivity of 5.7 kOe and M_r/M_s=0.95. Increasing the milling speed (300 rpm) resulted in particle agglomerates with H_c=5.2 nm and M_r/M_s=0.60. Additionally our study has shown that longer milling time leads to a substantial decrease of coercivity.

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THE ROLE OF OXYGEN ON THE RECYCLABILITY OF SINTERED NDFEB MAGNETS USING HYDROGEN

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The Magnetic Materials Group (MMG) at the University of Birmingham have demonstrated previously that it is possible to use hydrogen to extract sintered NdFeB magnets from electronic waste [1] and to re-use the extracted alloy powders to form both sintered and resin bonded magnets [2,3,4]. One of the challenges in using scrap NdFeB magnets is that this material will contain a significantly higher oxygen concentration when compared to that of a primary cast NdFeB alloy. This presents challenges both in terms of the activation of the scrap material to hydrogen and in terms of the properties achieved by the re-processed magnets. In this paper, a novel, low energy milling route is presented which was used to process hydrogen embrittled sintered NdFeB magnets inside an argon glovebox in order to minimise the oxygen pick-up. The milled materials were then aligned, pressed isostatically and transferred inertly to a vacuum sintering furnace where they were sintered at >1000^{o}C for 1 hour. At each stage, the oxygen content of the re-processed magnets was monitored in the starting magnets, milled powders, green compacts and final sintered magnets. It was evident that the overall oxygen content increased by ~1100-1200 ppm in the final re-sintered magnets but the milling step only introduced around 290 ppm of oxygen. This is much lower than a typical value expected from the jet milling process of a hydrogenated cast alloy. Despite this modest rise in oxygen content during re-processing it was still necessary to powder blend additional NdH_2 with the hydrogenated NdFeB alloy powders in order to achieve full density and hence appreciable magnetic properties. It was also evident that, if the hydrogenated alloy powders were exposed to air for >2 hours, then this had a dramatically adverse effect on the magnetic properties of the recycled magnets.

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WEDNESDAY MORNING

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MAGNETIC PARTICLE IMAGING FOR CARDIOVASCULAR ANGIOGRAPHY AND MOLECULAR IMAGING

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The performance -- sensitivity and spatial resolution -- of Magnetic Particle Imaging (MPI), a new medical imaging technology for whole-body imaging of magnetic tracers, depends largely on the structural, chemical & magnetic characteristics of the tracers, in addition to instrumentation parameters. Magnetic Particle Imaging (MPI) shows promise for medical imaging, particularly in vascular angiography of patients with chronic kidney disease. As the first biomedical imaging technique that truly depends on magnetic relaxation dynamics of nanoscale materials, MPI requires highly optimized and biocompatible magnetite nanoparticle tracers to generate good-quality images. Here, we describe the development of the most optimal tracers for MPI with magnetic properties that were designed using a sound theoretical framework, an organic synthetic route leading to highly phase-pure and monodisperse magnetite nanocrystals, subsequent phase-transfer and functionalization for biocompatibility and adequate *in vivo* circulation. In phantom MPI imaging, with image reconstruction in either real or Fourier space, these optimized tracers showed significant improvement, compared to existing tracers, in both normalized signal intensity and spatial resolution, the latter approaching sub-mm resolution critical for translational applications of angiography and molecular imaging of cancer. If time permits, experimental measurements of biodistribution and cytotoxicity using a mouse model, critical for any *in vivo* application, will also be presented.

This work was supported by NIH grants 1R01EB013689-01/NIBIB &1R41EB013520-01

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NANOMAGNETISM IN THE LIVING ENVIRONMENT: BIOTRANSFORMATION OF MAGNETIC NANOPARTICLES AND IMPACT FOR IMAGING AND THERAPEUTIC APPLICATIONS

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Interactions of magnetic nanoparticles with the biological environment determine both their biomedical promises and their safety profile. The bio-nano-interface is where nanoparticles engineered by chemists meet biological components such as blood proteins [1], cells [2] and interstitial tissue which determine their biological fate. In turn, the biological activity impacts the chemical and physical properties of nanoparticles, changing to some extent their physical response until complete degradation [3]. The purpose of this lecture is to outline the different aspects of bio-nano-interactions and examine the consequences that may concern the applications of superparamagnetic iron oxide nanoparticles for magnetic resonance imaging [4] and therapeutic hyperthermia. We have developed nanometrology methods based on magnetism and high resolution electron microscopy to investigate the short and long term biotransformation of magnetic nanoparticles in the body [5]. Through different types of magnetic nanostructures (iron oxide nanocubes [6, 7], multicore cooperative nanoflowers [8]) with various surface coating, we will attempt to identify the critical factors which dictate nanoparticles efficacy for antitumoral hyperthermia and rule their biodistribution and degradation in the body. The ultimate goal is to be able to propose functional nanomaterials that are both safe y design and still efficient in the biological environment.

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Antiferromagnetic spintronics

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To date spintronics research and applications of magnetically ordered systems have focused on ferromagnets (FMs). There are, however, physical limitations for FM materials to realize the full potential of spintronics. We present a concept in which these limitations are circumvented in spintronics based on antiferromagnets (AFMs). The concept is based on relativistic magnetic and magneto-transport anisotropy effects in whose common characteristics is that they are an even function of the microscopic magnetic moment vector, i.e., can be equally strong in AFMs as in FMs. As a demonstration we present our experimental observation of >100% tunneling anisotropic magnetoresistance in a device with an IrMn AFM tunnel electrode, of an ohmic anisotropic magnetoresistance in an AFM semiconductor Sr_2IrO_4, and the realization of an electrically readable AFM memory which is insensitive to magnetic field perturbations and produces no magnetic stray fields [1,2].

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SYMPOSIUM 5.4

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MAGNETIZATION REVERSAL IN SELF-ORGANIZED EPITAXIAL MAGNETIC NANODOTS

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The understanding and control of the magnetic anisotropy and the magnetization reversal at the nanometre scale is a major challenge to tailor new magnetic recording devices. In this framework, the study of magnetic properties of self-organized systems appears to be promising as the size distribution is narrower and therefore the results obtained by averaging over a large assembly of particles are less complex to analyse [1].

In this talk, I will review our recent works on the understanding of magnetization reversal of nanometre size magnets obtained by self-organized epitaxial growth on the Au(111) surface. After an introduction to the macrospin model and its range of application [2], I will focus on the study of model nanostructures consisting of a 3d magnetic and a 5d non-magnetic element. For immiscible elements that easily realize core-shell epitaxial nanostructures, we have shown that the magnetic anisotropy in the magnetic core can be drastically modified by magneto-elastic effects induced by the non-magnetic shell [3]. For miscible elements like Co and Pt, depending on the growth procedure, we have realized either mixed or core-shell nanoparticles. The structural parameters have been determined by Extended X-ray Absorption Fine Structure and the magnetic properties by X-ray Magnetic Circular Dichroism and Magneto-Optic Kerr Effect [4]. In this system, we have shown that hybridization effects are dominant to understand the trend in the out-of-plane magnetic anisotropy, i.e. a strong decrease in mixed particles and an increase in core-shell particles [5]. A phenomenological pair model for magnetic anisotropy is able to reproduce qualitatively these results.

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MIXING ANTIFERROMAGNETS TO TUNE NiFE-(IRMN/FEMN) INTERFACES AND RELATED TA-MRAM EXCHANGE BIAS DISPERSIONS

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INTRODUCTION

Industrial qualification for magnetic devices like TA-MRAM [1] imposes stringent requirements on the cell to cell distributions of exchange bias properties. Randomly spread spin-glass-like phases at ferromagnetic/antiferromagnetic sheet films interfaces have been identified as a possible cause of such distributions in nanofabricated devices [2]. It is therefore crucial to master the amount of interfacial spin-glass-like phases.

METHODS

In this study, NiFe/(IrMn/FeMn) based TA-MRAMs were fabricated. Alloying is supposed for our various multirepetitions of thin IrMn and FeMn antiferromagnets. The sheet films interfacial qualities were recorded via measurements of the low-temperature contributions to the blocking-temperature distributions: the smaller the contribution, the less glassy the interface [2].

RESULTS AND DISCUSSION

A gradual reduction of the low-temperature contribution to the blocking-temperature distribution was observed when evolving from IrMn- to FeMn-like alloys. A subsequent increase of the room temperature loop shift was observed. Such beneficial adjustment was attributed to interfacial improvement due to lower amount of Mn. These results were correlated to the cell to cell exchange bias properties dispersions of the corresponding nanofabricated devices.

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FOCUSED KERR MEASUREMENTS ON PATTERNED ARRAYS OF EXCHANGE BIASED SQUARE DOTS

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Exchange anisotropy due to interfacial coupling between a ferromagnet and an antiferromagnet is extensively studied and exploited in technological applications particularly for MRAMs. When the device size is strongly reduced such that it corresponds to only few grains, one can expect a dot to dot distribution of the exchange bias field.

In this study we have investigated finite size effects on exchange bias in arrays of Cu/IrMn/Co square dots (lateral size from 200 to 50nm). Series of samples with increasing IrMn thickness and Cu buffer layer thickness were considered to tune the grain size distributions [1.2], which were characterized by Atomic Force Microscope. Focalized Kerr measurements allowed measuring the hysteresis loops of a few dots on different locations in the patterned and continuous samples.

The statistical results show that the grain size distribution does not influence the bias field distribution. Moreover, the dot size has no influence on the exchange bias properties. By comparing these samples with equivalent patterned unbiased Co dots, we conclude that the exchange bias field distribution is dominated by the ferromagnetic layer properties.

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EFFECT OF GRAIN CUTTING IN EXCHANGE BIASED NANOSTRUCTURES

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INTRODUCTION

Exchange bias occurs in a magnetic system when a Ferromagnetic (F) and Antiferromagnetic (AF) layer are in contact. It manifests itself as a shift in the hysteresis loop (H_{ex}) and an increase in the coercivity (H_c) [1]. The development of magnetic random access memories (MRAM) has led to a renewed interest in the behavior of exchange bias in nanostructures.

In this work we present experimental results fitted against a modification of the York model of exchange bias [2] which assumes grain cutting at the edges of nanostructures [3]. The AF is modeled as an amalgam of randomly orientated, non-interacting grains the distribution of which is lognormal. Each AF grain is single domain with energy barrier [2],

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By assuming a uniform K_{AF}

The change in H_{ex} and with nanostructure size was calculated and compared to experiment as shown in Fig. 1.

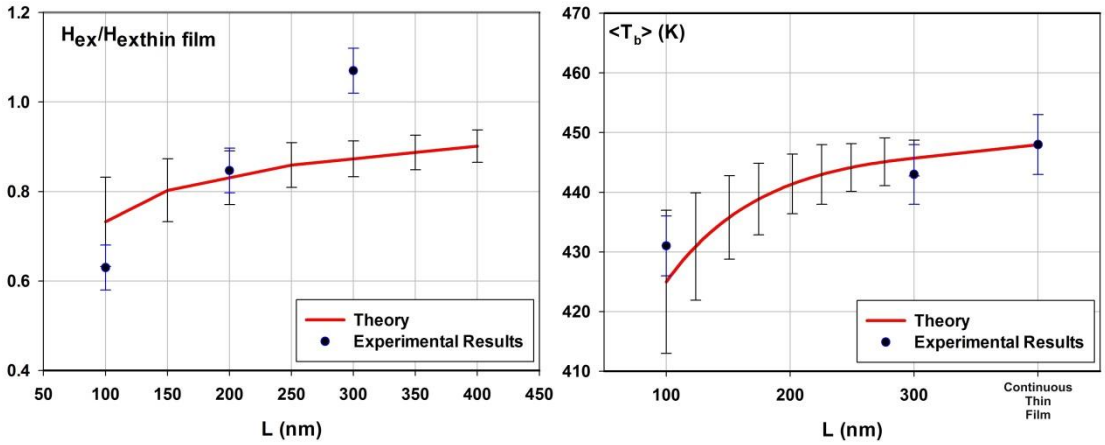

Fig 1. a) Variation in H_{ex} and b) median blocking temperature with structure size normalised to the thin film case.

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ANISOTROPY DEPENDENCE OF MAGNETIC COUPLING IN HARD/SOFT CO/PY BILAYER ANTIDOT ARRAYS

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The magnetic behavior of ordered arrays of Co/Py bilayer antidot thin films has been investigated and compared to the counterpart continuous thin films. This semi-hard/soft bi-magnetic system shows magnetic coupling that could be related with that observed in modern permanent magnets [1]. The study has been performed on bilayer systems with constant Co thickness of 28 nm and variable Py thickness up to 43 nm, while the antidot diameter ranged between 15 and 25 nm with constant antidot distance of 105 nm [2]. Magnetic characterization, performed by Vibrating Sample Magnetometer and Magneto-Optic Kerr effect, reveals the existence of a coupling between both layers whose strength is modified by the antidots presence and depends on the relative thickness of layers. For the samples with 10 nm and 43 nm of Py thickness, the hysteresis loop is one-phase but the hard magnetic role changes from the Co to the Py. This magnetic behavior is ultimately interpreted in terms of the modification of the effective magnetic anisotropy by the antidots. This assumption has been confirmed by means of hysteresis loops at low temperature.

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INTERFACE-MEDIATED EXCHANGE-BIAS IN FLUORESCENT ZnO-Fe@Fe_xO_y COLLOIDAL HYBRID NANOCRYSTALS

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The ability of colloidal chemistry to grow complex nanostructures led into hybrid nanocrystals (HNCs) made of domains of diverse physico-chemical nature, heteroepitaxially connected that are capable to carry multiple technological tasks. We report on a new HNC based on ZnO nanorods (NRs) decorated by Fe-based nanodomains. [1] When a large number of small Fe@Fe_xO_y nanodomains grow on ZnO, the interfacial communication across the Fe-core and Fe_xO_y-shell generates sizeable exchange-bias (H_{eb}) mediated by frozen interfacial spins (Figure 1a). This is suppressed in HNCs with lower density of larger Fe@Fe_xO_y domains, incorporating a void between the core and shell (Figure 1b). Due to synergetic action (stress) across the semiconductor-magnetic sections, a strongly blue-shifted near-band-edge (NBE-Figure 1c) UV emission raises the technological performance of such HNCs.

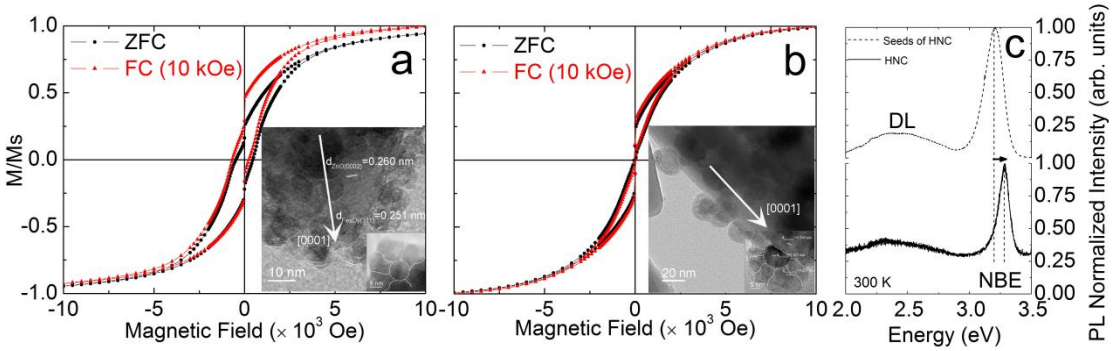

Figure 1. (a, b) Zero- (ZFC) and field- cooled (FC) magnetization for HNCs at 5 K. (c) Photoluminescence (PL) for HNCs (inset in (a)).

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$L1_0$ TETRAGONAL PHASE IN CONTINUOUS AND NANOPATTERNED FE-PD FILMS

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In the last decade, tetragonal intermetallic phases such as FePt, CoPt and FePd have been intensively studied as active ferromagnetic materials for high-density data storage due to their high magnetocrystalline anisotropy (107-108 erg/cm3). As an alternative, arrays of ordered nanostructures (holes and dots) with high magnetic anisotropy have been produced by conventional and self-assembling nanolithographic techniques. Polystyrene nanosphere (PN) lithography has been recently exploited for magnetic thin films nanostructuring on large scale. $Fe_{50}Pd_{50}$ thin films having thickness *t* ranging in the interval 20 – 100 nm have been deposited onto Si substrates by sputtering technique in an Ar atmosphere. As-prepared films consist of a $Fe_{50}Pd_{50}$ disordered solid solution, being deposited without heating the substrate. Patterned FePd films were obtained by assembling on the continuous thin films commercially available PNs into a monolayer (starting mean diameter in the interval 200 ÷ 800 nm). Subsequently, dot arrays were obtained by reducing the PNs diameter by Plasma Matrix and finally submitting the film to sputter etching with Ar+ ions (see Fig. 1 left panel; dots diameter ≈ 300 nm). Conversely, array of antidots in $Fe_{50}Pd_{50}$ have been obtained by exploiting an alternative lithographical method using polystyrene nanospheres as diffraction masks in combination with a mercury lamp. The order-disorder transformation towards the $L1_0$-ordered tetragonal phase has been induced by post deposition annealing in vacuum (600 °C for 1200 s). Sample morphology has been studied by means of SEM and AFM microscopy in all films. Room-temperature hysteresis loops have been measured by an Alternating Gradient Magnetometer in the parallel and perpendicular configuration confirming the presence of the tetragonal phase in all annealed samples (see Fig.1, right panel). MFM microscopy has been exploited to study the magnetic domain pattern (in the remanent state) revealing a complex multidomains structure in both dot and antidot arrays. The effect of patterning (i.e. dot/hole diameter and mutual distance) on the magnetic properties will be highlighted. The magnetic properties of annealed samples have been studied and correlated with film microstructure.

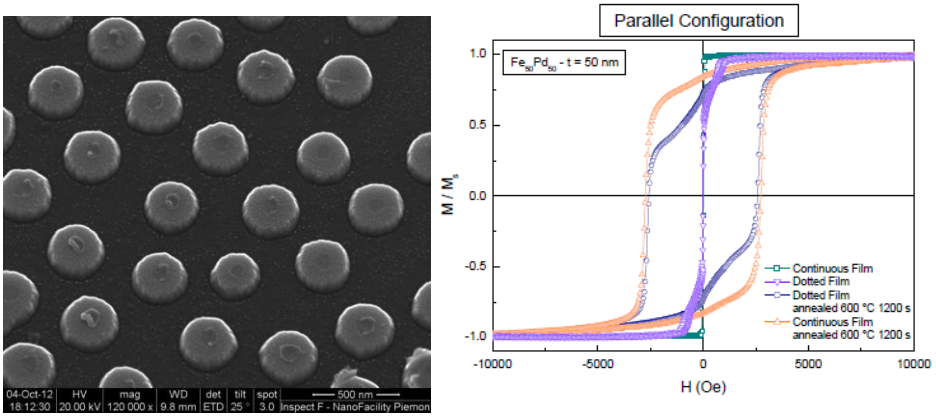

Fig. 1. Left panel: SEM image of dots with a diameter of ≈ 300 nm. Right panel: room-temperature hysteresis loops of as-prepared and annealed continuous and patterned films.

SYMPOSIUM 2.1

Electric field control of spin transfer torque in multiferroic tunnel junctions

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Keywords: *Spin transfer torque, Multiferroic tunnel junctions, Tunnel magnetoresistrance*

Based on model calculations we predict that the the spin transfer torque (STT) in magnetic tunnel junctions with ferroelectric barriers can be strongly influenced by the polarization of the barrier. The STT in such multiferroic tunnel junctions is calculated within the non-equilibrium Keldysh formalism generalized for non-collinear transport and implemented in the framework of a single-band tight-binding (TB) model. We calculate the bias dependence of both the in-plane (T_∥) and out-of-plane (T_⊥) components of STT as a function of the ferroelectric polarization (P) in the barrier. We find that the components of STT strongly depend on both the magnitude and the direction of the polarization. In particular switching of the polarization direction can dramatically alter the value of the STT, as illustrated in Fig. 1. This can even lead to a change of sign of T_∥ and the voltage-induced part of T_⊥. The effect is proportional to the magnitude of the polarization.

Moreover, polarization also influences the shape of the STT bias dependence. While for a simple insulating barrier T_∥ is fairly linear in the experimental bias range and T_⊥ quadratic, the asymmetric electrostatic potential introduced by the polarization causes T_∥ to acquire a quadratic component and T_⊥ linear (Fig. 1). This feature introduces an additional degree of freedom in the design of the shape of the STT to optimize the switching efficiency. The ability to change the STT magnitude and even sign during operation, by switching the polarization direction, may lead to novel device functionalities.

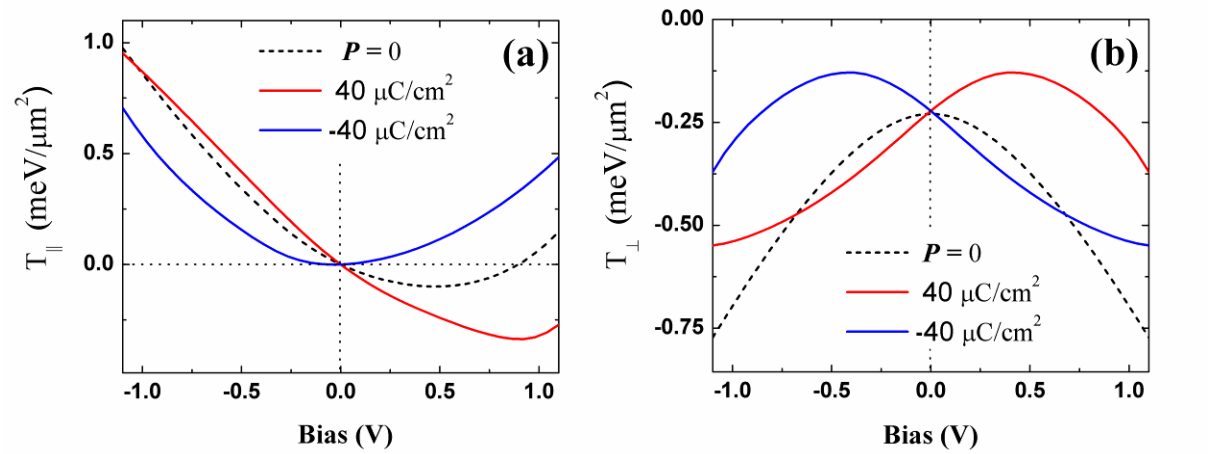

Fig.1. Bias dependence of (a) T_∥ and (b) T_⊥ components of STT for symmetric multiferroic tunnel junctions for a simple insulating barrier (dashed lines) and a ferroelectric barrier with P = ±40.0 μC/cm² (solid lines).

IDENTIFICATION AND MOTION OF DOMAIN WALLS IN CYLINDRICAL NANOWIRES

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INTRODUCTION

IBM proposed a concept for a three-dimensional (3D) data storage device, in which series of magnetic domain walls (DWs) act as tracks of bits moved along vertical nanowires. This stimulated an intense research activity on DWs in one-dimensional systems. While so far all physics and demonstrations concerned flat stripes made by lithography, cylindrical nanowires are more relevant for 3D designs. For these, simulations also predict dramatic differences in DW type and higher performance in motion [1]. Here we provide experimental results in such nanowires. We unlock the bottleneck of DW nucleation based on several top-down strategies: bent nanowires (FIG1) or nanowires with modulated diameter and demagnetized with a dc field applied across their axis. The two types of DWs suggested by simulations were formally identified by high spatial resolution XMCD-PEEM: transverse wall and Bloch-point wall. Surface and transmission (in the shadow [2]) imaging were combined to gain a full view of the three-dimensional arrangement of magnetization (FIG2). Quasistatic magnetic fields of a few mT are enough to shift DWs, and the pinning strength of artificial notches and outgrowths has been quantified, to about 30mT for our geometry. These steps open the path to experiments of DW motion under field or spin-polarized currents, and revive the perspectives for 3D data storage devices.

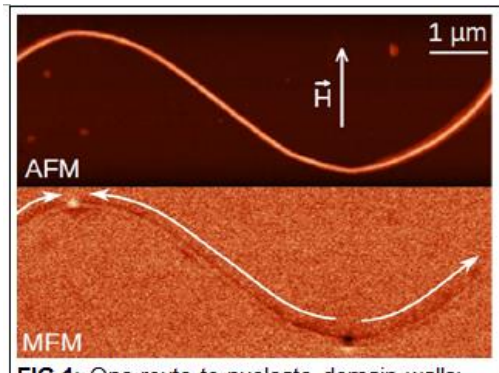

FIG.1: One route to nucleate domain walls: bent wires. Domain walls are forced to nucleate at the bends after the application of a magnetic field along the radii. The direction of magnetization along the wires is depicted with white arrows. Black and white contrasts stand for 'tail-to-tail' and 'head-to-head' domain walls, respectively.

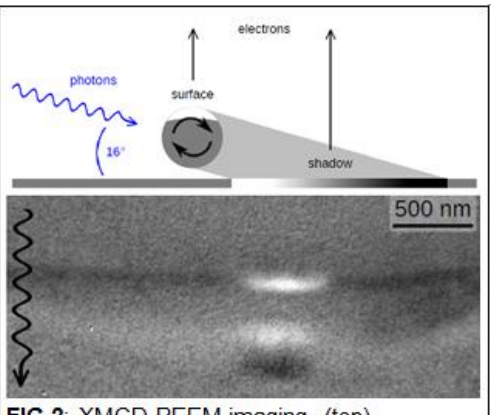

FIG.2: XMCD-PEEM imaging. (top) schematic of surface plus transmission imaging (bottom) experimental imaging of a Bloch-Point domain wall (wire above, its transmission contrast below)

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Magnetization dynamics of patterned array of permalloy ellipses

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Arrays of micron-sized ellipses and discs are good candidates for magnonic crystals as the spin-wave spectra can be tailored by size, distance and coupling to the underlaying film, etc. Besides, a vortex structure can produce further features in non-saturated samples. In this work we explore the magnetization dynamics of periodic structures with elliptical shape using the vector network analyzer ferromagnetic resonance technique (VNA-FMR), in the range of 0.1 to 10.0 GHz. Arrays of Permalloy ellipses with 50 nm thickness, and dimensions 2μm x 1μm and spaced by 2 μm in both directions were produced combining e-beam lithography, magnetron sputtering and lift-off techniques onto a Si wafer. The samples were characterized by vibrating sample magnetometry and magnetic force microscopy. The chosen dimensions of the ellipse and periodicity of the arrays resulted in dipolar interaction between the elements and a two-vortex magnetic state as depicted in the M vs H curves measured along the major axes. The dispersion relations obtained from the broadband measurements were found to exhibit the uniform Kittel mode and an optical mode, owed to the interaction between the elements, in the saturated state. On the other hand, for the two-vortex state a rich structure of spin-wave modes was observed. Micromagnetic simulations were performed in order to have a further insight of the experimental results.

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DOMAIN WALL TILTING IN MAGNETIC TRACKS IN THE PRESENCE OF DZYALOSHINSKII-MORIYA INTERACTION

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The presence of inversion asymmetry in an ultrathin magnetic layer can lead to an additional anti-symmetric exchange magnetic energy term, namely the Dzyaloshinskii-Moriya interaction (DMI) which may strongly affect the magnetization pattern. We have recently shown that the DMI in ultrathin films with perpendicular anisotropy can lead to Néel walls with very high stability [1]. Here, we show that the DMI not only modifies the DW internal structure but also its shape. When driving the DW dynamics with an external magnetic field or a spin polarized current, micromagnetic simulations reveal that a large DMI can lead to a sizable tilting of the DW surface in a nanotrack. The DW tilting affects the DW dynamics for large DMI and the tilting relaxation time can be much larger than the internal DW magnetization relaxation time as it scales with the square of the track width. Our results shed light on the DW dynamics in ultrathin magnetic layers and should help to interpret recent experiments of current and field-induced DW dynamics [2].

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ENGINEERING ULTRAFAST MAGNETISM

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Controlling magnetic states of matter on ultrashort timescales is crucial to engineering the next-generation magnetic devices combining ultrafast data processing with ultrahigh-density data storage.

Here, we report on femtosecond laser-driven dynamics of multi-sublattice magnetic materials, with both ferromagnetic and antiferromagnetic coupling between sublattices, investigated using element-specific, femtosecond time-resolved XMCD. These measurements [1], fully supported by phenomenological and atomistic spin simulations, provide evidence for a demagnetization time that scales with the elemental magnetic moment and varies with the sign of the exchange interaction. As such, one can control the speed of magnetization processes in multi-sublattices materials, being either switching or demagnetization, by properly choosing the magnitude of the constituent magnetic moments and the sign of the exchange interaction that couples them, as exemplified for the case of a synthetic ferrimagnet.

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EXCESS COERCIVITY AND DOMAIN WALL MOTION WITH EXCHANGE BIAS

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The exchange-bias effect is most clearly revealed by magnetometry of the ferromagnet, typically from measurements of the hysteresis loop of macroscopic samples [1]. Microscopic models have been put forth that explain with varying degrees of qualitative accuracy several aspects of the exchange bias mechanism [2,3]. However, they have not been able to adequately describe the physics of domain wall motion in these systems, which is prevalent in most systems of interest. Here we develop a phase-field model to describe the domain evolution in exchange-biased perpendicular Co/Pt systems. It incorporates measured distributions of pinned uncompensated antiferromagnetic spins (pUCS) [4]. With a single set of parameters, obtained from experiment and literature, the model can describe the measured macroscopic magnetization process and measured microscopic ferromagnetic domain dynamics with quantitative accuracy. With the same set of parameters, we model the reversal processes from hypothetical distributions of pUCS in the otherwise equivalent system, to study e.g. its influence on the excess coercivity [5,6] of exchange-biased ferromagnets. In contrast to the mechanisms for excess coercivity proposed by models to-date, in which irreversible processes [3] in the antiferromagnet are central, we find that it suffices to include spatial inhomogeneity of the pUCS to produce excess coercivity.

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DOMAIN GROWTH AND DIPOLAR BIAS IN MAGNETIC THIN FILMS COUPLED TO A PERIODIC PINNING POTENTIAL

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The influence of arrays of magnetic nanodots on the dynamics of domain walls in soft Co/Pt multilayer stacks will be presented. The nanodot arrays are separated from the multilayers by thin Pt spacers leading to a predominantly dipolar coupling between the arrays and the multilayer. In the absence of nanodots, domain wall dynamics is dominated by thermally activated creep [1], while in the presence of the nanodots, shifted hysteresis loops with enhanced coercivities are observed, in analogy with exchange bias in F/AF sandwiches [2]. This asymmetric magnetization reversal is related to strong deviations from creep dynamics arising from the dipolar potential landscapes associated to the nanodot arrays. Strikingly different domain wall morphologies are observed, with both dendritic and faceted domain structures growing from nucleation centers. We show that the average domain wall mobility of a magnetic thin film can be controlled by an external parameter, in this case the magnetization state of arrays of magnetic nanodots, opening the possibility of controlling domain wall propagation paths in thin magnetic films.

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SYMPOSIUM 8.1

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BIOCOMPATIBLE MAGNETIC NANOGELS FOR CELLS DELIVERY

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Superparamagnetic nanoparticles with functionalized surfaces are widely used as labels for molecules [1] and cells [2] thereof enabling for their remote manipulation by means of external magnetic fields. Magnetically driven targeting would enable delivery of significant amount of drug or number of cells to key areas of specific organs. Driven by this possibility, recently, a number of studies have looked at magnetic targeting. In vivo studies have shown that magnetic labeling, particularly with superparamagnetic iron oxide nanoparticles (SPIONs) is relatively easy and safe. Limited work however has been done on using externally applied magnetic fields to guide SPIONs used as drug cargo carriers or for labeling stem cells to specific target for tissue regeneration [3].

On the other hand, currently many nanomaterials, such as soft nanoparticles, are under investigation and development for their use in biomedical applications. Among soft nanoparticles, polymeric gels in the nanometer range, known as nanogel particles, have received considerable attention. Nanogel particles, which are formed by polymeric chains loosely cross-linked to form a three-dimensional network, swell by a thermodynamically good solvent but do not dissolve in it. Nanogels are composed of hydrophilic polymers capable of undergoing reversible volume-phase transitions in response to environmental stimuli. Among them, temperature-sensitive nanogels showing a volume phase transition temperature (VPTT) near physiological temperature have been investigated in detail.

In this work, magnetic labeled nanogels based on biocompatible and temperature-sensitive polymers having a lower critical solution temperature (LCST) around 32-38ºC in aqueous solutions, swelling at low temperatures and collapsing at high ones, are presented. This unique behavior makes these new soft nanoparticles attractive as drug and cells delivery systems [4-6].

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ACKNOWLEDGEMENTS

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HIGHLIGHTING SOME MAGNIFYCO PROJECT RESULTS: IRON OXIDE NANOCUBES AS HEAT MEDIATORS FOR COMBINING HYPERTHERMIA TREATMENT WITH DRUG DELIVERY

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In the last 4 years, within the MAGNIFYCO consortium, eleven European groups have been working on the development of magnetic nanomaterials that can act as drug “nanocontainers” for dual cancer treatments combining hyperthermia and controlled drug release (www.magnifyco.eu).

Within the project aims, the consortium had to identify efficient heat mediators based on superparamagnetic nanocrystals. A wide variety of iron-based nanocrystals were studied. We found out that among the different types of iron oxide nanocrystals synthesized by non-hydrolytic colloidal methods, nanocubes of 19-24 nm edge have very high specific absorption rate (SAR) values thus making them promising as heat agents under alternating magnetic field. *In vitro* and *in vivo* studies, in our case ovarian cancer was the selected tumor model, have been carried out within the consortium and important conclusions can be drawn on the heat-ability of iron oxide nanocubes, not only on the system itself but also when confined in living cells or in a tumor. Procedures to specifically functionalize these nanoobjects with stimuli-responsive polymer shell for drug delivery purposes or with specific antibody fragments (AFRA) to target ovarian cancer cells have been also intensively investigated. Besides the partial success achieved in some of those studies, much can be learned from our experience.

An overview of these results will be presented.

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ON CHIP MAGNETIC PLATFORM FOR SINGLE PARTICLE DELIVERY AND PARTICLE TRANSIT MONITORING

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Single molecule imaging and handling are of particularly relevant for in-vitro biological application (e.g. drug delivery studies), because they offer a clear and direct way to investigate functions and dynamics of single biomolecules.

In this paper, we exploit a fully magnetic and electrical system to achieve a controlled deliver and detection of single magnetic nano and micro-particles. This system is based on domain walls (DWs) displacement by means of external magnetic fields in confined ferromagnetic zig-zag nanostructures to attract, move [1] and sense [2] particles in suspension over the chip.

To this scope, we employed as attracting pole DWs created at the corner of zig-zag structures for particles manipulation and electrical contacts (see the inset of Fig.1) to monitor the DW presence through anisotropic magnetic resistance (AMR) measurements.

The magnetic particle presence over the DW affects the value of the magnetic depinning field of the single DW. In Fig. 1, the variation of the voltage drop across a corner of the zig-zag structure due to the AMR, while sweeping the magnetic field, is used to detect the transit of the particle over the corner. For a 1 □m-sized bead the variation of depinning field is12±3 Oe.

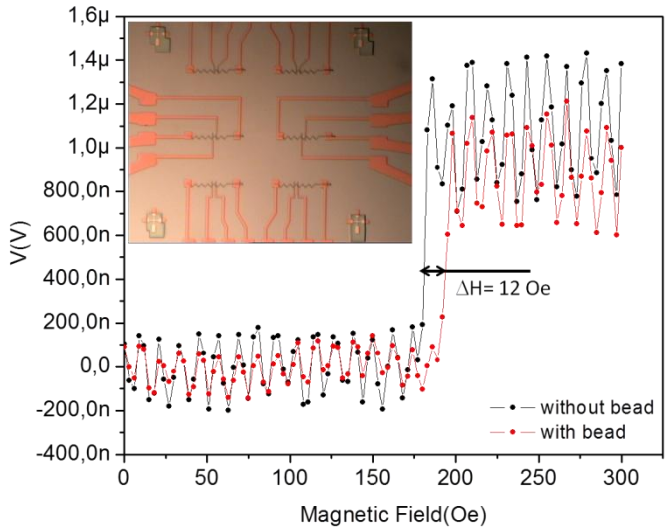

Fig.1: Voltage drop across the zig-zag as a function of the magnetic field for the clean zig-zag (black), during the transit of the beads (red). In the inset: optical image of the device

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IRON NANOWIRES INCORPORATED INTO A PDMS MEMBRANE

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Previously, magnetic polymer membranes have been developed using superparamagnetic beads for various applications [1-3]. We report a magnetic polymer membrane consisting of iron nanowires incorporated in a polydimethylsiloxane (PDMS) thin film. Iron nanowires are fabricated by electrodeposition in nanoporous aluminum oxide. The nanowires' height and diameter are 8 µm and 35 nm, respectively. The nanowires are mixed with PDMS at concentrations of 10% and free-standing magnetic PDMS membranes are fabricated with a thickness of 70 µm. The orientation of the nanowires in the membrane can be adjusted by applying a magnetic field during the PDMS curing process, customizing the membrane's magnetic properties. Figure 1 shows the cross section of a membrane with vertically aligned nanowires taken by transmission electron microscopy (TEM), a scanning electron microscopy (SEM) image of a single nanowire, and the magnetization curves obtained with a vibrating sample magnetometer along the vertical and horizontal directions. By aligning the nanowires, the membrane becomes magnetically anisotropic with a pronounced easy axis in vertical direction. The high remanence and coercivity values are distinct features that cannot be obtained with superparamagnetic beads. For example, large magnetic forces can be produced at low magnetic fields (see Figure 2). A large-stroke membrane deflection of 230 µm is obtained by applying a magnetic field gradient of 220 Oe/mm. The proposed membrane provides several novel features, which can be tailored for optimized performance in various applications.

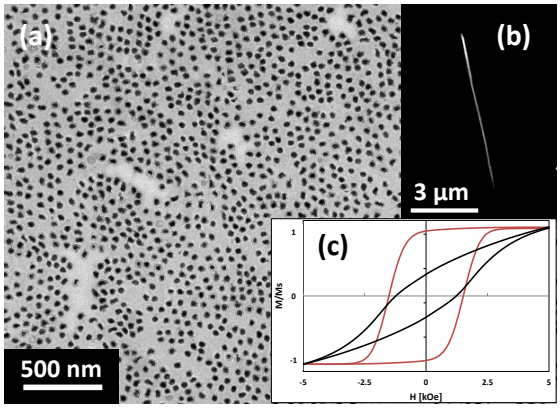

Figure 1: (a) TEM image of the PDMS membrane with vertically aligned nanowires. (b) SEM image of a single Fe nanowire. (c) Magnetization curves vertical and horizontal to the PDMS membrane of vertically aligned Fe nanowire.

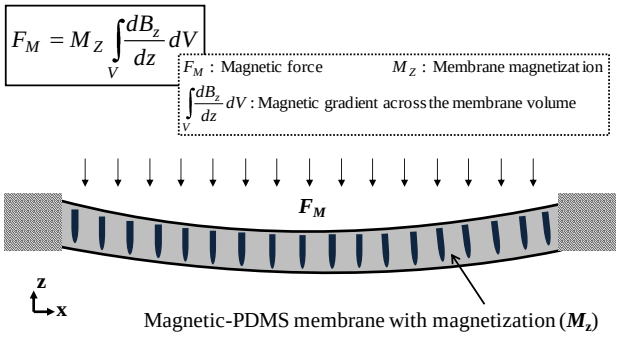

Figure 2: Illustration of the magnetic-PDMS membrane deflection due to magnetic forces.

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MAGHEMITE NANOCLUSTERS: STATIC, DYNAMIC MAGNETIC PROPERTIES AND MONTE CARLO SIMULATIONS

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Recently, there is interest in nanoarchitectures that entail an assembly of nanocrystals (NCs). The reason is the cooperative physical properties that arise due to the proximity and coupling effects of their individual building blocks. Magnetic nanoclusters (MNCs) of 50 nm and 86 nm, consisting of maghemite nanocrystals (PMNCs), are grown by a high-temperature polyol process. As MNCs and PMNCs are covered by polyacrylic acid (Fig.1(a)) [1], they are highly dispersible in aqueous media. The response of aqueous dispersions is characterized by DC and AC SQUID magnetometry, while Monte Carlo (MC) simulations, based on the Metropolis algorithm, give an insight to the microscopic mechanisms. DC magnetometry shows that MNCs have ferrimagnetic behavior. Interestingly, the T-evolution of the AC susceptibility uncovers some hidden complexity. A spin-glass like (T_G) behavior coexists with a high-temperature blocking (T_B) response (Fig.1(b)). MC simulations provide a rational by considering the balance between the surface anisotropy, spin-disordering and dipolar interactions.

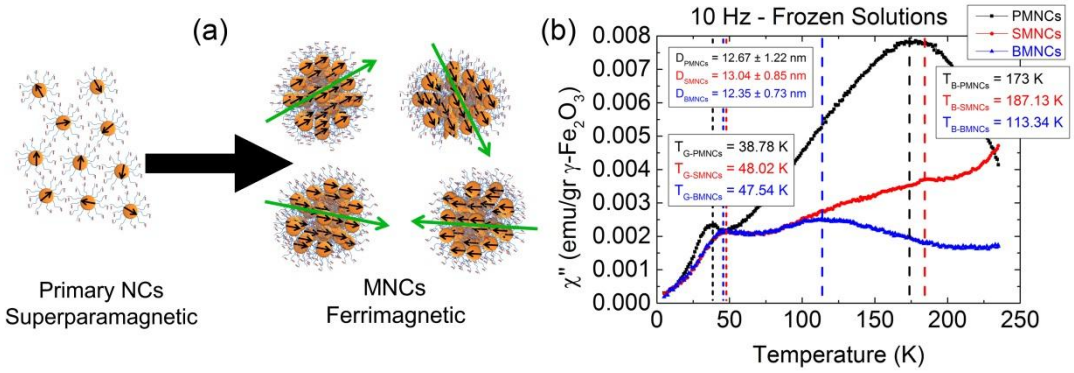

Figure 1. (a) Schematic of the MNCs formation. (b) Imaginary part of AC-suceptibility (χ'') for three frozen solutions (T_G- spin glass; T_B- blocking).

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SYMPOSIUM 3.4

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TETRAGONAL HEUSLER COMPOUNDS FOR SPINTRONICS AND BEYOND

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Heusler compounds are a remarkable class of materials with more than 1,000 members and a wide range of extraordinary multifunctionalities including half-metallic high-temperature ferri- and ferromagnets, multiferroic shape memory alloys, and tunable topological insulators with a high potential for spintronics, energy technologies and magnetocaloric applications. Recent development of efficient spintronic devices is based on the spin transfer torque (STT) phenomenon. In 2007 $Mn_{3-x}Ga$ was identified as a potential electrode for STT applications [1]. In general tetragonal Heusler compounds Mn2YZ as potential materials for STT applications can be easily designed by positioning the Fermi energy at the van Hove singularity in one of the spin channels [2]. The Mn^{3+} ions in Mn_2YZ cause a Jahn Teller distortion. High calculated magnetic anisotropy energy (MAE) is the sufficient condition for a material with perpendicular magneto-crystalline anisotropy (PMA). Materials with saturation magnetizations (MS) of 0.2 – 4.0 μ_B, high Curie temperatures (T_C) of 380 – 800 K, high spin polarizations, PMA, and required lattice constant matching with MgO can be realized with ferri- or ferromagnetic Heusler-related compounds. Such materials are strongly recommended for the spin transfer torque magnetic random access memory (STT-MRAM) data storage and the spin torque oscillators (STO) for telecommunication. Additional properties can be designed in tetragonal Heusler compounds with three magnetic sublattices. Mn_2PtIn is a tetragonal Heusler compound with a large exchange bias behavior. This property likely originates from the glassy nature of the low temperature magnetic state, as indicated by ac susceptibility and zero-field-cooled relaxation measurements [3]. Thin films and device of the Tohoku group show promising results [4,5].

With respect to the requirements of STT materials, the most promising systems are those Heusler compounds based on Mn_2YZ, combined with transition metals that are more electronegative than Mn Y= Co, Fe, Ni, Rh, …) and Z= Al, Ga, Sn. For these combinations, the inverse cubic Heusler structure with three distinct magnetic sublattices is formed, as shown in Figure 1a. The corresponding tetragonally distorted inverse Heusler structure is shown in Figure 1b. Because of the interatomic distances, the Mn atoms in the different sublattice couple ferrimagnetically ensuring the desired low effective magnetic moment. The derived energy profiles allow for distinguishing between a stable tetragonal distortion (e.g., Mn_3Ga), a stable cubic structure (e.g., Mn_2CoGa), and a shape memory system (e.g., Mn_2NiGa). $Mn_{2.5}Co_{0.5}Ga$ happens to be a system which lies exactly at the borderline between the stable and unstable cubic structures see Figure 2 a. Figure 1c provides an overview of several cubic and tetragonal Mn_2YZ Heusler compounds. Starting with the stoichiometric Mn_3Ga compound we can explore the complete phase diagram of $Mn_{3-x}Y_xZ$. As illustrations, we consider the detailed experimental characterization of the systems Mn3-xCoxGa, $Mn_{3-x}Fe_xGa$ and $Mn_{3-x}Ni_xGa$. The measured magnetic moment and T_C for different compositions in the two systems are plotted in Figure 2, too. Partially substituting Mn by Co leads to the $Mn_{3-x}Co_xGa$ system, with the tetragonal structure being stable for Co concentrations as high as x = 0.4. While the tetragonal alloys exhibit features attractive for STT applications, the cubic systems represent a large class of 100% spin polarized half-metallic Heusler materials that robustly follow the Slater-Pauling rule similar to the Co_2YZ compounds. In summary, our results unambiguously demonstrate that the phase space of tetragonal Heusler compounds is much larger than only $Mn_{3-x}Ga$, and that the important STT parameters can be tailored by adjustments of the composition [6]. A significant amount of work remains, but following the path outlined here it should be possible to design a wide range of Heusler STT materials with PMA that fulfill all the requirements: complete tunability of the magnetic moment, the lattice parameters, MCA, and SOC, which is necessary for fulfilling some of the conflicting requirements for low switching current, fast switching and thermal stability. Additionally further interesting properties such as spin gapless semiconductivity [7] and giant exchange bias [8].

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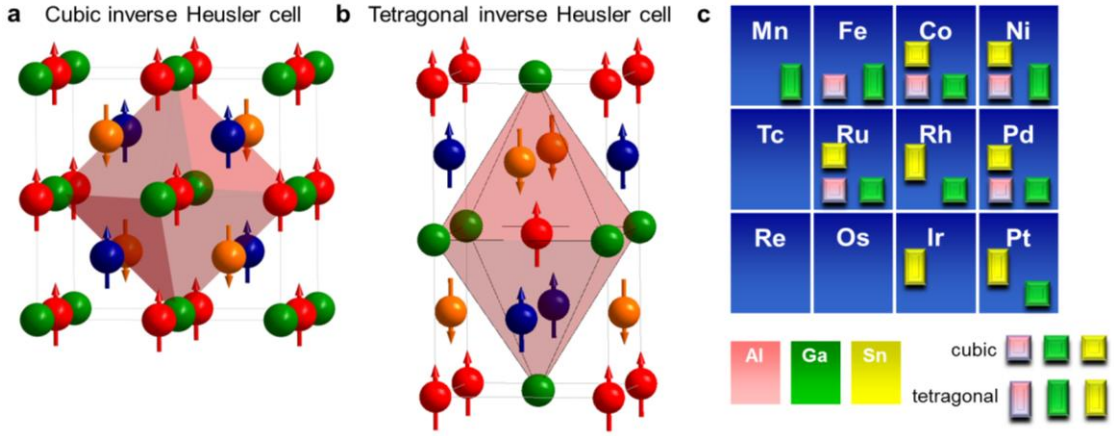

Fig. 1 a), b) Cubic and tetragonal cells of Mn_2YZ Heusler compounds. c) The structure of Heusler compositions calculated, synthesized, and analyzed with Y = Group 7-10 elements from the Periodic Table and Z = Al, Ga, and Sn.

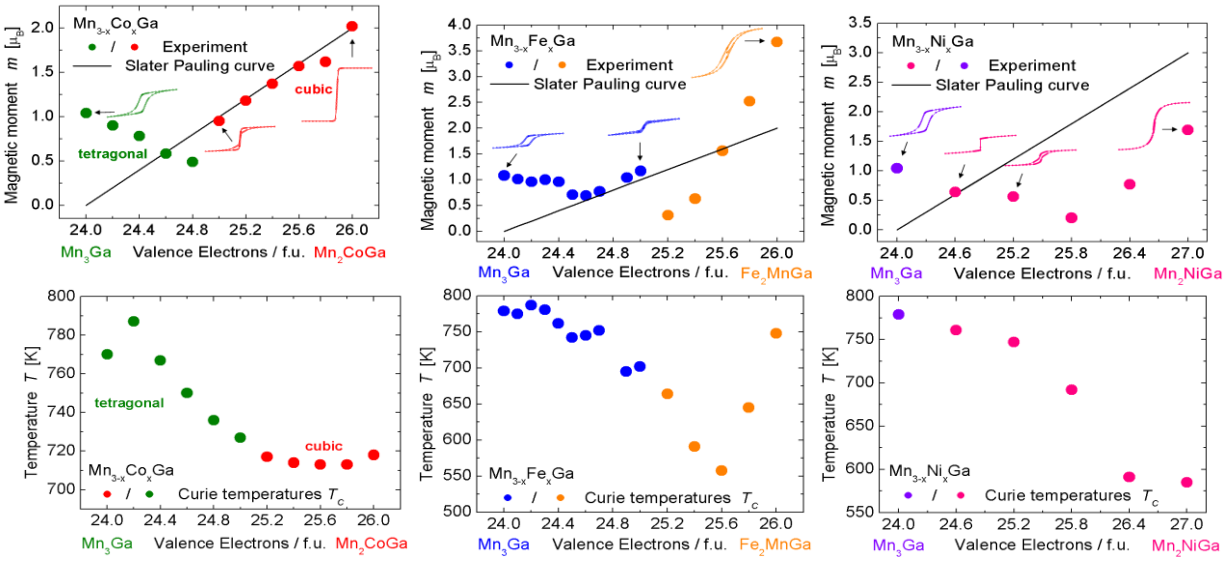

Fig. 2 Saturation magnetic moments of $Mn_{3-x}Co_xGa$ [2] $Mn_{3-x}Fe_xGa$ and $Mn_{3-x}Ni_xGa$ alloys measured at T = 5 K and compared with the Slater-Pauling values. Lower Figures are the corresponding TC of the alloys.

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ANTIFERROMAGNETS FOR SPINTRONICS APPLICATIONS: SPIN-ORBIT COUPLING EFFECTS.

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The magnetic anisotropy energy (MAE) and element-specific contributions to the MAE have been studied for Mn-based antiferromagnetic alloys with layered $L1_0$ structure within the framework of the local spin-density approximation and the fully relativistic torque method. It is found that the contribution to the total MAE from nonmagnetic 3*d* and 4*d* elements in MnIr, MnNi and MnPd ordered alloy is determined not only by Mn contribution but also by strong spin-orbit coupling on non-magnetic transition metal atom. In addition we observe a strong dependence of the MAE on the state of magnetic order. This effect appears to be due to competition between in-plane and uniaxial atomic specific contributions from Mn and transition metal atoms to the MAE. The switching of the magnetization in considering AFM materials may lead to the giant change in the magnetoresistance and thus it may proposed a new route in antiferromagnetic spintronics The idea is to control the magnetization reversal in antiferromagnets via the changing the c/a ratio in antiferromagnetic thing films. We illustrate this idea by calculating the respective anisotropic changes in the relativistic Density of State of in novel high temperature Mn_2Au antiferromagnetic compound and MnIr alloy..

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HALF-METALLIC BCC MULTICOMPONENT ALLOYS BASED ON IRON

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As has been already shown in several papers, *bcc* multicomponent alloys based on Fe are interesting from both, applied and basic physics. Their ordering processes result in formation of large class of Heusler-type alloys, some of them having extreme characteristics [1 and references therein].
Ab-initio calculations provide very useful tool for designing new materials with desirable properties. Assuming particular concentrations of component chemical elements one can predict electronic and magnetic properties of the alloy. Evaluation of the spin polarization of ferromagnetic materials is a key factor while looking for materials potentially applicable in spintronics. To realize high-performance devices, highly spin polarized ferromagnets are required.

The aim of this study is systematic theoretical investigation of the systems with bcc structure built of Fe, V, Cr, Mn, Ti, Al and Si, covering inter alia some Heusler alloys based on Fe bcc. Band structure calculations of the investigated alloys were carried out within the framework of FP-LAPW method in GGA approximation. By varying concentrations of component elements, for some systems, total compensation of magnetic moments, a gap or a pseudogap at the Fermi level as well as half-metallic character of the alloys were obtained. Tailoring of half-metallic behaviour of the alloys will be presented in the contribution. Some theoretical predictions have been already confirmed experimentically [1].

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STUDY OF THE STRUCTURE INFLUENCE ON THE MAGNETISM OF $Fe_{70}Al_{30-x}Si_x$ ALLOYS

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Mechanically deformed $Fe_{70}Al_{30}$ suffer order-disorder transitions that induce a dramatic reinforcement of the magnetism [1]. This behaviour can be explained by taking into account the relationship between microstructure and magnetism. Indeed, the iron rich side of FeAl phase diagram presents three main structures: ordered $D0_3$ and B2, and disordered A2. On the other hand, in FeSi alloys, which also show these three structures (in the Fe rich side of the phase diagram) the magnetic moment decreases with order-disorder transition [2]. For this reason, Si is a very appropriate adding element for studying the complex magnetic behavior of $Fe_{70}Al_{30}$ alloys.

In this work, we study the relationship between the magnetic and structural properties of ball milled $Fe_{70}Al_{30-x}Si_x$ alloys with x=9, 15 and 21 by means of Mössbauer spectroscopy, magnetic measurements and X-ray diffraction.

The results show that the increase of the magnetization and the mean hyperfine field is related to the disordering of the B2 structure, but not to the disordering of the $D0_3$ structure. Besides, when plotting the normalized variation of lattice parameter produced by the disorder versus the normalized variation of magnetization we observe a linear relationship, showing that lattice parameter and magnetic properties are also related.

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FINITE TEMPERATURE MAGNETISM FROM FIRST PRINCIPLES

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Numerical investigations of magnetic phenomena at finite temperatures are mostly based on Heisenberg type of spin-models treated with methods of statistical physics (Monte-Carlo or Langevin dynamics simulations) [1] Although the parameters of such models can be calculated from first principles [2,3], neglecting higher-order spin-interactions and longitudinal spin-fluctuations may imply drastic restrictions of such investigations.

In this talk we will present a 'first principles only' approach to study finite temperature magnetism. The method is based on the Disordered Local Moment (DLM) picture that can be merged efficiently with the Local Spin-Density Functional Approximation (LSDA) of Density Functional Theory (DFT) [4]. In particular, solving the Kohn-Sham-Dirac equation allows for investigating relativistic effects [5]. To keep track of spin-dynamics simulations, we also will present a scheme to derive temperature dependent spin-model parameters from first principles. We will demonstrate the new computational schemes for the temperature dependence of the magnetocrystalline anisotropy energy (MAE) of chemically ordered and disordered bulk FePt alloy and we explicitly show that, in terms of spin-models, it is intimately connected with anisotropic intersite exchange interactions. Similar to a recent work [6], we investigate the metamagnetic transition in bulk FeRh and find that the antiferromagnetic-ferromagnetic phasetransition occurs as a subtle interplay of spin-disorder and thermal expansion effects.

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MAGNETIC FIELD-INDUCED ULTRASHARP MAGNETIZATION JUMPS IN $La_{0.9}Ce_{0.1}Fe_{12}B_6$ INTERMETALLIC COMPOUND

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Several unusual and intriguing magnetic phenomena have been observed in the polycrystalline $La_{0.9}Ce_{0.1}Fe_{12}B_6$ compound. First, below 35 K, $La_{0.9}Ce_{0.1}Fe_{12}B_6$ is antiferromagnetic in a zero magnetic field, but it can be transformed into the ferromagnetic state both irreversibly (below 25 K) and reversibly (above 55 K) depending on the magnitude of the applied magnetic field, the temperature, and the direction of their changes. Second, the irreversible antiferromagnetic-ferromagnetic transition at low temperature is abrupt, the steps have a sudden onset below a critical temperature, are extremely sharp and occur at critical fields which are dependent on the absolute value of the cooling field in which the sample is prepared. Field cooling similarly increases the low-field magnetization at temperatures below the onset of the step transitions, but the step transitions are shifted to higher fields as a result of field cooling. The spontaneous jumps are also seen in magnetostriction and resistivity data. Third, the crucial point in the relaxation experiment data is the fact that the evolution with time of the magnetization displays a spontaneous jump when both the temperature and the magnetic field are constant. These results bear a striking similarity with the phenomenon of an ‘‘incubation time’’ encountered in isothemal martensitic transformations. To the best of our knowledge, there have been no reports of such a steplike magnetic relaxation in any boride materials.

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INFLUENCE OF ELECTRODEPOSITION FREQUENCY AND WAVEFORM ON THE ALLOY COMPOSITION AND MAGNETIC PROPERTIES OF CoNi NANOWIRE ARRAYS

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This study aims to provide an understanding of the physical nature of crystal structural dependent magnetic behavior of CoNi nanowires electrodeposited into hexagonally ordered nanoporous (diameter 20÷40 nm) alumina template. A series of CoNi alloy nanowires with different percentage of Co and Ni atoms was prepared using alternating current with different frequency and waveform (Table 1). Results show that the easy axis of magnetization rotates from parallel to perpendicular direction regarding to nanowire axis as the atomic percentage of cobalt increases in CoNi alloy nanowires Fig.1.

Table 1. EDX results for different electrodeposition condition.

atomic percentage%	Sinusoidal waveform			square waveform		
	200Hz	500Hz	800Hz	200Hz	500Hz	800Hz
Co	68.85	69.06	81.01	65.26	69.64	85.09
Ni	31.15	30.94	18.99	34.74	30.36	14.91

We plotted the angular dependencies of the coercive force H_c as well as squareness (M_r/M_s). Angle was defined zero when the external magnetic field was applied along the nanowire axis and was changed with tilting the sample with 10 degree steps up to 360°, Fig.1. An isotropic magnetic behavior for all samples is seen when the field applied perpendicularly to the nanowire axis due to the absence of long-range ordering of nanopores in the template, but magnetic parameters are completely different, Fig.1.

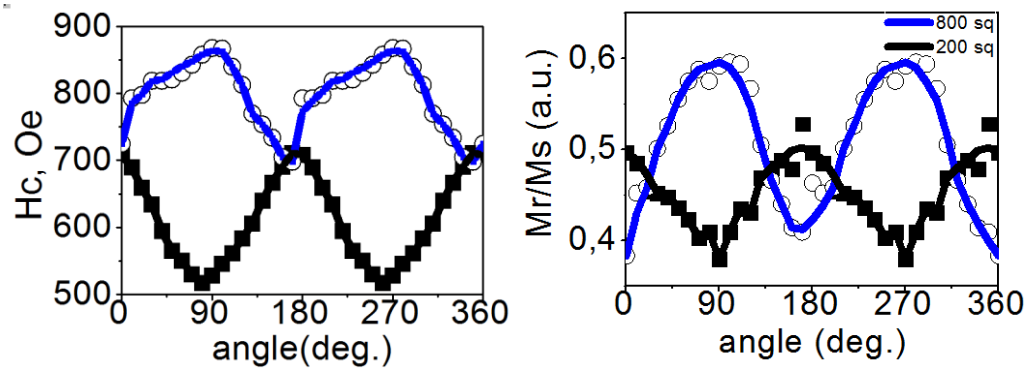

Figure 1. Angular dependences of $M_r/M_s=f(\varphi)$ and $H_c= f(\varphi)$ for nanowire arrays electrodeposited at different frequencies.

WEDNESDAY AFTERNOON

FEMTOSECOND ALL-OPTICAL CONTROL OF MAGNETISM AT THE NANOSCALE

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From the discovery of sub-picosecond demagnetization over a decade ago to the recent demonstration of magnetization reversal by a single 40 femtosecond laser pulse, the manipulation of spins by ultra short laser pulses has become a fundamentally challenging topic with a potentially high impact for future spintronics, data storage and manipulation and quantum computation. Theoretically, this field is still in its infancy, using phenomenological descriptions of the none-equilibrium dynamics between electrons, spins and phonons. A proper description should include the time dependence of the exchange interaction and nucleation phenomena on the nanometer length scale. A practical challenge is how to bring the optical manipulation of magnetic media to the required nanoscale, which may be possible using plasmonic or wave-shaping techniques. Recent results to probe and control magnetic order on the nanoscale will be discussed.

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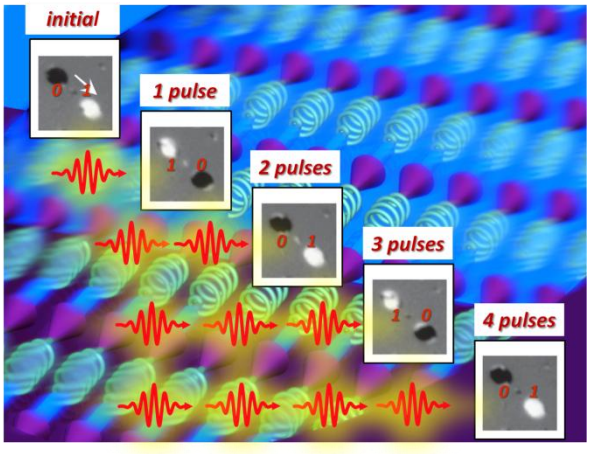

Demonstration of magnetic domain switching by unpolarized laser pulses (T.Ostler et al)

JEMS 2013, Rhodes, august, 2013

SYMPOSIUM 5.5

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LANTHANIDES IN THE FRAME OF MOLECULAR MAGNETISM

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INTRODUCTION

Lanthanides have been investigated for many years for their magnetic properties, which are actively exploited for industrial applications. Lanthanide based molecular magnets are more recent and, after a slowly accelerating start now the interest for Ln derivatives is in the exponential increase regime. Their appeal is essentially due to their large unquenched orbital contribution to the magnetization, which confers them many interesting properties.[1]

In particular, the interest toward these systems took off when it was discovered that slow relaxation of the magnetization at low temperature can be observed in molecules containing just one metal ion, providing the first examples of single ion magnets, SIM. This was of particular relevance since it showed that what was felt to be a weak point of Ln, i.e. the weak exchange coupling involving f- electrons, could actually be circumvented to provide a high enough magnetic anisotropic barrier.

RESULTS AND DISCUSSION

The Florence group has developed many different areas of Lanthanide Chemistry and Physics, starting in pioneering times by developing successful explanation of exchange interactions in Gd containing complexes. Increasing complexity led to the synthesis and characterization of mixed lanthanide-organic radical polymers, which were shown to behave as single chain magnets and to undergo a transition to chiral order, a long searched fundamental property. More recently, the interested shifted toward the application of lanthanide molecular systems in molecular spintronics.

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SHORT−RANGE CORRELATIONS IN D−F CYANIDE−BRIDGED ASSEMBLIES

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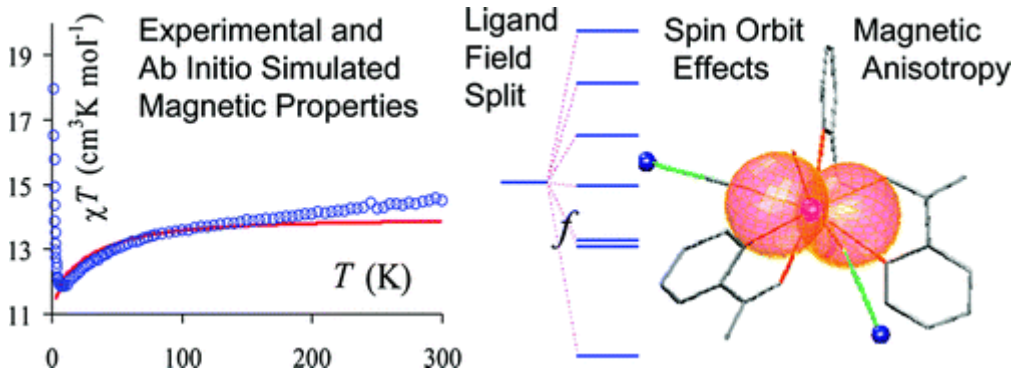
INTRODUCTION

The design of novel anisotropic and well-isolated one-dimensional (1D) magnetic systems is among the challenging subjects within the field of molecular magnetism. Although the experimental research on such systems started in the 1980s,[1] it has recently received a new impetus with the introduction of molecular materials.[2] In extended 1D polynuclear compounds, the presence of alternating *d* and 4*f* metal centres is of special interest. This is because of the strong superexchange promoted by the former, combined with the peculiar crystal-field effects of the latter. Moreover, the 1D coordination polymers represent a special case because of their fairly simple topology. On one hand, the chain structure allows a relative simple scheme of parameterization, with one or two exchange coupling constants. On the other, it raises the problem of dealing with infinite systems when tackling their modelling.

It will be presented the magnetism of 1D *d–f* cyanide–bridged assemblies derived from $[M(CN)_8]^{3-}$ and $[RE(pzam)_3]^{3+}$ building-blocks (M =Mo(V), W(V), RE =rare earth ions, pzam = pyrazine–2–carboxamide).[3–5] The estimation of the *d–f* exchange interaction will be discussed based on measurements of thermodynamic properties and magnetic susceptibility. This allows separating more reliably the effects of the ligand field splitting from the contributions arising from the (anisotropic) exchange coupling. Finally, we will give a description of the combined effects of ligand field and spin–orbit coupling in determining the magnetic anisotropy of the *f* metal center.



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ROOM TEMPERATURE PHOTOMAGNETIC MOLECULAR SWITCHES: TRANSITION METAL COMPLEXES WITH PHOTOACTIVE LIGANDS

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Spin-crossover (SCO) and valence-tautomeric (VT) metal complexes are among the best known classes of molecular bistable systems. Their optical, magnetic and other physicochemical properties can be reversibly switched by changing the temperature, applied pressure, or irradiation with light. Although photoswitching in SCO complexes is well documented in a light-induced excited spin state trapping (LIESST) effect, this phenomenon is usually operative at low temperatures T < 50 K. This imposes serious limitations for its application in genuine photodevices. The photoswitching in VT systems is even more difficult to achieve: typically temperatures below 20 K are necessary to stabilize photoinduced states.

We develop molecular coordination compounds that overcome low-temperature limitations of the LIESST effect and allow the photoswitching in SCO and VT systems at *room temperature*. To accomplish this we introduce *photoisomerizable ligands* to metal complexes in such a way that ligand-based photoreaction modifies the ligand field. Consequently, this light-driven modulation induces a spin transition at the metal ion in SCO compounds or an electron transfer in VT systems. Since the photoisomerization of the ligand can be accomplished at room temperature, the photoswitching of the electronic states and associated magnetic properties for both SCO and VT systems becomes feasible at room temperature.

We will report on the synthesis, characterization and investigation of photophysical properties of a series of molecular switches – first-row transition metal complexes featuring photoactive ligands (Figure 1).

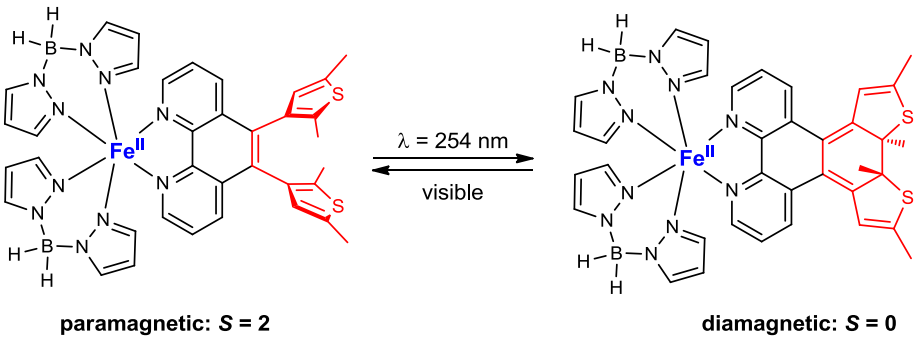

Figure 1 Example of a photomagnetic molecular switch based on a spin-crossover Fe^{II} complex.

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SURFACE MOBILITY TUNING OF NANOSTRUCTURED SELF-ORGANIZATION: FROM MOUND FORMATION TO STEP FLOW GROWTH

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A major challenge in nanotechnology today is to find a way of positioning functional nanostructures on surface in regular patterns. In last years, step-terrace morphology of underlying substrates has been demonstrated as useful tool for tailoring the self-organization process during crystal growth, offering enormous potential for the implementation of new nanodevices.

Fully spin-polarized $La_{2/3}Sr_{1/3}MnO_3$ (LSMO) manganite thin films exhibit a tendency towards self-organized growth forming regular arrays of three dimensional nanostructures, directly promoted by the topological features of the substrate [1,2]. In this work we report an experimental morphological phase diagram where a new growth mode (Fig. 1(b)) appears to compete with the mound formation (Fig. 1(a)) and the step flow regime (Fig. 1(c)) and shows that the surface mobility and the deposition rate must be chosen within a narrow window in order to achieve the self-organized nanostructures formation.

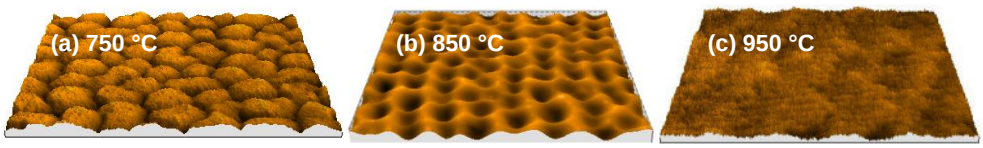

Figure 1. 3D AFM images (1x1 nm^2) of LSMO films grown at different temperatures

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ORGANIC/FERROMAGNETIC INTERFACES OF INTEREST IN MEMRISTORS: A CHEMICAL CHARACTERIZATION BY PHOTOEMISSION SPECTROSCOPY

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The combination of organic spintronics and electric based memories effects has been detected in vertical spin valve made by a π-conjugated organic semiconductor Tris(8-hydroxyquinolinato)aluminium Al(C9H6NO)3 (Alq3) sandwiched between two ferromagnetic electrodes La0.7Sr0.3MnO3 (LSMO) and Cobalt[1-2]. Spin injection efficiency and electric switching behaviour of these devices are strongly correlated -low resistive states present spin valve effect while high resistive states do not- and charge/spin trapping effects at the hybrid organic-inorganic interfaces has been proposed as possible mechanism accounting for both effects. In this view the knowledge of chemical properties of such interfaces represents then a necessary step for controlling the phenomena. For this purpose we investigated by photoemission spectroscopy LSMO/Alq3 and Alq3/Co interfaces and by Hard X-ray spectroscopy the corresponding buried interfaces in working devices.

The presence of Oxygen defect states in the LSMO bottom contact improves the overall quality of memristive behavior in terms of stability, voltage extension and spin valve effect. On the other hand the intentional oxidation of the organic layer (by different oxygen exposure after deposition) has a twofold effect: it promotes the electrical conduction of devices and it affects the quality of Co/Alq3 interfaces. The comparison between device functionality and chemical investigation highlights the role of Oxygen states in memristive effect.

This work has supported by FP7 projects NMP3-LA-2010-246102 (IFOX), NMP-2010-SMALL-4-263104 (HINTS), and from Italian MIUR through the FIRB project n°RBAP117RWN.

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MAGNETIC COUPLING OF PORPHYRIN MOLECULES THROUGH GRAPHENE

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By means of element-selective X-ray magnetic circular dichroism (XMCD) measurements, presented in Fig. 1, we show that the moments of paramagnetic Co-octaethylporphyrin (CoOEP) molecules on graphene can be stabilized against thermal fluctuations by a remarkable antiferromagnetic coupling to a Ni substrate underneath the graphene. This coupling is mediated via the π electronic system of graphene, while no covalent bonds between the molecule and the substrate are established.[1] The Co ions reveal a huge in-plane orbital moment that is comparable in size to the spin moment. Reversible switching of the Co orbital moment by (77 ± 6)%, without modifying the spin state S=1/2, is achieved by adsorption and thermal desorption of carbon monoxide acting as a chemical stimulus.

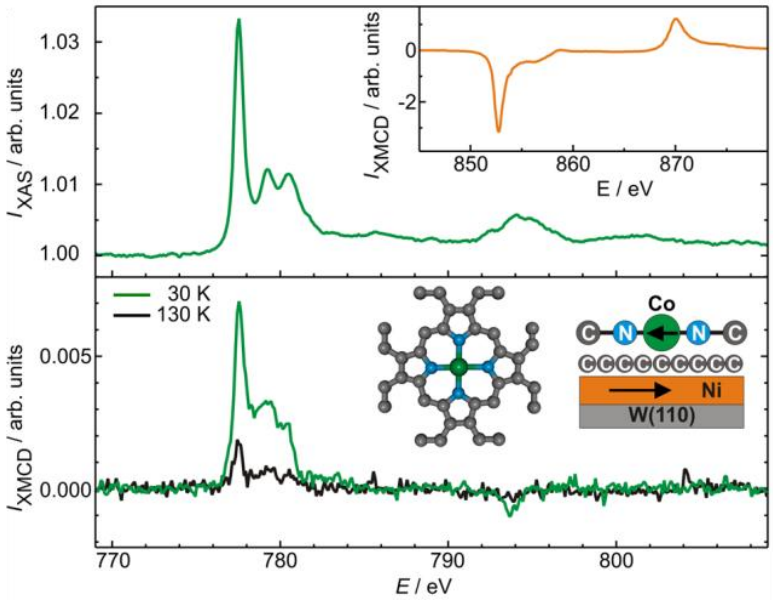

Figure 1: Co $L_{2,3}$ X-ray absorption (top) and XMCD (bottom) spectra of 0.7 monolayer of CoOEP on graphene/Ni/W(110) measured without applied magnetic field at 30 K (green lines) and 130 K (black line). Insets: (upper panel) Ni $L_{2,3}$ XMCD spectrum (orange line) at 130 K that shows opposite sign compared to the Co XMCD spectrum and thus proves the antiferromagnetic coupling. (Lower panel) Schematic top view of CoOEP molecule and side view of the sample.

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NOVEL SKYRMION STATES IN NANOWIRES OF CHIRAL MAGNETS

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In bulk non-centrosymmetric magnets the chiral Dzyaloshinskii-Moriya exchange stabilizes tubular skyrmions with a reversed magnetization in their centers [1]. While the double-twist is favorable in the center of a skyrmion, it gives rise to an excess of the energy density at the outskirt. Therefore, magnetic anisotropies are required to make skyrmions more favorable than the conical spiral state in bulk materials [2].

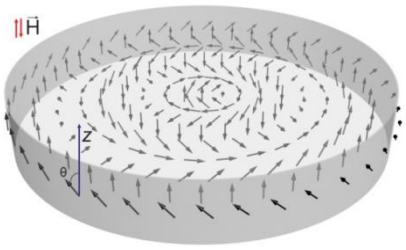

Fig.1. Skyrmion-target in a nanowire.

Using Monte Carlo simulations, we show that in magnetic nanowires unusual skyrmions with a double-twisting core (Fig. 1) and a number of concentric helicoidal undulations are thermodynamically stable even in absence of single-ion anisotropies. Such skyrmions are free of magnetic charges and, since the angle θ describing the direction of magnetization at the surface depends on the radius of the nanowire and an applied magnetic field, they carry a non-integer skyrmion charge $s > 1$. This state competes with clusters of spatially separated $s=1$ skyrmions. For very small radii, the ring skyrmion transforms into a skyrmion with $s < 1$, that resembles the vortex-like state stabilized by surface-induced anisotropies [2].

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SYMPOSIUM 2.2

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THEORY OF SPIN-ORBIT COUPLED TRANSPORT IN MAGNETIC BILAYERS

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It has been recently demonstrated that appropriately designed spin-orbit coupling (SOC) can be used to generate spin torque (coined as SOC-torque) in a single ferromagnet, without the need of an external polarizer [1-3]. This effect has been observed experimentally in both perpendicular and in-plane magnetic systems, consisting in ferromagnetic metals [4,5] and dilute magnetic semiconductors [6]. Interestingly, due to the complex structure of metallic systems, the microscopic origin of the current-driven magnetization dynamics is still under debate and the contributions of spin Hall and band structure effects are still under intense investigation [7].

In this work, I will address the different origins of the SOC-torque and discuss experimental implications. In a first part, will address the nature of the band structure of such bilayers in the presence of interfacial symmetry breaking using *ab initio* calculations. It can be shown that such an inversion asymmetry in the system produces two important effects: the well-known Rashba field (and related Rashba torque) on the itinerant electrons, and the celebrated Dzyaloshinskii-Moriya interaction on the localized spins. In the second part, I will discuss the nature of spin Hall effect in these bilayers. I will introduce a diffusive model for spin Hall effect in metallic bilayers and show how it can generate spin torque, anisotropic magnetoresistance and anomalous Hall effect. The connection between these three effects can be exploited as a probe of the origin of the SOC-torque. In the third part, I will discuss the nature of the Rashba torque and its complex angular dependence in a simplified 2-dimensional model. Implications in terms of experimental observations will be proposed.

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Dynamics of Topological Solitons in Perpendicular Magnetic Anisotropy Nanostructures

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Confined solitons in perpendicular magnetic anisotropy materials (PMA) exhibit a rich excitation spectrum that is directly linked to their topological properties, as described by their Skyrmion number. They have been predicted to exhibit intriguing dynamics such as a gyrotropic motion, breathing-like expansion and shrinking of their size as well as ultra-fast switching [1, 2]. We provide here a first experimental demonstration of dynamics of magnetic PMA topological solitons in CoB/Pt nanostructures with a pump-probe scheme and picosecond time resolution, using Scanning Transmission soft X-ray Microscopy and Holography. Specifically, we observe i) the gyrotropic motion of such solitons, as well as ii) their expansion and shrinking dynamics (Figure 1). Our results elucidate the link between the dynamics of PMA solitons and their underlying topological properties and provide a much wider scope for dynamical experiments in magnetic elements.

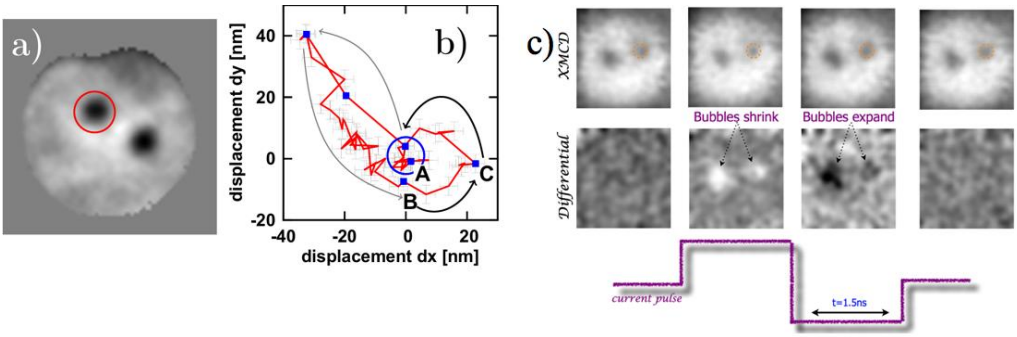

Figure 1 a) A 600nm diameter CoB/Pt dot in a multi-bubble state. b) The gyrotropic trajectory of the investigated bubble (outlined by a red circle in a)). c) Shrinking of the bubbles in the positive part of the pulse and their subsequent expansion in the negative part, contrasted with the static images before and after the pulse.

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MICROMAGNETIC SIMULATION OF A FERROMAGNETIC PARTICLE

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In this work the magnetic behavior of a ferromagnetic particle has been investigated by means of micromagnetic modeling through the Finite Element Method. The simulations were performed on a particle with uniaxial magnetocrystalline anisotropy and ellipsoidal shape, including spherical, oblate and prolate cases, and dimensions up to 100 times the exchange length.

A damped PDE is used to describe the motion of a magnetic moment in an effective magnetic field, resulting from the variational derivative of Gibbs energy with respect to the magnetic polarization. A Rayleigh dissipation function is used to take into account the relaxation of the moment towards equilibrium. The time-dependent PDE is used as an iterative procedure rather than a real time model. Contributions to the effective field arise from exchange, magnetic anisotropy, Zeeman and magnetostatic energy. The magnetostatic field is calculated simultaneously by solving the Laplace equation for the magnetic scalar potential. The average mesh size in the magnetic domain is kept smaller than the width of a Bloch wall. In order to treat the open boundary problem an infinite element scheme is used.

The results indicate the critical size for coherent rotation, curling and multidomain reversal modes. Above a critical size the formation and motion of domain walls is clearly observed. The estimated domain wall width is lower than the one referenced in international literature. From the demagnetization curves the associated nucleation and coercive field are estimated (fig. 1).

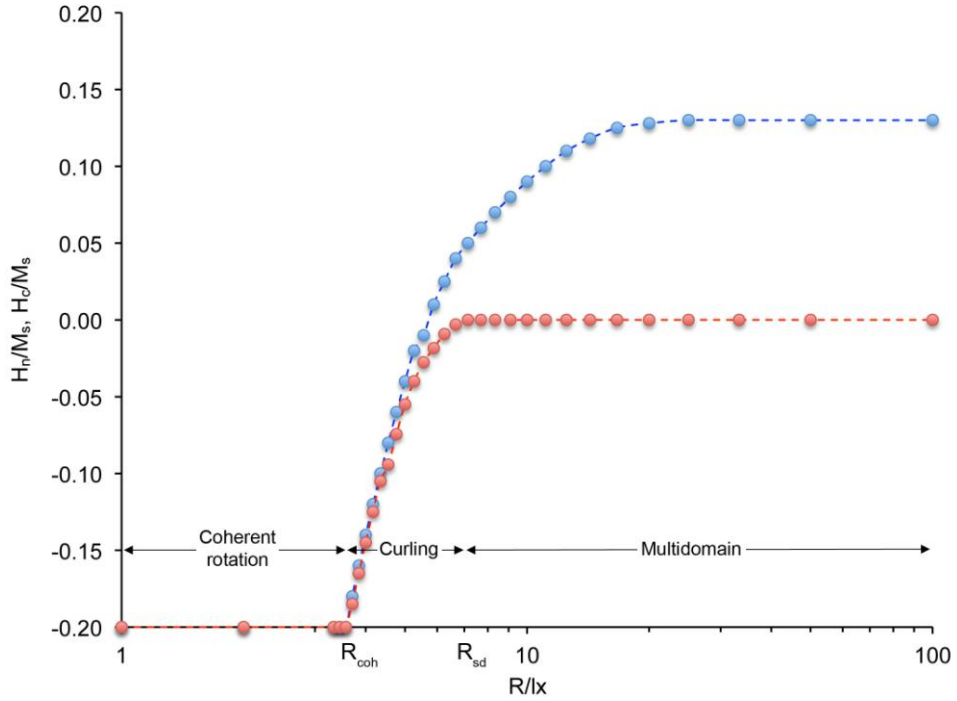

Fig. 1 Nucleation (H_n, blue) and coercive (H_c, red) field vs the radius of a spherical particle with hardness parameter κ=0.32 and easy axis parallel to external field.

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COMPARING THERMAL ESCAPE RATES OF GRADED MEDIA AND SINGLE PHASE GRAINS WITH FORWARD FLUX SAMPLING

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INTRODUCTION

Detailed knowledge about thermal stabilities of magnetic nanostructures is essential to design high density magnetic storage devices. We demonstrate a statistical method for calculating rate constants of rare switching events, called Forward Flux Sampling (FFS) [1]. FFS allows for determining the escape rates of thermally excited magnetic nanostructures under the influence of arbitrary external magnetic fields with reasonable computational effort. Within this method the phase space between two metastable states of a structure is divided into segments. To proceed from one of these states to the opposing dynamical trajectories are generated by integrating a set of Langevin equations, which originate from the stochastic version of the Landau-Lifshitz-Gilbert equation at finite temperature, between the sequent interfaces. By means of this approach we show, in a comparison between single phase grains graded media grains [2], that the latter are not restricted to the superparamagentic limit as single phase grains are. Graded media grains can provide small volumes, low coercivity and high thermal stability at the same time.

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ENERGY BARRIERS IN CIRCULAR FERROMAGNETIC NANODOTS

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One of the key parameters for using the magnetic particles (dots) as memory elements is the switching time of the dots from one to other magnetization state. This switching time is determined by an energy barrier between the initial and final state of the dot.

We measured the energy barriers between different magnetization states of 2D array of permalloy circular dots of submicron sizes (radius of 150 nm, thickness of 14 nm) by broadband ferromagnetic resonance. Time decay of the ferromagnetic resonance signal in the dot arrays was detected on millisecond time scale near the vortex nucleation field [1]. The observed effects are explained by overcoming the field dependent energy barriers between the single domain state and vortex state in the process of vortex nucleation. The magnetic relaxation times and energy barrier values were found from the resonance line intensity and compared with ones calculated within the rigid vortex model. There is strong dependence of the energy barriers on the magnetic field and dot geometrical parameters.

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CALCULATING ULTRAFAST DEMAGNETIZATION ON THE AB INITIO LEVEL: FUNDAMENTAL ISSUES

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ABSTRACT

The femtosecond demagnetization discovered in 1996 represents a critical test of magnetization dynamics theories. The demagnetization is induced by a fs laser pulse and takes place under strongly non-equilibrium situations. Here, we provide a generalized computational method for this challenging situation and review the validity of approximations commonly used in the field, with emphasis on calculations of the Elliott-Yafet electron-phonon spin-flip (SF) scattering [1]. We also show what errors are to be avoided in treating the pump-probe setup [2].

For the laser-pumped electronic system we consider both thermalized and non-thermal electron distributions. We compute the electron-phonon SF rates and examine the evolution of the total spin momentum [3]. We find that the demagnetization rate is very low for any thermalized electron distribution compared to non-thermal distributions present within the first hundreds of femtoseconds following the pump. We also show that the density of states and the energy-dependence of the SF probability have to be included accurately in calculations. A comparison of demagnetization rates is provided for all ferromagnetic transition metals.

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PROBING NANOWIRE EDGE ROUGHNESS USING AN EXTENDED MAGNETIC DOMAIN WALL

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The motion of a domain wall in a magnetic wire under the influence of a magnetic field below the critical depinning threshold is dominated by thermal fluctuations, and is characterised by discrete jumps between metastable pinning sites. The dynamic propagation of domain walls is therefore highly dependent on nanowire morphology and the depinning mechanism under thermal fluctuations will ultimately determine the lower limit of the device size. Building on the expertise in controlled behaviour of magnetic domain walls, we present a Lorentz TEM study of the depinning of magnetic domain walls using pulsed and static magnetic fields. Domain walls are injected into the wire using a nucleation pad in a key like structure, thereby assuring a large degree of repeatability. By varying the pulse duration, we show that the injection and depinning of domain walls is thermally activated and can be described by a stochastic model where depinning occurs at the wire edges. We utilise the vertex of a transverse wall to probe the wire edge roughness on nanometre and micrometre length scales. We extract a mean pinning strength in addition to the density of random defects along the wire.

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SYMPOSIUM 8.2

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Engineering iron oxide nanoparticles for applications in nanomedicine: MRI and cell therapies

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Nanomedicine is defined as the application of nanotechnology to healthcare. It has the potential to enable early detection and prevention of diseases as well as to improve their diagnosis, treatment and follow-up.

Among nanoparticles for therapy and/or diagnosis, magnetic nanoparticles made from iron oxide have a privileged status because of their biocompatibility combined with their specific responses to magnetic fields. The wide range of biomedical applications of iron oxides has spurred remarkable advances concerning the fabrication of magnetic nanoparticles with tailored properties and easy processability. Indeed, controlling the physico-chemical characteristics of the particles is crucial since those will have a direct influence over their functional properties and performances. I will discuss aspects regarding the design of iron oxide nanoparticles with optimized properties and how those depend on the nanoparticles synthesis and functionalization including their interaction with biological cell media. The use of such systems as drug delivery vehicles and contrast agents for MRI will also be discussed [1.2.3]. In addition exploiting iron oxide nanoparticles to label endothelial progenitor cells for cellular therapy in brain ischemia treatment will be presented. Preliminary in vivo cell tracking experiment demonstrates that magnetized endothelial progenitor cells can be guided to cortical areas of the brain by an external magnetic field [4].

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ORIGINS OF MAGNETIC HYPERTHERMIA

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INTRODUCTION

There are three mechanisms that can give rise to magnetic hyperthermia: hysteresis loss, susceptibility loss and viscous loss. 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. In this paper we review the critical particle sizes at which the different mechanisms become dominant. This is shown schematically in Figure 1. For example for a frequency of 100kHz the critical size for superparamagnetic behavior (D_p) for magnetite nanoparticles with an anisotropy constant K = $5x10^5$ ergs/cc is D_p =10.3nm [1]. We find that for a typical colloid containing particles of ~12nm diameter in water the measured susceptibility loss peaks at around 10kHz and hysteresis loss dominates as shown in Figure 2. However, for a typical system with a field amplitude of 250Oe and a frequency of 100kHz the loss is limited to particles with D<13.1nm. The larger particles then cause heating by stirring. This has been observed by comparison of heating in the liquid and solid states.

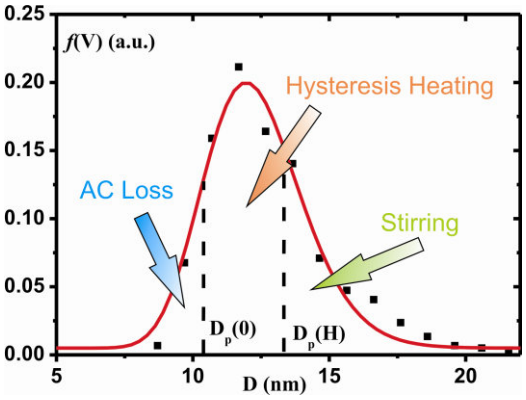

Figure 1. Schematic diagram showing the critical sizes at which different loss mechanisms dominate.

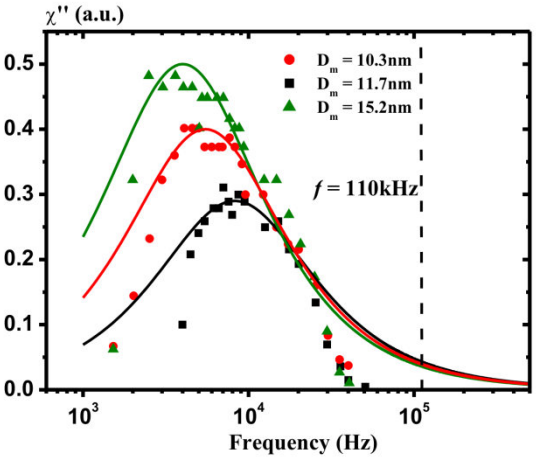

Figure 2. AC susceptibility as a function of frequency for samples of different particle size.

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CAN AC MAGNETIC HYPERTHERMIA BE EXPLOITED IN COMMERCIAL FERROFLUIDS ADDRESSING DIVERSE BIOMEDICAL ASPECTS?

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Multifunctional magnetic nanoparticles are considered as promising candidates for various applications combining diagnosis, imaging and therapy [1]. In the present work we elaborate on the commercial colloidal solution “FluidMag” [2] as a possible candidate for a magnetic hyperthermia agent, that is a dispersion of magnetite nanoparticles (NPs) which is employed for purification or separation of biotinylated biomolecules from different sources (e.g. blood).

Transmission Electron Microscopy showed that the NPs have a spherical shape with mean diameter of 12.3 nm (± 20%), and SQUID magnetometry revealed their superparamagnetic character. The temperature rise of the samples when exposed in an AC external magnetic field quantified by the Specific Loss Power (SLP) may be optimized as indicated in figure 1.

The promising results of the AC hyperthermia efficiency of “FluidMag” suggest that with the appropriate manipulation beside its actual role it can simultaneously be exploited as magnetic hyperthermia agent.

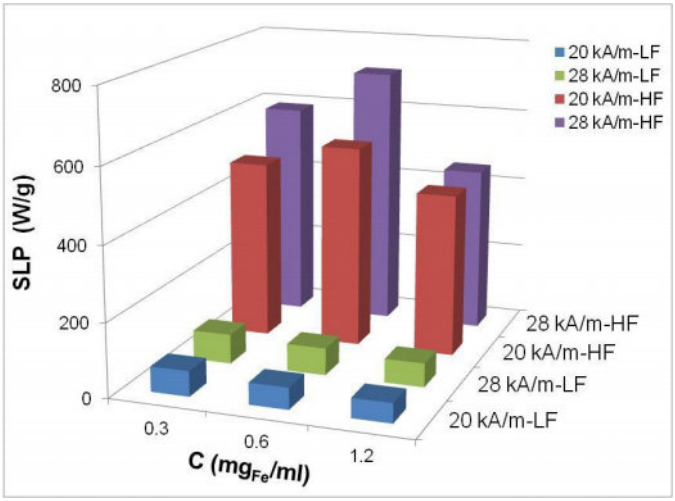

Figure 1: SLP at various concentrations under two AC magnetic field frequencies (LF:210 kHz, HF:765 kHz) and two field intensities (20, 28 kA/m).

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INDUCED CELL TOXICITY ORIGINATES DENDRITIC CELL DEATH FOLLOWING MAGNETIC HYPERTHERMIA TREATMENT

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ABSTRACT

Magnetic hyperthermia (MH) is based on the use of magnetic nanoparticles (MNPs) to selectively increase the temperature of MNP-loaded target tissues when applying an alternating magnetic field (AMF) in the range of radiofrequency. To date, all MH research has focused on heat generation in an attempt to elucidate the mechanisms for the death of MNP-loaded cells submitted to AMF. However, recent in vitro studies have demonstrated the feasibility of inducing dramatic cell death without increasing the macroscopic temperature during AMF exposure. Here, we show that the cell death observed following AMF exposure, specifically that of MNP-loaded dendritic cells (DCs) in culture, was caused by the release of toxic agents into the cell culture supernatants and not due to a macroscopic temperature increase. We performed MH in vitro experiments to demonstrate that the supernatant of the cell culture following AMF exposure was highly toxic when added to control unloaded DCs, as this treatment led to nearly 100% cell death. Therefore, our results demonstrate that heat is not the only agent responsible for triggering cell death following MH treatment. This finding offers new perspectives for the use of DCs as the proverbial Trojan horse to vectorise MNPs to the target tumour area and these results further support the use of DCs as therapeutic agents against cancer when submitted to AMF. Furthermore, this discovery may help in understanding the mechanism of cell death mediated by exposure to AMF.

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MAGNETIC NANAOPARTICLES SYNTHESIZED BY CHEMICAL SLICING METHOD

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Magnetic nanoparticles (MNPs) are potentially useful in adjuvant cancer therapy in the form of magnetic hyperthermia (MH) by localization of treatment to cancerous tumour with minimum side effects to the patient [1]. We propose a novel MNP fabrication method using template-assisted electrodeposition. First, multi-layer Ni_xFe_{1-x} nanowires are fabricated within an AAO template which is immersed in a chemical bath. The composition of the Ni at each layer is determined by the applied potential at the deposition sequence. The nanowires are then etched by HNO_3. Due to the differential etching rate, some of the NiFe layers will be completely removed, while the layers that are not dissolved remain as disc-shaped nanoparticles, as shown in the Figure 1(a). Inset is a magnetic force microscopy image of the magnetization configuration of the MNPs. This approach is able to accommodate more than 200 layers per AAO template, thereby yielding 200 times more MNPs than a lithography substrate of equal size. Micromagnetic simulation was performed to understand the magnetic configurations. Simulation results show that MNPs with diameter 100nm can accommodate two distinct vortex magnetization configurations during the reversal process, as shown in Figure 1(b). The switching between the two configurations is expected to generate heat that can be potentially used to destroy cancer cells.

(a) (b)

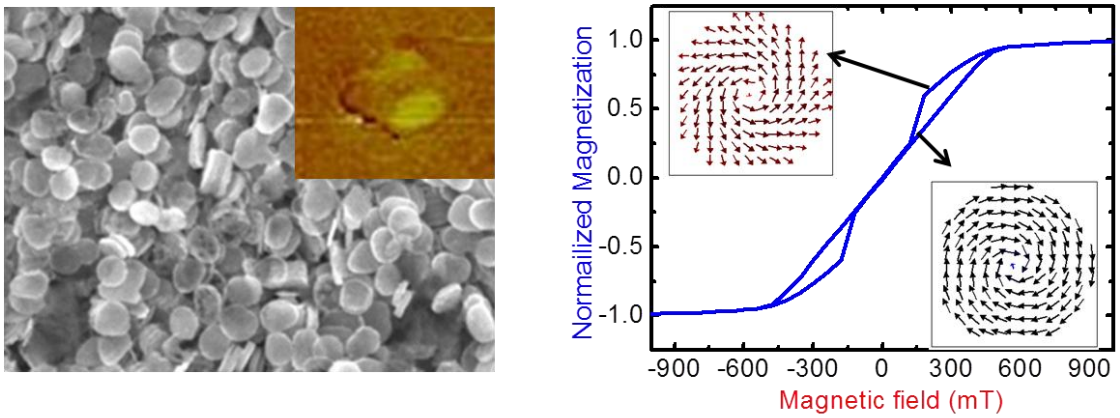

Figure 1 (a) Scanning Electron Microscope image of the MNPs. Inset is the MFM image. (b) The simulated hysteresis loop of the magnetic nanoparticle.

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CoZn-FERRITE NANOPARTICLES FOR MAGNETIC FLUID HYPERTHERMIA

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Magnetic fluid hyperthermia is a versatile complementary method for treating cancerous diseases. It uses the fact that the healthy cells are more resistant to increased temperatures than the cancerous ones. Particles of a suitable magnetic material subjected to an r.f. field may locally increase the temperature and either directly cause the apoptosis of the tumorous cells or increase their sensitivity to radiation or drugs.

Unintentional overheating of the healthy tissue may be prevented by choosing an appropriate magnetic material, whose heating efficiency decreases with increasing temperature and a self-controlled temperature regime is reached. Nanoparticles of CoZn ferrite may serve this purpose as their size, composition and ion distribution control their transition to the superparamagnetic or paramagnetic state. The magnetic cores of $Co_{0.4}Zn_{0.6}Fe_2O_{4+\gamma}$ with two different sizes were prepared by the coprecipitation method followed by annealing and mechanical treatment. The subsequent silica encapsulation of the samples led to coloidally stable non-toxic water suspensions.

The magnetic losses were determined from AC hysteresis loops and compared with the calorimetric measurements of the particle suspensions. The calorimetry was supplemented by investigation of thermal exchange between the heated/cooled sample and its surrounding which enabled to derive corrections for non-adiabaticity of the calorimeter.

For comparison of the heating efficiencies of the ferrite cores (A–12 nm, B–24 nm) the losses were evaluated at 22 °C (see Fig.1).
The volumetric power dissipation depends on H_0 (AC field amplitude) as

$$P = \pi\mu_0\chi_0 H_0^2 \nu \frac{2\pi\nu\tau}{1+(2\pi\nu\tau)^2} \qquad (1)$$

Our samples A and B fulfil relation (1) with H^n, where n is close to 2.

The support by project GACR P204/10/0035 is gratefully acknowledged.

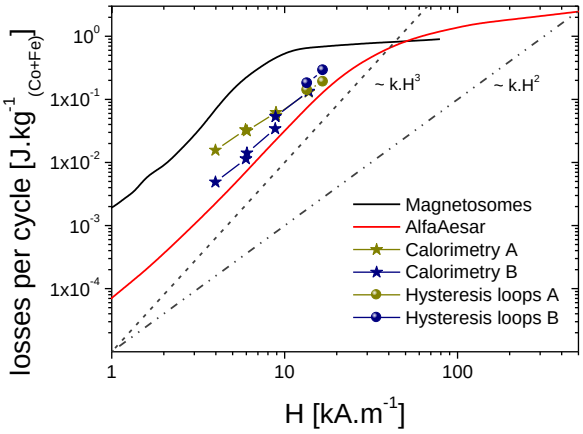

Fig. 1. Dependences of losses per cycle on the field amplitude of samples A and B. For comparison, the curves of magnetosomes (Fe_3O_4) and commercial product (γ-Fe_2O_3 99%, AlfaAesar) are shown [*JMMM 321 (2009) 1501*]. The data from calorimetric measurements are also given.

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COLLAPSE OF PROTEIN MACROMOLECULE INDUCED BY A FORCE AS AN ANALOG OF REMAGNETIZATION

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Recently, methods to investigate protein unfolding at the single-molecule level have been developed. In experiments, the stretching force is applied between a pair of amino-acid residues and the dependence of the distance between them is measured as a function of the force. Those dependencies share the common property – all of them demonstrate the general feature: when the force reaches some critical value, the protein begins to flow out, i.e., its length decreases readily without further force increasing. That looks like a sharp phase transition and analogous to the coercive remagnetization of ferromagnets.

Describing that transition is also possible in terms of the “magnetic” mean-field theory which predicts the phase transition of a protein macromolecule from the elastic to plastic state under the mechanical stretching. As in the “magnetic” Ising model, the critical force depends significantly on the mean number of links per one amino-acid residue – the larger that number, the higher the force turning the protein in the plastic state. Proteins with the mean coordination number less than some critical value could not exist in the globular form – arbitrarily small force destroys that state.

Outlined results are generally agree with experiments. That gives ground for considering the “magnetic” effective field theory as a model for adequate describing integral mechanical properties of proteins.

SYMPOSIUM 3.5

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NEW MAGNETIC BORIDES CONTAINING PLANAR B_6 RINGS: EXPERIMENT AND THEORY

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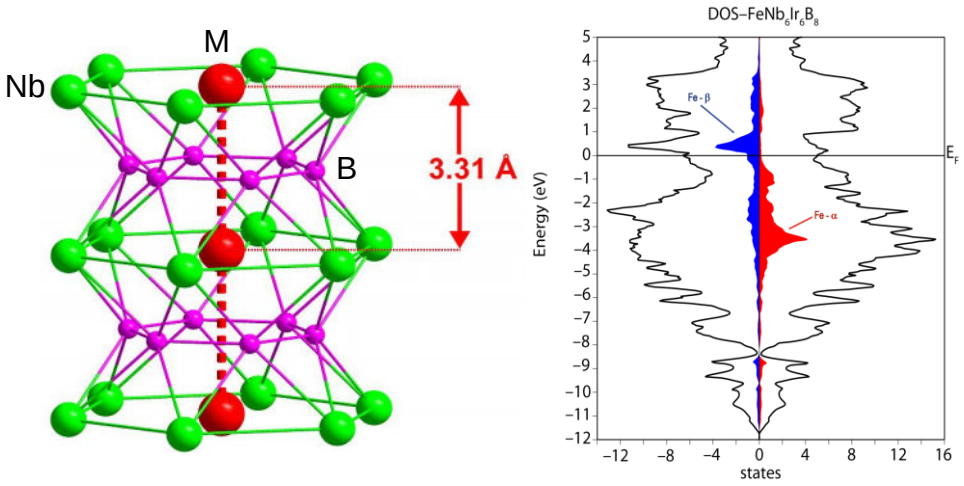
We have recently reported on a novel compound, $Ti_7Rh_4Ir_2B_8$, containing in its structure the first planar B_6 ring found in the solid state. [1] The occurrence of such a planar B_6 ring in metal borides may have been expected because it can be considered the starting motif to generate the boron layer in the AlB_2-type structure. Other isostructural borides were also published recently. [2] We have been able to substitute Ti (or Nb)-chains by chains of magnetically active elements (Cr, Mn, Co, Fe, Ni) to produce new itinerant magnets (antiferro-, ferri- and ferromagnets).[3] We have transferred this synthetic strategy to the ternary phase $Nb_7Ir_6B_8$ and obtain new quaternary phases containing one dimensional sandwich-like MB_6 (M = Cr, Mn, Co, Fe, Ni) substructures (Figure 1, left). [4] Theoretical DFT investigations predict various magnetic characteristics including Pauli paramagnetism as well as ferromagnetism (Figure 1, right) among the series. The predicted magnetic properties have been confirmed experimentally.



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STRUCTURE AND MAGNETIC PROPERTIES OF $Hf_2(Co_{1-x}Fex)_{11}B$ MELT-SPUN ALLOYS

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Introduction. There is economic and scientific interest in attaining good permanent magnet properties without rare-earth elements. The new compounds of $Hf_2Co_{11}B$, as a competitive candidate for rare-earth free permanent magnets, with suitable properties for high-energy product permanent magnets is lately reported [1]. In this work is reported our research on $Hf_2(Co_{1-x}Fex)_{11}B$ melt-spun ribbons.

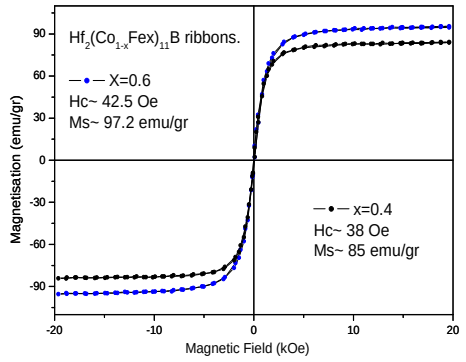

Figure 1. *Typical hysteresis loops of* $Hf_2(Co_{1-x}Fex)_{11}B$ (x=0-0.6) *melt-spun ribbons (v=25 m/s).*

Experimental. $Hf_2(Co_{1-x}Fex)_{11}B$ (x=0-0.6) alloys were prepared by arc-melting in an argon atmosphere. The alloy ingots were induction melted in an argon atmosphere and then ejected under argon pressure onto copper wheel rotating at surface velocities of 15-35 m/s. The heat treatments of the melt-spun ribbons were carried out in vacuum at temperatures between 600 and 800 ^oC followed by fast quenching. The specimens were examined by X-ray powder diffraction (XRD) using Cu-K_α radiation. Differential thermal analysis (DTA) and thermomangetic analysis were performed with a Perkin Elmer Pyris Diamond TG/DTA. The hysteresis loops of the specimens were measured at room temperature by VSM under a maximum applied field of 2.0 T.

Results and discussions. Magnetic hysteresis loops from the as-spun ribbons measured at 300 K are shown in Fig. 1. The melt-spun sample at 25 and 35 m/s shows soft ferromagnetism, with a coercive field ~ 40 Oe. Ribbons spun at the lower wheel speed of 15 m/s are under investigation, and it is expected to have a different behavior. X-ray diffraction patterns show that the as-spun ribbons are partially amorphous and could be nanocrystalline after moderate annealing conditions. The hydrogen effect was studied in order to improve coercivity enhancement.

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EFFECT OF Fe ADDITION ON MAGNETIC PROPERTIES OF Mn BASED $Mn_{49}Ni_{42-x}Sn_9Fe_x$ METAMAGNETIC SHAPE MEMORY ALLOYS

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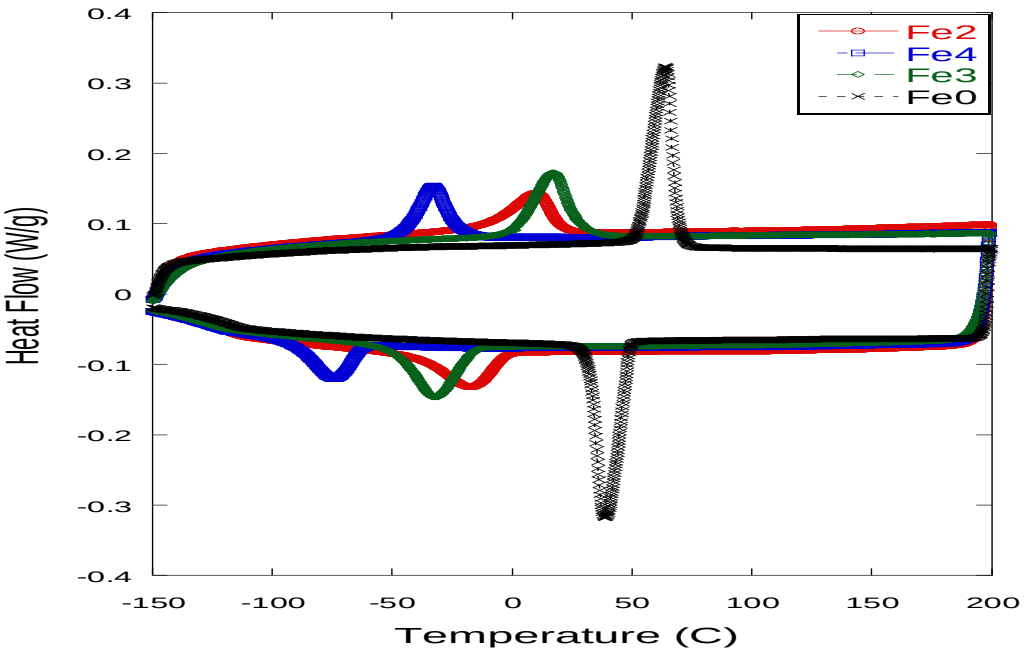
The Ni-based Ni-Mn-X (X=In,Sn,Sb) metamagnetic shape memory alloys (MMSMAs) exhibiting the martensitic transformation (MT) from a ferromagnetic austenite to a martensite with much lower magnetization have obtained a considerable attention [1,2]. Recently the Mn-based MMSMAs as re-designed aforementioned materials have been suggested and their studies demonstrated competitive magnetocaloric and magnetoresistance properties [3].

A new series of Mn-based $Mn_{49}Ni_{42-x}Sn_9Fe_x$ (X=0-6at.%) MMSMAs has been designed and fabricated in the present work. The influence of Fe substitution for Ni and high magnetic field on the magnetization was studied in detail. The martensitic transformation temperatures decrease with increasing Fe content as DSC curves demonstrate (figure 1). The presence of the FCC γ–phase has been found for higher content of Fe. The experimental results are discussed in terms of concurrent ferro- antiferromagnetic interactions.

Figure 1. DSC curves of alloys



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STRUCTURAL AND MAGNETIC PROPERTIES OF THE HEUSLER COMPOUNDS Mn_2FeGa AND Fe_2MnGa

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In recent time Mn based Heusler alloys received significant research interest as they show several interesting fundamental as well as functional properties [1,2]. In particular, Mn_2YZ based materials are considered to be promising candidates for spintronics and spin-torque transfer (STT) applications due to a large spin polarization of the conduction electrons and a large anisotropy in tetragonal phase. The tetragonal ferrimagnetic (FI) compound Mn_3Ga is the center of attraction due to its low saturation magnetization, high Curie temperature (T_C), and high spin polarization [3]. To further tune the magnetic properties of the system we substitute Mn by Fe to obtain Mn_2FeGa and Fe_2MnGa. Mn_2FeGa crystallizes in a tetragonal structure after annealing at low temperatures (≤ 400 °C), whereas, it becomes pseudo-cubic for higher annealing temperatures. The sample annealed at 400 °C shows a ferrimagnetic ordering with high T_C of 650 K. The sample also shows a hard-magnetic behavior at room temperature. In contrast, Fe_2MnGa crystalizes in a pseudo-cubic that shows ferromagnetic ordering with a T_C of around 800 K. The sample shows a first-order FM-AFM transition around 300 K.

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IN PLANE AND OUT OF PLANE MAGNETIC PROPERTIES IN $Ni_{46}Co_4Mn_{38}Sb_{12}$ HEUSLER RIBBONS

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INTRODUCTION

Recently melt spinning in Heusler system has gained much attention as it produces strongly textured polycrystalline ribbons. In the present study, we have studied the magnetic and magnetocaloric properties along two characteristic directions of the melt spun ribbon $Ni_{46}Co_4Mn_{38}Sb_{12}$. Here in plane (IP) refers to the case where the field is applied parallel to the ribbon plane and out of plane (OP) refers to the field applied perpendicular to the ribbon plane.

RESULTS AND DISCUSSION

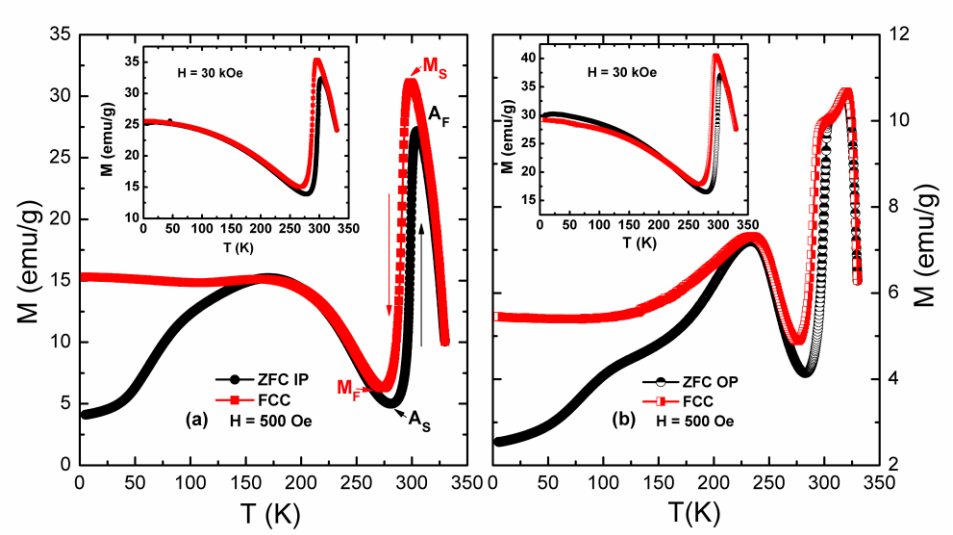

Figure 1. Thermomagnetic curves for (a) IP, (b) OP robbons.

The martensitic transition shows similar behavior for both IP and OP ribbons (Figure 1). The thermomagnetic irreversibility is found to be larger in the OP ribbon, indicating that the magnetic anisotropy is larger in this case. The M(T) for OP ribbon shows the Hopkinson maximum. The IP magnetization shows saturation at lower field in comparison to the OP. Isothermal magnetic entropy change is found to be nearly same for both the ribbons. The coercivity and exchange bias values are larger for the OP ribbon. Crystallographic texturing of the ribbons and its effect in the easy magnetization direction are found to be the reason behind the differences between the two ribbons.

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NON-COLLINEAR MAGNETISM AND A SPIN CROSSOVER IN MN_2RHSN HEUSLER COMPOUND

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INTRODUCTION

Most of the exploited magnetic compounds are the so-called collinear magnets: materials in which the magnetization is formed by local magnetic moments aligned parallel or antiparallel to one another (ferromagnets, antiferromagnets or ferrimagnets). At the same time, the possibility to change the orientation of local magnetic moments in a controlled way provides a manifold of new alternatives to tune the parameters of spintronics devices.

Magnetic properties can be tuned first of all in the multicomponent systems containing several magnetic sublattices with various types of interactions - classical spin exchange and relativistic effects, such as magnetocrystalline anisotropy and Dzyaloshinsky-Moriya antisymmetric exchange. An extremely rich materials source for adjustment of these parameters is provided by ternary Heusler compounds which count over 1000 members. Due to the broad range of physical properties (half-metallic ferromagnetism, antiferromagnetism, compensated ferrimagnetism, topological insulators, spin-gapless semiconductivity, spin-resolved electron localization, superconductivity,) they serve as a perfect playground for almost any material engineering task. In the following we will demonstrate the design scheme for Heusler magnets with a large magnetic non-collinearity unmet in this materials class so far, together with its experimental verification.

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INTERMARTENSITIC TRANSITIONS IN MAGNETIC SHAPE-MEMORY ALLOYS

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Magnetic shape memory Ni-Mn-Ga Heusler alloys are known for their complex magneto-structural properties around the martensitic transition taking place between a high-temperature austenite phase and a low temperature martensite phase. Additionally, within the martensite phase, intermartensitic transformations can also be observed as shown in a number of works.[1-4] We study here the details of the structural and magnetic properties of the intermartensitic transformation in a series of Ni-Mn-Ga alloys in the critical composition region, where the austenite Curie temperature and the martensitic transformation temperature nearly coincide.[5] We undertake temperature dependent magnetization, resistivity and x-ray diffraction studies to investigate the magnetic, transport, and structural properties. We find correlation in all temperature-dependent data, where in particular the Rietveld-refined x-ray diffraction data indicate an incomplete intermartensitic transition from 7M to mixed 7M-tetragonal structure on decreasing temperature.

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THURSDAY MORNING

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Future prospects of magnetoresistance, spin manipulation technology and their applications to novel spintronic devices

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This paper describes review and future prospects of the basic technologies for spintronics and their applications to various devices. As shown in Fig. 1, the main driving force for the progress of spintronics has been the improvement of magnetoresistance effect. The magnetoresistance (MR) ratio at RT and low magnetic field (~10 mT), which is the performance index in various device applications, has increased up from about 1% to several hundred percent thanks to the giant magnetoresistance (GMR) effect, the tunnel magnetoresistance (TMR) effect in MTJs with an amorphous Al-O tunnel barrier, and the giant TMR effect in MTJs with a crystalline MgO(001) tunnel barrier. The development of MTJs with CoFeB/MgO/CoFeB structure [1,2] was especially important both for basic researches and device applications. These effects have already been applied to the read head of hard disk drive (HDD). TMR effect in Al-O-based MTJs has also been used in Mb-scale magnetoresistive random access memory (MRAM) with the toggle writing (Oersted field writing). Moreover, the giant TMR effect and spin-transfer torque (STT) switching in MgO-based MTJs enable us to develop relatively high-density STT-MRAM with in-plane magnetization and ultrahigh-density STT-MRAM with perpendicular magnetization that can replace DRAM. We will discuss major challenges for developing next-generation STT-MRAM. We will also talk about novel devices such as spin-torque oscillator (STO), nano-sized physical random number generator named Spin Dice, and voltage-driven MRAM.

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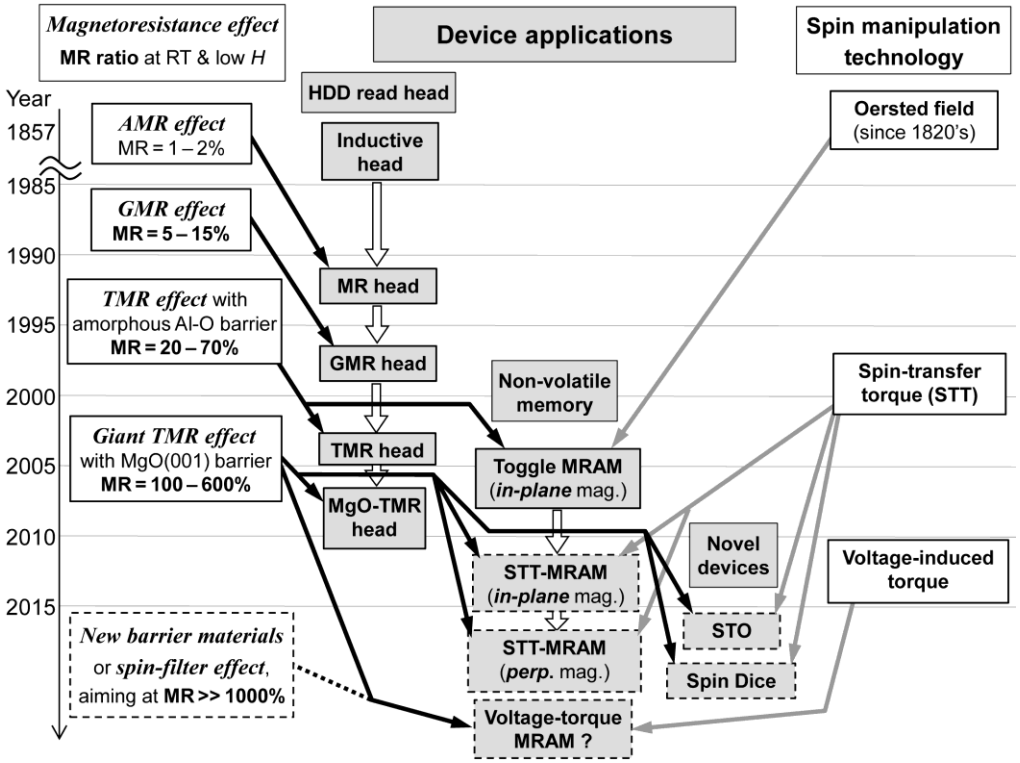

Figure 1 History and future prospects of magnetoresistive effects, spin manipulation technologies, and their applications to practical devices.

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MOLECULAR QUANTUM SPINTRONICS USING SINGLE-MOLECULE MAGNETS

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Everyday life is full of useful magnets, solids, oxides, metals and alloys. On the contrary, molecules are most often considered as non-magnetic materials. However, recent discoveries show that molecules can bear large magnetic moments that can have a stable orientation like traditional magnets. They have therefore been called single-molecule magnets (SMMs) and they might be the ultimate limit for information storage. They do not only exhibit the classical macroscale property of a magnet, but also new quantum properties such as quantum tunnelling of magnetization and quantum phase interference, the properties of a microscale entity. Such quantum phenomena are advantageous for some challenging applications, e.g. molecular information storage or quantum computing.

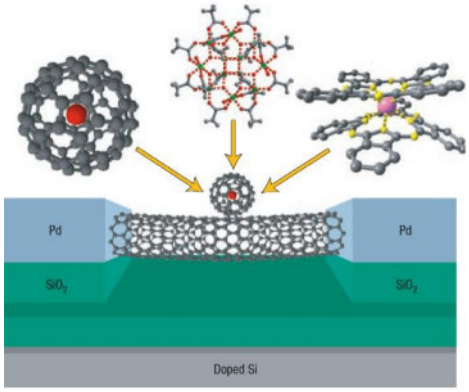

Figure 1: A suspended carbon nanotube device decorated with magnetic molecules: (form left to right): a C60 fullerene including a rare-earth atom, the Mn12 SMM and the rare-earth-based double-decker [Tb(phtalo-cyanine)$_2$] SMM. The gate voltage of the device is obtained by a doped Si substrate covered by a SiO2 insulating layer.

This presentation will first resume the basics of molecular magnets and then address the field called molecular quantum spintronics, which combines the concepts of spintronics, molecular electronics and quantum computing [1]. Various research groups are currently developing low-temperature scanning tunnelling microscopes to manipulate spins in single molecules, while others are working on molecular devices (such as molecular spin-transistors, spin valves and filters, and carbon-nanotube-based devices [1]) to read and manipulate the spin state and perform basic quantum operations. The talk will discuss this - still largely unexplored - field and present our first results [2-4].

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Search for new magneto(di)electrics: the case of some oxides with magnetic frustration

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The improper ferroelectrics where ferroelectricity (FE) originates from a particular magnetic ordering, are challenging for generating new applications and understanding multiferroism. In that perspective, the frustrated magnetic network of cobaltites, ferrites and chromites are responsible of complex magnetic ordering responsible for magneto(di)electric properties. This is the case of layered delafossites such as the magnetoelectric $CuCrO_2$ [1] which crystallizes in a complex antiferromagnetic structure (T_N=25K) [2]. Its doped $CuFe_{1-x}Rh_xO_2$ ferrite counterpart is also found to be a multiferroic [3]. In both cases, the metal network is triangular but this condition is not enough as illustrated by the lack of FE below T_N=65K in the crednerite $CuMnO_2$, which degeneracy is lifted by the orbital ordering of the Jahn-Teller Mn^{3+} ions [4]. The ferrimagnetic cobaltite $CaBaCo_4O_7$ provides another example of magnetoeclectric compound. [5]. The latter crystallizes in the polar space group $Pbn2_1$, the point group symmetry being reduced to m'm2' by its ferrimagnetic ordering similarly to some magnetoelectric boracites [6].

From the comparison between different oxides, some candidates will be proposed to go towards magnetoelectrics operating at higher T.

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SYMPOSIUM 5.6

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MAGNETISM OF SINGLE Co ATOMS ON GRAPHENE

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We characterize the magnetic properties of individual Co atoms on graphene combining scanning tunneling microscopy (STM) and X-ray magnetic circular dichroism (XMCD). First, using spin excitation spectra (SES) [1] recorded with low-temperature STM we elucidate the magnetic properties of single Co atoms adsorbed on graphene on Pt(111). For this system, we find Co to adsorb on the graphene hollow-site. Using a spin Hamiltonian description [2], we deduce an effective spin S=1 with a magnetic ground state m_Z=0 and a giant magnetic anisotropy D = (8.1 ± 0.4) meV with out-of-plane hard axis. Applying an external out-of-plane magnetic field, the two excited states m_Z=±1 are Zeeman-split with a Landé g factor g = 2.2 ± 0.4.

In the second part, we describe how the magnetic properties of Co atoms change varying the strength of the coupling between graphene and its substrate. By means of XMCD measurements at the X-Treme beam line of the Swiss Light Source, we determine the spin and orbital moments of Co atoms on graphene supported on different transition metals. For the case of weak coupling, such as for graphene/Ir(111) and Pt(111), Co atoms have an out-of-plane hard axis with vanishing values of the orbital moments. The situation is drastically different for graphene/Ru(0001), where graphene is strongly coupled with its substrate. XMCD measurements reveal a magnetic anisotropy K = 3 ± 0.5 meV with out-of-plane easy axis, and a d^8 configuration with a spin moment m_S = 1.9 ± 0.1 μ_B and a giant orbital moment m_L = 1.5 ± 0.1 μB. We speculate that a graphene top-site adsorption [3], possibly favored by the Ru(0001) substrate, could be at the origin of such a large value of m_L.

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HIGH RESOLUTION LORENTZ MICROSCOPY STUDIES OF THE MAGNETIC DOMAIN STRUCTURE OF LSMO FILMS ON STO SUBSTRATES

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$La_xSr_{1-x}MnO_3$ is an attractive candidate material for spintronic applications [1] but it can be difficult to correlate its magnetic behavior to spatially-variable factors including substrate-induced strain, doping and defects. We showcase recent work using a customized JEOL ARM200F electron microscope with sub-nanometer resolution in Lorentz imaging and high performance nano-analytical capabilities: a system uniquely capable of correlating local structure to function.

A typical magnetic induction map of $La_{0.33}Sr_{0.67}MnO_3$(120nm)/STO(111), figure 1a, shows a multi-domain structure, suggesting the absence of strong anisotropy. Figure 1b shows the 180° domain wall from the region enclosed by the white box in figure 1a, with a measured domain wall width of 7.3 nm. Given the film thickness, Bloch walls are likely to be favored, the width of which scales with $\delta = \sqrt{A/K}$. The value measured here is comparable to that predicted for $LaSrMnO_3$/STO(110), where $\delta \sim 10$ nm ($K = 1.9 \times 10^4$ J/m^3 [2]).

We present details of the impact of local crystallography on the magnetic domain structures of $LaSrMnO_3$ films, covering aspects of plan-view sample preparation, differential phase contrast imaging and micromagnetic simulations.

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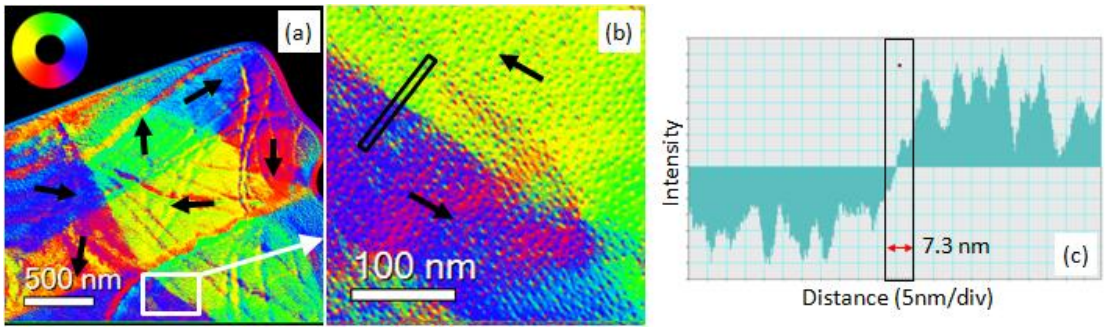

Figure 1. (a) Magnetic induction colormap of a $LaSrMnO_3$/STO(111) film showing a multi-domain state. A color wheel inset indicates the direction of magnetic induction. (b) A close-up of the region enclosed by the white box in (a), showing a 180° domain wall. (c) A line profile across the domain wall indicated by the black box in (b) gives a wall width of 7.3 nm.

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THE IMPORTANCE OF CRYSTAL STRUCTURE ON MAGNETIC ORDERING IN RARE-EARTH–TRANSITION-METAL LAMINATES

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INTRODUCTION

There has been considerable effort to push the saturation magnetisation of ferromagnetic materials beyond $\mu_0 M_S = 2.4$T of $Fe_{70}Co_{30}$ [1] – the fundamental Slater-Pauli limit for transition metal (TM) based magnets. Much higher saturation, i.e. magnetic moments per atom, can be achieved by employing rare earth (RE) metals such as Gd [2]. Those ferromagnetic REs suffer from a Curie temperature much lower than that of TMs but combining REs and TMs directly (via alloying or lamination) leads to antiparallel coupling [3]. By resorting to density functional calculations Sanyal et al. identified a set of TM-RE laminates where a Cr mediator is used to realise ferromagnetic coupling [4]. First experiments gave no indications of an overall moment increase, which is due to the RE ordering face-centred cubic in thin-film form, which impacts massively on its magnetic properties [5,6]. We now present crystallographic information and M_S(T) data from SQUID magnetometry on plasma-sputtered stacks that use Y seeding to promote appropriate hexagonal stacking of the Gd (figure 1).

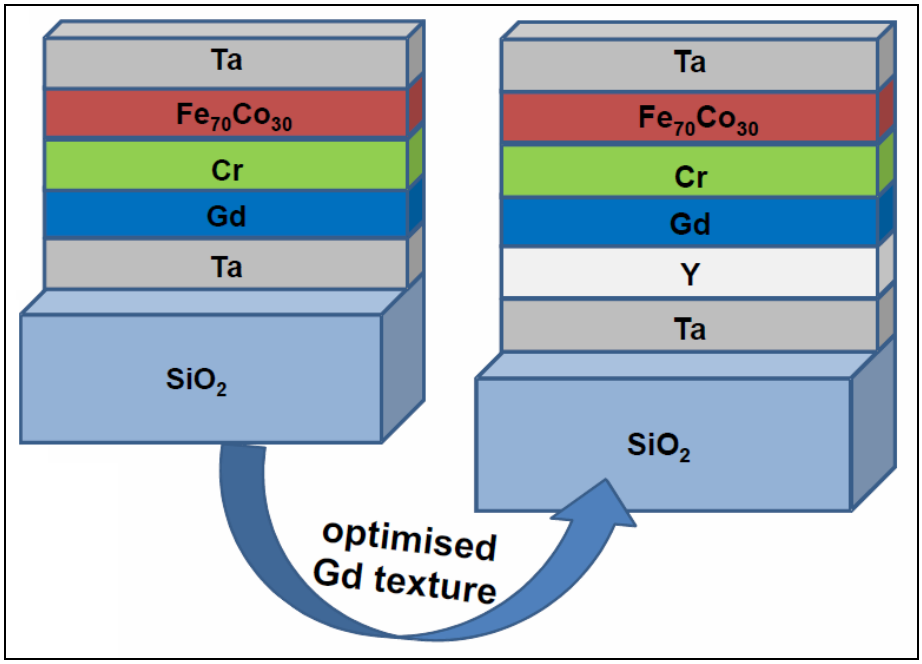

Figure 1: Y seedlayer optimisation of the Gd layer in a RE-Cr-TM stack.

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ABSENCE OF AN INDUCED MAGNETIC MOMENT IN Pt ON $Y_3Fe_5O_{12}$

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The investigation of pure spin currents in ferromagnetic metals or semiconductors is usually affected by charge currents occurring simultaneously. To avoid such interference, ferromagnetic insulators like $Y_3Fe_5O_{12}$ (YIG) have come into the focus of current research. The detection of spin currents is usually based on their conversion to charge currents in an adjacent metallic paramagnetic Pt layer taking advantage of the inverse spin Hall effect. Magnetotransport experiments in $Pt/Y_3Fe_5O_{12}$ heterostructures, however, reveal a magnetoresistance effect of Pt, displaying a hysteresis with a maximum at the coercive fields of $Y_3Fe_5O_{12}$ [1,2,5]. This unexpected observation is interpreted controversially in terms of a novel spin-Hall magnetoresistance [1,2,3] or a magnetic proximity magnetoresistance [5].

To clarify this situation, we employ an element-specific study of the magnetic behavior of $Pt/Y_3Fe_5O_{12}$ heterostructures. Using X-ray magnetic circular dichroism (XMCD) measurements, we explore the possible existence of induced magnetic moments in thin Pt films with different thicknesses from 10 nm down to 2 nm deposited *in-situ* on epitaxial layers of the ferrimagnetic insulator $Y_3Fe_5O_{12}$. Our data unambiguously show that (if present at all) the induced moment in Pt is negligibly small and cannot account for the observed hysteretic magnetoresistance. From our XMCD spectra, we estimate an upper limit for the induced magnetic moment in Pt of (0.003 ± 0.001) Bohr magnetons per atom [4], in contrast to a later report [5]. We unambiguously demonstrate that a magnetic proximity effect cannot be responsible for the observed magnetoresistance in Pt on $Y_3Fe_5O_{12}$. Our data strongly support the recent model of a novel spin-Hall magnetoresistance which was discovered experimentally [1,2] and described theoretically [3].

This work was supported by the European Synchrotron Radiation Facility (ESRF) via HE-3784, by the Deutsche Forschungsgemeinschaft (DFG) via SPP 1538, and by the German Excellence Initiative via NIM.

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FINE TUNING OF ELECTRON DISTRIBUTIONS IN 3d AND 4d TRANSITION METAL OXIDES BY STRAIN AND INTERFACE ENGINEERING

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INTRODUCTION

The properties of transition metals are crucially determined by the electron distribution in the d orbitals which determine among other, their magnetic, electronic or chemical reactivity properties.

In thin films, epitaxial strain imposed by the substrate, as well as the symmetry breaking produced by the interfaces (being the surface the most dramatic one) can lift the degeneracy of d orbitals, resulting in special orbital occupancies which can severely modify the properties of the material.

While this is well known in metals, transition metal oxides (TMO) remain scarcely investigated. Recent reports successfully explored the orbital occupancy of manganite thin films [1,2], being this a prototype 3d-TMO. It was shown how epitaxial strain clearly tunes the orbital occupancy and, a preferential occupation was identified at the surface of the films, as a result of strong rupture of symmetry.

The methodology and results obtained for manganite thin films open a way to explore orbital occupancies in other oxides. Of particular interest is $SrRuO_3$ (SRO) which is metallic and sits at the verge of a paramagnetic to ferromagnetic transition. Indeed, whereas SRO is ferromagnetic, this is not the case of $CaRuO_3$. Therefore, it may not be a surprise that the properties of SRO are very sensitive to fine tuning of its electronic properties. Indeed, by varying the strain and film thickness of SRO, different behavior are observed, leading to new transport properties [3] or even identifying new spin configurations [4], which could be explained by means of electron localization or modifications of the crystal field. In spite of these dramatic effects, little is known on the electronic occupancy of the $4d^4$ (t_{2g}^4 – low spin) electrons of SRO, and more precisely, on how the t_{2g} electrons occupy the available dxy, dxz and dyz states and its impact on functional properties.

Here we report for the first time, measurements in X-Ray Linear Dichroism (XLD) in SRO epitaxial films. These measurements, requiring high energy X-rays, had been performed at the BOREAS line of ALBA synchrotron. We identify an evolution with strain and layer thickness of the XLD signal, directly related to 4d electron orbital occupancy. We discuss, in addition, the influence of the different orbital configurations on the Ru magnetic moment (explored by X-Ray Magnetic Dichroism), which can put some light on the origin of some unexpected phenomena in ultrathin SRO films. These results are put in context by comparing to the related effects on 3d-systems and the radial extension of 4d/3d orbitals.

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MAGNETIC HYSTERESIS AND SPIN CONFIGURATION IN MAGNETOSTATICALLY INTERACTING MULTILAYERED NANODISCS

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The remagnetization process of nanostructures depends on their size, shape and array configuration [1-3]. In this study we investigated the remagnetization in multilayered nanodiscs $(Py/Cu)_N$, where $N \in [1 \div 5]$. The thicknesses of Py and Cu layers were 22 nm and 5 nm, correspondingly. We have fabricated two series of nanodisc arrays with diameters D=600nm and 1000nm.

The study of the magnetic structure by magnetic force microscopy (MFM) has shown that in single Py nanodiscs at magnetic field H=0 the vortex state is formed. In nanodiscs with N=2 the C–state is observed (Fig.1a). In nanodiscs with N≥3 the vortex state is realized (Fig.1b). The saturation field H_s depends linearly on N, Fig.1c. In multilayered nanodiscs the hysteresis loops has inflections due to the nucleation and annihilation of vortex states in magnetostatically interacting Py layers at different fields, Fig.1c.

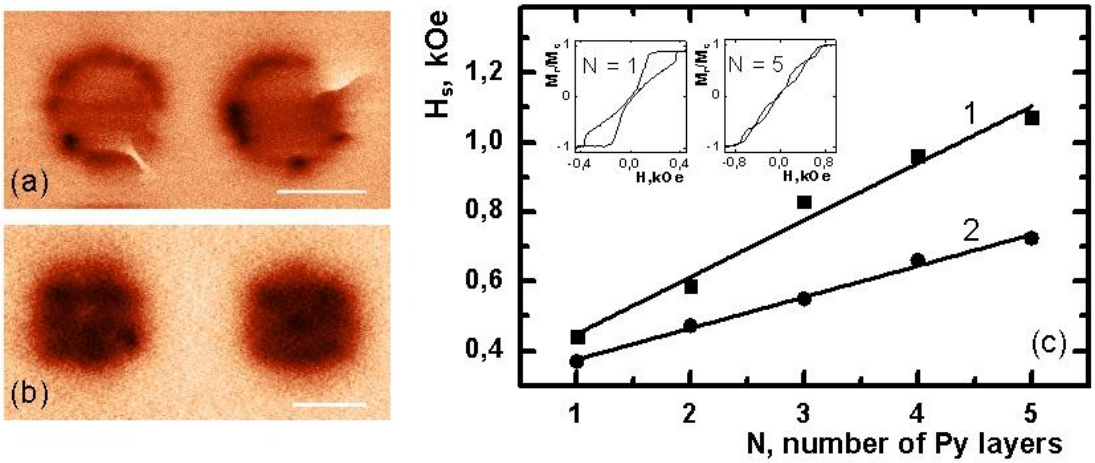

Figure 1. MFM images of nanodiscs with N=2 (a) and N=3 (b). Scale bars are 500 nm. (c) Saturation field as a function of N for nanodiscs with D=600nm (line 1) and 1000nm (line 2).

ACKNOWLEDGMENTS

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MICROMAGNETICS OF THREE DIMENSIONAL MAGNETIC DOMAIN WALLS IN CYLINDRICAL NANOSTRUCTURES

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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.

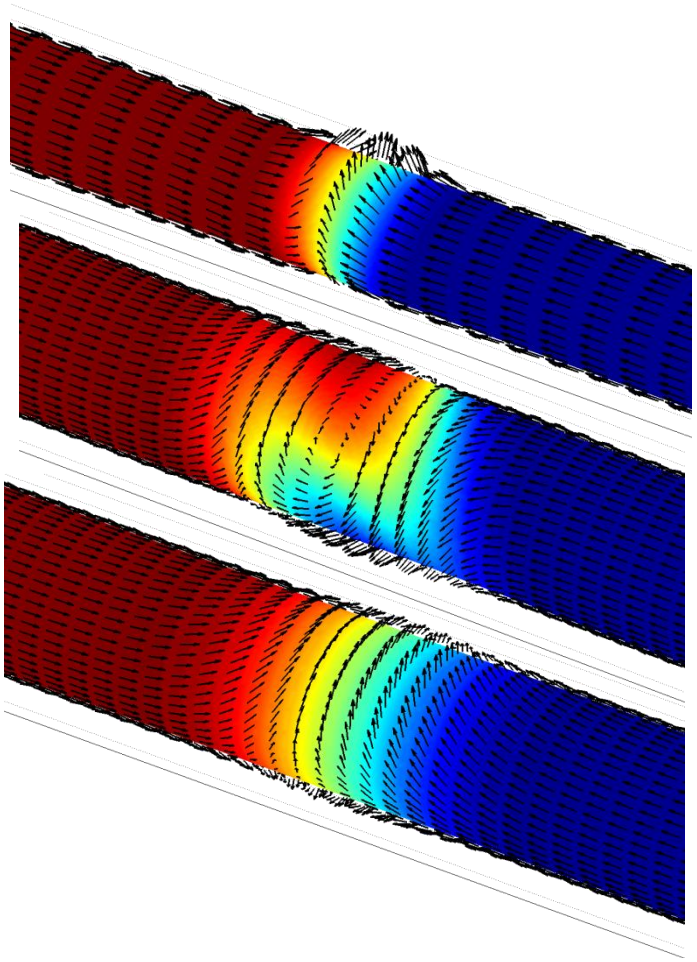

***Figure 1**: 3-D views of transverse (top), VA (middle) and vortex (bottom) DWs. Arrows indicate the direction of magnetisation while the colour map shows the axial component of magnetisation.*

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SYMPOSIUM 2.3

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SPIN WAVE MEDIATED SWITCHING OF THE VORTEX CORE WITHIN 100 PICOSECONDS AND BELOW

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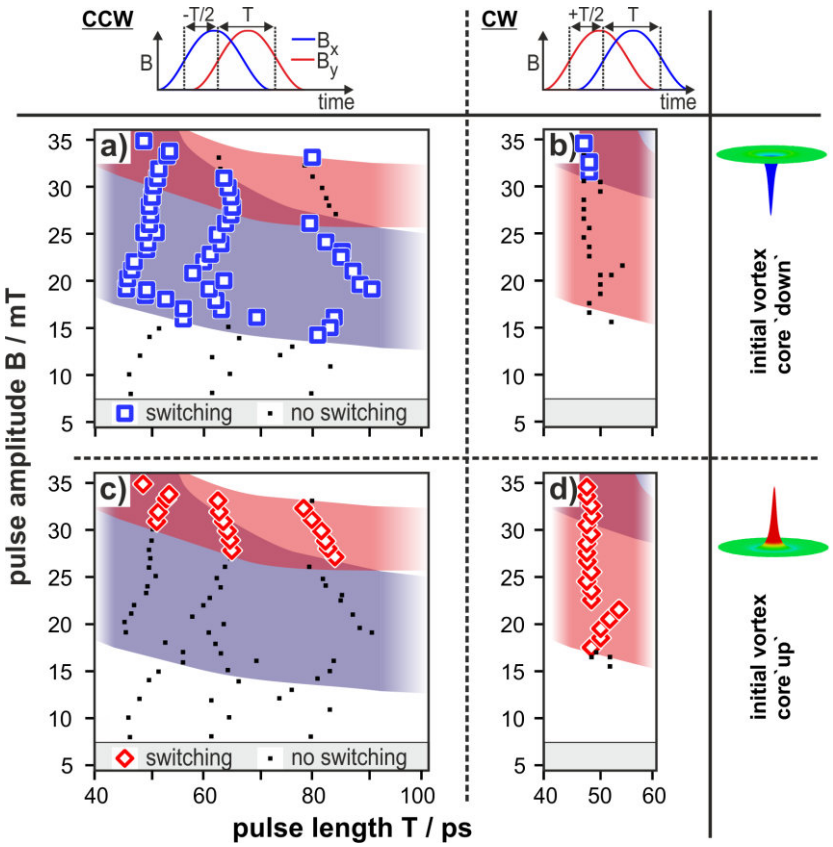
Essential progress in the understanding of nonlinear magnetic vortex dynamics was achieved when low-field vortex core toggling was discovered by excitation of the gyrotropic eigenmode at sub-GHz frequencies [1]. At frequencies more than an order of magnitude higher magnetostatic spin wave modes are observed in vortex structures. We could demonstrate [2] significantly faster and unidirectional vortex core reversals by exciting these spin wave modes at multi-GHz frequencies.

Here we show how to speed up spin wave mediated vortex core switching well below 100 ps by excitation with orthogonal magnetic pulses. The figures below show experimental phase diagrams of core reversal for a Permalloy disk, diameter: 500nm, thickness: 50nm, for varied lengths, amplitudes and senses of rotation (a,c: CCW – b,d: CW) of the two-pulse sequence. The reversal process was imaged directly by time-resolved scanning transmission X-ray microscopy at BESSY II, Berlin, confirming micro-magnetic simulations where vortex core switching times of less than 100 ps were found.



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THERMALLY ASSISTED ALL-OPTICAL HELICITY DEPENDENT MAGNETIC SWITCHING IN $FE_{100-x}TB_x$ FILMS

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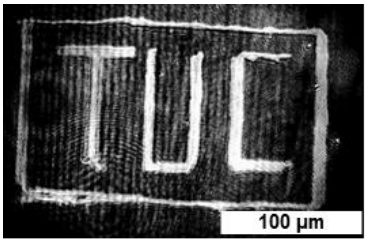

Fig. 1: All-optical switching in $Fe_{75.5}Tb_{24.5}$ using ultrashort laser pulses.

Magnetization switching is at the heart of both modern information storage technology and fundamental science. Ultrafast laser pulses are promising to explore and finally reach the ultimate speed limit of this process without any external magnetic field [1, 2]. We present all-optical switching (AOS) in amorphous ferrimagnetic $Fe_{100-x}Tb_x$ alloy films with circularly polarized laser pulses (Fig. 1) [3]. A Tb content of 22 to 34 at.% is necessary for AOS to occur. Outside this composition range pure thermal demagnetization is observed. AOS occurs not only below and above the magnetic compensation temperature (T_{comp}), but also in samples without T_{comp}. We find that AOS is associated with laser heating up to the Curie temperature. AOS is intimately linked to a low remanent magnetization M_R. Above a threshold magnetization of 220 emu/cc helicity dependent AOS is replaced by pure thermal demagnetization.

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EXCHANGE INTERACTION IN COLLINEAR AND NON-COLLINEAR MAGNETS

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INTRODUCTION

The non-collinear magnetic alignment can appear as the ground state of several magnetic materials, the calculation of exchange interaction between magnetic moments is crucial for spin dynamics calculation. Although the exchange formula in case of collinear arrangement is known for a long time [1], a counterpart for non-collinear arrangement is lacking.

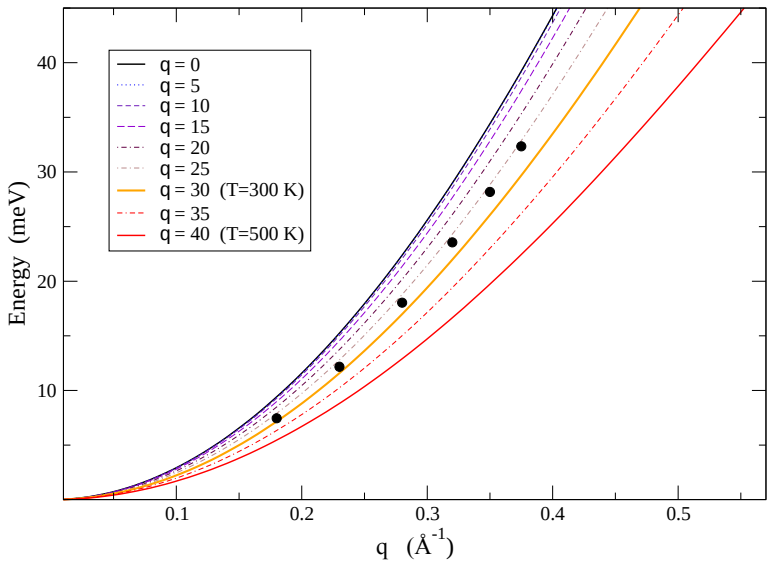

Fig. 1. Spin-wave dispersion relation in bcc Fe. The black circles refer to the room temperature neutron scattering measurement [2].

RESULTS

We show that the general exchange formula has an anisotropic-like term even in the absence of spin-orbit coupling, and that this term is large in bcc Fe and quite small in fcc Ni. We demonstrate that one should consider a biquadratic effective spin Hamiltonian even in case of collinear arrangement. In non-collinear systems this term results new tensor elements without importance at low temperature. We plot bcc Fe magnon spectra showing same quantitative results as the finite temperature neutron scattering experiments [2], black circles in Fig 1.

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ON THE ROLE OF THE MAGNETIZATION COMPENSATION POINT IN ALL-OPTICAL MAGNETIZATION SWITCHING

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Understanding ultrafast all-optical magnetization switching (AOS), *i.e.* the permanent reversal of the magnetization by the sole action of a femtosecond laser pulse in the absence of any applied magnetic field, is a challenging issue which could have tremendous impact for the magnetic recording industry. While a qualitative agreement between spin atomistic simulations and experiments exists[1], the exact role played by the magnetization compensation point T_M in the ultrafast demagnetization[2] and switching[3] in ferrimagnetic rare-earth transition-metal alloys is still not completely clear. By combining femtosecond X-ray transmission measurements with picosecond time-resolved photo-emission electron microscopy (PEEM), both using X-ray magnetic circular dichroism, we report on new insights into the AOS mechanism in GdFe based ferrimagnetic alloys. In agreement with previous experiments and theoretical predictions, AOS is seen below and above T_M, and in particular against a 0.18 T magnetic field. However, at temperatures far from T_M, no AOS is observable. Collapse of the reversed domain could be ruled out using time-resolved XMCD PEEM imaging. Static imaging of the magnetic domain configuration after AOS reveals that no domain wall (DW) motion occurs within the 100 nm spatial resolution, ruling out a nucleation and growth switching mechanism favored by the DW velocity divergence at T_M. Furthermore, investigation of the formation speed of the transient ferromagnetic-like state as a function of T_M shows very pronounced variations. These results provide evidence that the T_M is somehow a more important condition for the formation of the transient ferromagnetic-like state[4] and the occurrence of AOS than initially thought.

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MAGNETO-OPTICAL SYSTEM FOR THE STUDY OF PICOSECOND MAGNETIZATION PROCESSES

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We present magneto-optical system for the study of nano- and picosecond magnetization reversal processes. The system works by using Faraday or Kerr effects and allows us to study dynamic domains and integral magnetization reversal signals simultaneously. Mode-locked Nd:YLF laser with pulse duration of 10 ps was used as the light source for high speed photography and registration of dynamic domain structures. Photo-detectors with response time of 30 ps were used for registration of integral magnetization reversal signals. Time resolution of the system is determined by the duration of the laser pulses and the response time of the photo-detectors.

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OPTICAL MANIPULATION OF THE EXCHANGE SPIN-SPIN INTERACTION ON SUB-PICOSECOND TIMESCALE

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The exchange interaction is the strongest and fastest force in magnetism. However, the optical control of the exchange interaction has been experimental challenge so far. Though the photon energy associated with the optical excitation (~ 1.5 – 3 eV) exceeds the energy of the exchange interaction (~ 10 meV) all the experimental studies on sub-picosecond laser control of magnetic order have been described assuming that the optical excitation leaves the exchange interaction unperturbed [1]. Here we report experimental results which explicitly demonstrate that the exchange interaction can be manipulated through ultrafast laser excitation. We show that sub-picosecond optical excitation of orthoferrites modifies the energy of the exchange spin-spin interaction in these compounds and thereby triggers instantaneously coherent quasi-antiferromagnetic spin oscillations. The latter are recorded using THz emission of the samples (Fig. 1). From the strength of the electric field of the emitted THz wave we can estimate that the amplitude of the emitting magnetic dipole is ~ 1 μA cm^2, showing that a sub-picosecond laser pulse with a fluence ~ 1 mJ/cm^2 was able to change the energy of the exchange interaction of ~ 0.01 %.

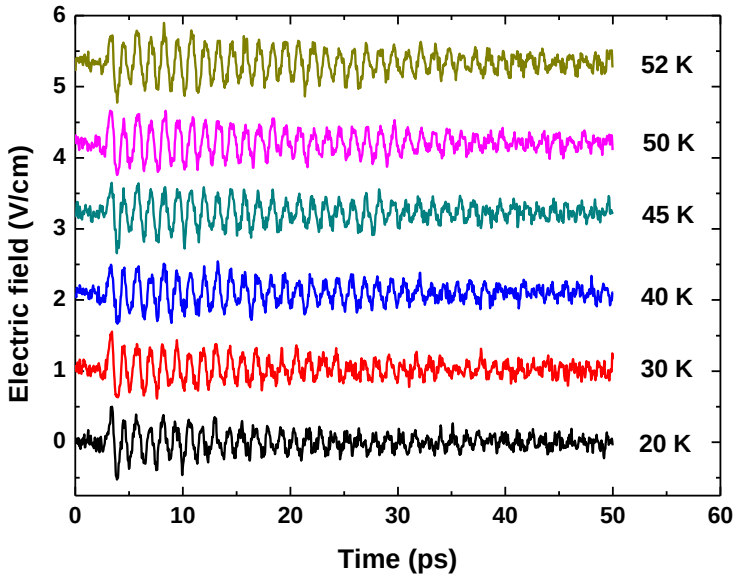

Figure 1. The THz emission generated in $TmFeO_3$ illuminated by 100 fs laser pulses at different temperatures below 55 K.

To conclude, the demonstrated feasibility of sub-picosecond optical control of the exchange interaction opens a novel means of optical magnetization control, potentially achievable in any magnetic substance. Our results provide a way to manipulate magnetic order at the ultimate fastest timescale corresponding to the exchange energy.

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GILBERT DAMPING CONSTANT OF FePd THIN FILM

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Gilbert damping constant (α) of magnetic thin film with perpendicular anisotropy has received much attention for MRAM device applications. In this study, damping constant was evaluated for $Fe_{50}Pd_{50}$ (at. %) thin films with very flat surfaces, which were obtained on MgO(001) single-crystal substrates by employing a two-step process; low-temperature deposition at 200 ºC followed by high-temperature annealing at 400 ºC [1]. Broadband FMR measurements using a VNA were carried out for these 40nm thick films under static magnetic fields (H_{ex}) up to 1 kOe in the film plane. Fig. 1(a) shows the H_{ex} dependence of resonant frequency (f_r) measured for the films with disordered and partially ordered structures. The as-deposited film shows disordered $A1$ structure and the annealed one shows partially ordered $L1_0$ structure (S=0.32). The perpendicular anisotropy of the annealed film is calculated to be 1.5 kOe by fitting the data with Kittel's resonance condition. Fig. 1(b) shows α values as a function of inverse f_r for these films. The reason why the α of annealed film shows larger values will be discussed.

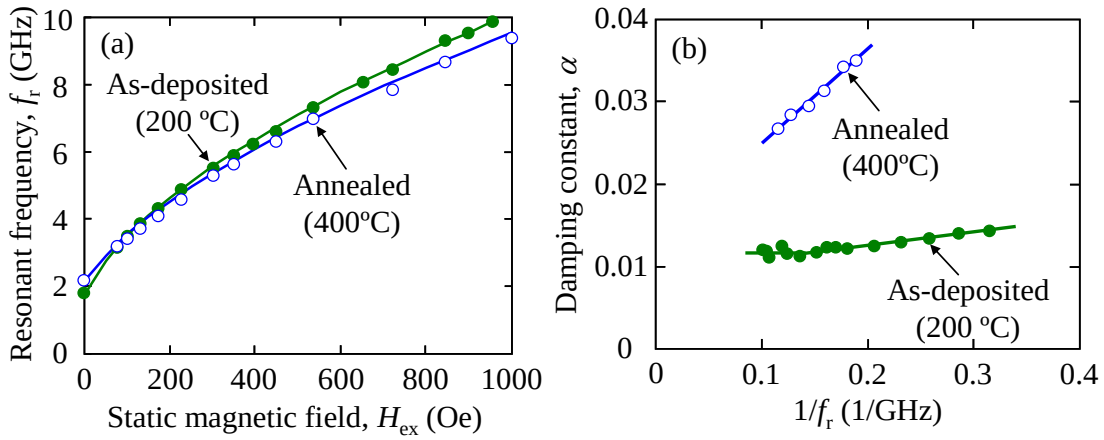

Fig. 1 Resonant frequency (a) and damping constant (b) measured for FePd films.

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SYMPOSIUM 7.1

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NANOSQUID-ON-TIP
TOWARDS SCANNING MAGNETIC MICROSCOPY WITH SINGLE SPIN SENSITIVITY

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A scanning magnetic probe microscope based on a nanoSQUID which is fabricated on the apex of a quartz tip has been developed [1,2]. The nanoSQUID-on-tip device is fabricated by pulling a quartz tube into a sharp pipette with diameters down to 50 nm followed by deposition of a thin superconducting film onto the sides and the apex of the pipette. The devices operate at 4 K in applied magnetic fields of up to 1T and display an extremely low flux noise of 50 $n\Phi_0/Hz^{1/2}$. As a result, a record spin sensitivity of better than 1 $\mu_B/Hz^{1/2}$ is achieved that is sufficient for detecting the magnetic moment of a single electron [3]. Using a quartz tuning-fork based AFM technique the nanoSQUID can be scanned few nm above the surface of the sample. The combination of high sensitivity, high spatial resolution, wide bandwidth, and close proximity to the sample opens the pathway to direct imaging and investigation of a wide range of static and dynamic magnetic phenomena on the nanoscale.

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CRYSTAL AND MAGNETIC STRUCTURES AND PHASE COEXISTENCE IN SUPERCONDUCTING IRON CHALCOGENIDES AYFE2-XSE2 (A=K, CS, RB)

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First iron-based high-temperature superconductors of 1111 type (LaO-FeAs) were discovered in 2008. Since then many new similar systems had been found with Tc=14-55K with similar superconducting properties such as Fe-Se (11), Li-FeAs (111) and Ba-Fe2As2 (122). They all possess quite simple crystal structures with similar symmetries. Towards the end of 2010, new alkali-metal (A = K, Cs, Rb) intercalated iron chalcogenides A-Fe2Se2 (A122) had been unexpectedly found. A unique feature of the new iron chalcogenides is the presence of robust antiferromagnetism with an extraordinary high Néel temperature above 500 K, and superconductivity with Tc=30 K. Alkali-metal chalcogenides have rather complex crystal structures with several phase transitions and are mixtures of phases even in the form usually described as a single crystal. A pronounced reversible phase separation revealed in A122 single crystals, as well as controversies regarding the origin of superconductivity and the stoichiometry and symmetry of the superconducting phase are still in the forefront of scientific activity. Phases resulting from phase separation metrically are very similar, so their detailed structure characterization is a delicate diffraction task.

In the talk I will present a diffraction view on the crystal structures, antiferromagnetic ordering and intrinsic phase separation in alkali-metal iron chalcogenides.

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MAGNETICALLY-ACTIVE IONIC MEMRISTORS

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INTRODUCTION

The properties of magnetic materials can be altered by applying an electric field. This has been demonstrated in thin films of ferromagnetic semiconductors [1],[2], as well as ferromagnetic metals [3],[4]. The effect is volatile, *i.e.* when the electric field is removed, the film returns to its original magnetic state. However, for technological applications, it would be desirable to have a film that retains the induced magnetic state until another command is given that switches it back into the original state.

Semiconductor oxides can be functionalized to show magnetic properties. In particular, Mn doped Zinc Oxide (Mn-ZnO) shows ferromagnetism at room temperature while Nickel Oxide (NiO) is an antiferromagnet. Magnetism in these oxides can be tuned by changing the concentration of oxygen vacancies [5]. Oxygen vacancies are also believed to be responsible for memristive switching in semiconductor oxides [6], an effect that can be used for solid-state memories.

We here show that memristive switching in Mn-ZnO and NiO coexists with a switching of the magnetic moment. Thin films of these oxides were sandwiched between two metallic electrodes and memristive switching was induced. We found that a switching of the resistive state corresponds to a switching of the magnetic moment in the film. In other words, the magnetic state can be altered in a reversible and non-volatile manner by applying an electric command.

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MOTT-INSULATING AND HIGH-Tc SUPERCONDUCTING STATES ARISING FROM STRONG CORRELATIONS IN ALKALI FULLERIDES

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Superconductivity in alkali-doped fullerides was for many years discussed within the BCS theory where the high-energy intramolecular phonons are responsible for the Cooper pairing with the *s*-wave symmetry. This view has been challenged with our recent discovery of Cs_3C_{60} compounds [1-3], which are under ambient pressure conditions Mott-insulators. In both accessible cubic Cs_3C_{60} polymorphs (A15 and fcc), the electron correlations prevail over the kinetic energy due to the electron delocalisation and are responsible for the antiferromagnetic insulating (AFI) ground states below T_N = 46 K and T_N = 2.2 K in A15 and fcc polymorphs [1,3], respectively. With the application of pressure, Cs_3C_{60} undergoes an insulator-to-metal transition and the superconductivity is restored at the surprisingly high temperature reaching maximum of T_C = 38 K at the pressure of 0.79 GPa in A15 polymorph [1].

Here we report on the comprehensive experimental investigation of the complete phase diagram of alkali-doped fullerides as a function of temperature and pressure. The stability of the phases is governed by the ratio *U*/*W* of onsite electron correlations (*U*) and the electronic bandwidth (*W*), which is in these compounds volume dependent. We combine temperature- and pressure-dependent local probe techniques (mostly nuclear magnetic resonance), bulk measurements and structural investigations to address the antiferromagnetic insulating, metallic and superconducting states. In particular we show that the BCS theory is unlikely explanation for the observed superconducting state and that other unconventional models where strong electron correlations are important must be considered.

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INTERLAYER MAGNETORESISTANCE OF MONOAXIAL CHIRAL MAGNET

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INTRODUCTION

In magnetic crystals belonging to chiral space group, the relativistic spin-orbit interaction called Dzyaloshinskii-Moriya (DM) interaction competes with Heisenberg-type ferromagnetic (FM) exchange coupling, which will result in an emergence of chiral magnetic orders and various interesting physical properties unique to chiral magnetic crystals. In this study, we report real-space and k-space analyses of chiral magnetic order in a hexagonal chiral magnetic crystal $CrNb_3S_6$ using transmission electron microscopy. Also, we have investigated the interlayer electric resistance in magnetic fields applied perpendicular to the chiral crystallographic axis.

METHODS

Chiral magnetic crystal $CrNb_3S_6$ was grown by chemical vapor transport method. Fresnel mode of Lorenz microscopy and small-angle electron scattering experiments have been performed to examine magnetic structures by using a conventional transmission electron microscope. Electric interlayer resistance was measured in a four-terminal ac resistance method.

RESULTS and DISCUSSION

A negative magnetoresistance (MR) is observed in a wide range of temperature below the Curie temperature while the chiral magnetic soliton lattice is formed and transforms into a forced ferromagnetic state [1]. We discuss the origin of the MR in terms of the chiral soliton lattice formation [2].

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I-V CHARACTERISTICS OF ENGINEERED AND NON-ENGINEERED SUPERCONDUCTING FILM

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We have thoroughly studied the I-V characteristics of two superconducting thin films, one with square array of anti-dots and another with non-engineered film. The I-V characteristics of these superconducting films are measured at different temperature and applied magnetic field. The I-V characteristics of nano-engineered superconducting or non engineered film investigated at well below transition temperature (T_c). The superconducting thin film with 2D array of antidots shows the sudden jumps in I-V characteristic at well below transition temperature T_c. But the non-engineered superconducting film has no steps or sudden jumps in the I-V curves at different temperatures and magnetic fields. There are three different regions can be defined from the I-V curves of periodic array of antdiots superconducting thin film.

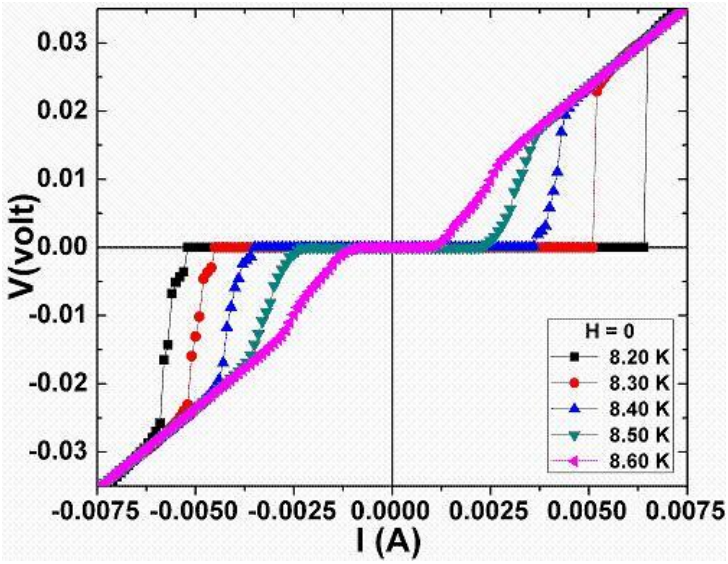

Fig.1 Voltage-current (I-V) characteristic of a square array of holes at different temperatures.

SYMPOSIUM 9.1

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SPIN REORIENTATION, DIELECTRIC RELAXATION AND MAGNETOCAPACITANCE EFFECT IN NOVEL MAGNETOELECTRIC SYSTEMS

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Multiferroic materials with simultaneous ferroelectricity and magnetism are potential for spintronic applications. A great amount of work has been done to explore novel room temperature multiferroic materials for realization of the mutual control of the electric and magnetic degrees of freedoms (magnetoelectric (ME) coupling) in the past few years. $DyMnO_3$ are $DyFeO_3$ have attracted great attention due to their rich ferroic transitions. Magnetic competition in $DyMnO_3$ could induce magnetic frustration, and complex spin states and cross-coupling between electric polarization and spin ordering can be realized. $DyFeO_3$ display a unique magnetic phase transition, spin reorientation from $\Gamma 4$ to $\Gamma 1$ around 35 K. Furthermore, magnetic field along c axis of $DyFeO_3$ single crystal (Pbnm) can induce a gigantic ME affect. Here, we studied systematically the spin reorientation and antiferromagnetic transition in $DyMn_{1-x}Fe_xO_3$ system and illustrate how the interactions among rare earth ions and transition metal ions affect these transitions. We believe this study will provide theoretical and experimental guidance in the search for novel room temperature multiferroic materials with strong ME coupling. In addition, large magnetodielectric coupling was observed in one compound. Dielectric relaxation study reveals the mechanism for the observed magnetodielectric effect.

$DyMn_{1-x}Fe_xO_3$ samples display a long-range cooperative Jahn-Teller orbital ordering, which becomes progressively less stable as x increases from 0 to 0.5, and disappear at $x > 0.5$ and spin reorientation starts to appear. The antiferromagnetic transition temperature (T_N) increases as x increases. Meanwhile, the spin reorientation temperature (T_r) and T_N gradually separate and widen the temperature range of the magnetic metastable state between T_r and T_N. When x=0.67, sample experiences the paramagnetism-antiferromagetism transition at 450K and the spin reorientation at 290K. Magnetodielectric properties were studied around the spin reorientation transition. Both giant positive and giant negative magnetodielectric coupling were observed near room temperature. The dielectric constant and loss of $DyMn_{1-x}Fe_xO_3$ samples show strong relaxation process. Electron hopping among mixed valenced transition metals is expected to be responsible for the relaxation. The activation energies were obtained though Arrhenius law fitting. The Fe content dependence of the characteristic frequency and the activation energy shows two transitions which are well consistent with the change in orbital ordering. Meanwhile, different magnetic orderings could affect the relaxation and induce the change in activation energy. Possible mechanisms are proposed based on the combination Maxwell-Vagner effect and magnetoresistance effect.

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PHASE COEXISTENCE AND SHORT-RANGE MAGNETIC ORDER IN MAGNETIC MULTIFERROICS

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Magnetic interactions competition in antiferromagnetic perovskites $AMnO_3$ may lead to cycloidal magnetic order and to ferroelectric polarization **P**. The direction and sense of **P** is dictated by the helicity of the cycloid. When cooling the material through its Néel temperature, domains of distinct helicity and ferroelectric polarization, are expected to be formed. The cycloidal plane can be flopped by an appropriate magnetic field **H**. Upon H-induced flopping and in absence of any electric-field poling, it is also expected that domains with opposite helicity should be equally probable resulting in zero net electric polarization.

However, the reality is more complex. These fascinating oxides, display an intriguing memory of its thermo-magnetic history that largely determine its ferroelectric polar state. For instance, after succesive floping of **P** by **H**, the system remembers the initial direction of **P** [1] and, its magntitude can be modified at whish by H-cycling. Even more exciting, it is found that upon colling accros the temperature temperature where long range cycloidal sets in, a macroscopic net polarizatization developns in absence of poling electric [2].

It will be show that these effects are associate to the coexistance of magnetic domains of different chiralirty and the concomitant presence of domain walls.

These findings add light on the complex magnetoelectric response of these oxides and provide some new guidelines and perspectives for designing new multiferroic materials where long range magnetic order may not be a prerequisite.

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MAGNETOELECTRIC COUPLING IN A FERROELECTRIC/FERROMAGNETIC CHAIN REVEALED BY FERROMAGNETIC RESONANCE

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We present a theoretical study [1] which models the ferromagnetic resonance (FMR) effect for a 2-2 composite multiferroic structure related to an unstrained $BaTiO_3$ in the tetragonal phase in contact with Fe. As predicted by recent *ab-inito* studies, e.g. [2], there exists a strong magnetoelectric coupling between the interface polarization and the magnetization resulting from the screening of the polarization by spin-polarized electrons in Fe. The calculations based on the classical approximation for the coupled polarization and magnetization dynamics [1] reveal that the spectra of absorbed power in FMR are sensitive to the orientation of the interface polarization and to an applied electric field. We also propose a method for measuring the magnetoelectric coupling coefficient by means of FMR.

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SUPER SPIN MEDIATED GIANT EXCHANGE BIAS IN MULTIFERROIC NANOCOMPOSITE

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We report that indeed in a naturally occurring nanocomposite of finer $Bi_2Fe_4O_9$ and coarser $BiFeO_3$, a giant exchange bias (both spontaneous and conventional) is observed below the blocking temperature. The exchange bias is tunable as well via concentration ratio of the component phases. Interestingly, we discover that the exchange bias originates here from an interaction between ferromagnetic $Bi_2Fe_4O_9$ and antiferromagnetic $BiFeO_3$ via *superspin glass interface* and not from the conventional direct antiferromagnetic-ferromagnetic moment coupling. The magnitude of the exchange bias and the temperature zone across which it is observed vary depending on the concentration ratio of the phases in the nanocomposite. More interestingly, the exchange bias was not known to be path-dependent previously. The present report shows that depending on the path or protocol followed in tracing a magnetic hysteresis loop, the magnitude of the exchange bias varies. This path-dependency is all the more important as this has been found in a composite with multiferroics. With multiferroics, it is possible to switch the magnetic anisotropy by even electric field which reduces the power consumption in a switching device enormously.

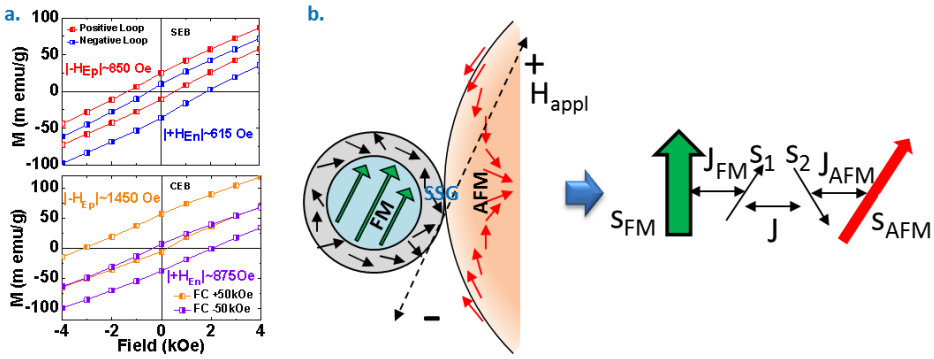

Figure: (a) Giant exchange bias (SEB and CEB) in BFO nanocomposite (b) Schematic spin diagram of FM-SSG-AFM interface

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SIGNATURES OF MAGNETIC CHIRALITY IN THE GEOMETRICALLY FRUSTRATED $Ba_3NbFe_3Si_2O_{14}$

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INTRODUCTION

Geometrical frustration of a spin lattice, signifying its incompatibility with the underlying crystal lattice, is the key promoter of exotic collective magnetic phenomena in condensed matter. In frustrated antiferromagnets, a dominant isotropic exchange interaction is often unable to raise the degeneracy of a ground state. Therefore, minute magnetic-anisotropy terms can become crucial in selecting a particular state.

The acentric triangular-based antiferromagnet $Ba_3NbFe_3Si_2O_{14}$ has been lately drawing considerable attention due to its unique long-range magnetic order [1] and accompanying multiferroic properties. The realization of its intriguing double-chiral single-domain magnetic structure appears mysterious.

METHODS

In order to unveil the ground-state selection mechanism in this material and to extend the research of its chiral properties we have performed electron spin resonance (ESR) [2] and inelastic neutron scattering (INS) [3] experiments.

RESULTS AND DISCUSSION

Our INS investigation has demonstrated an unprecedented dynamical fingerprint of the chiral ground state, reflected in one of the two excitation branches being completely chiral over the whole energy spectrum. The ESR investigation uncovered the crucial role of a minute Dzyaloshinsky-Moriya anisotropy in this system.

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PERSISTENT SPIN DYNAMICS AND MULTIFERROICITY IN FRUSTRATED $FeTe_2O_5Br$

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Exotic magnetic ground states are often induced by geometrical frustration. In particular, frustrated systems may develop complex incommensurate magnetic long-range orders (LRO) that induce electric polarization or even exhibit magnetic LRO accompanied by persistent spin dynamics (PSD). The two extraordinary phenomena have not been observed in the same compound yet, as each of them is rare on its own and still lacks a comprehensive description.

We focus on a layered $FeTe_2O_5Br$ system, which below T_{N1}=11K develops an incommensurate amplitude-modulated magnetic LRO that breaks the inversion symmetry [1]. Below the second transition, at T_{N2}=10.5K, accompanying electric polarization emerges [2].

Here presented results reveal surprisingly strong Fe-O-Te-O-Fe exchanges, forming a magnetic exchange network composed of Fe^{3+} (S=5/2) spin chains coupled by weaker frustrating interactions, which explains the origin of the complex LRO [3]. Moreover, the latter is accompanied by spin fluctuations, persisting at lowest accessible temperatures, hereby offering a well-defined framework and a coherent explanation for the coexistence of LRO and PSD [4].

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THURSDAY AFTERNOON

SYMPOSIUM 8.3

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GAS-PHASE PREPARATION OF CORE-SHELL MAGNETIC NANOPARTICLES FOR TUMOUR HYPERTHERMIA

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INTRODUCTION

Magnetic Nanoparticle Hyperthermia (MNH) is a promising treatment for cancer offering the possibility of a generic low morbidity therapy. Currently available Fe oxide nanoparticles, however, are unable to produce enough heat per gram to enable MNH to work without using it in combination with other treatments and also restrict it to certain types of cancer. The search is on for magnetic nanoparticles that have a much higher Specific Absorption Rate (SAR), which describes the power converted into heat per unit mass (W/g). This usually means having a pure Fe core within the nanoparticle, which also entails producing the nanoparticles as a core-shell structure so that the outer part is biocompatible and protects the metallic core. Gas-phase synthesis offers the possibility of producing core-shell nanoparticles in which there is independent control of the core size and shell thickness and flexible choice of materials in either. The problem of getting the gas-phase nanoparticles into a liquid suspension has been solved by co-depositing the gas-phase nanoparticles with a narrow size distribution and water vapour in Ultra-High Vacuum (UHV) conditions[1]. The talk will present the method and the SAR performance of various core-shell nanoparticles including Fe@Ag and Fe@Fe oxide produced this way. Due to the high magnetic moment of the nanoparticles synthesised by the new method they also have a high performance as MRI contrast enhancers. The new method even allows some control of the shape of the particles and the effect of this on MRI relaxivity will be presented.

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COMPOSITE ZnO-Fe_3O_4 NANOSTRUCTURES WITH MULTIFUNCTIONAL PROPERTIES

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We have realized a new nanocomposite material by coupling superparamagnetic magnetite nanoparticles (Fe_3O_4 NPs) to zinc oxide tetrapods (ZnO TPs). After growing TPs from the vapour phase and synthesizing NPs by thermal decomposition of $Fe(acac)_3$ in oleylamine, we have obtained ZnO-Fe_3O_4 nanocomposites exploiting an optimized thermal annealing.

Transmission Electron Microscopy evidences the sticking and partial aggregation of NPs on TP legs (Fig.1, left); it also confirms the high structural quality of the two materials in the nanocomposite. Coherently, the nanocomposites show the ZnO strong UV emission and a significant room temperature (RT) magnetic moment ($M_S \cong 15 Am^2/kg$; Fig. 1, right). Despite the aggregation, only a very small fraction of NPs is magnetically blocked at RT, giving M_r/M_S and $\mu_0 H_C$ values of 2% and 0.0017 T, respectively. Consequently, once removed the magnetic field, the nanocomposites do not experience agglomeration.

We have evaluated the filter-free photocatalysis application as a case study: the degradation rate of two organic dyes has been measured, outperforming that of bare ZnO TPs; the magnetic functionality permits an easy recovery from the treated water by magnetic field.

In conclusion, we have demonstrated that a simple preparation technique allows coupling the attractive properties of ZnO (e.g. surface reactivity, strong UV emission, piezoelectricity) with the magnetic functionality of Fe_3O_4 NPs [1].

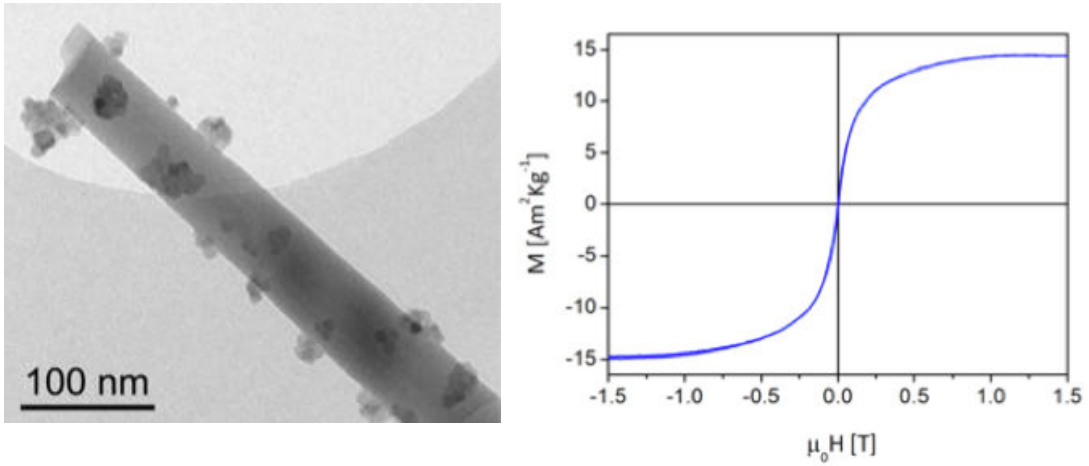

Figure 1. *(left) TEM image of a ZnO TP leg; (right) hysteresis loop of ZnO-Fe_3O_4 nanocomposites.*

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HIGHLY EFFICIENT HEAT DISSIPATION IN MONODISPERSE IRON OXIDE NANOPARTICLES

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We study the evolution of specific absorption rate (SAR) and the mechanisms involved for IONP of different sizes (from 7 till 22 nm), alternating magnetic field conditions (up to 430 kHz and 50 mT) and dispersion viscosity. The IONP were synthesized by an improved method based on thermal decomposition of an iron precursor in organic media. The resulting IONP are highly uniform in size and morphology, highly crystalline and with optimal magnetic properties [1]. IONP surface was modified with dimercaptosuccinic acid leading to highly stable colloidal suspensions and hydrodynamic diameters around 60 nm for all particle sizes. Figure 1 shows the IONP specific absorption rate (SAR) values obtained in aqueous dispersions for different sizes and magnetic field amplitudes at moderated frequencies (77 kHz) [2]. Thus, SAR values increases with size and field amplitudes reaching values up to 300 W/g. The comparison of SAR values in water and agar dispersions indicates that Néel relaxation is the main mechanism in the heat dissipation process for all IONP sizes. Furthemore, our results confirm that IONP interactions increase with IONP size leading to a reduction of SAR values when increasing the iron concentration.

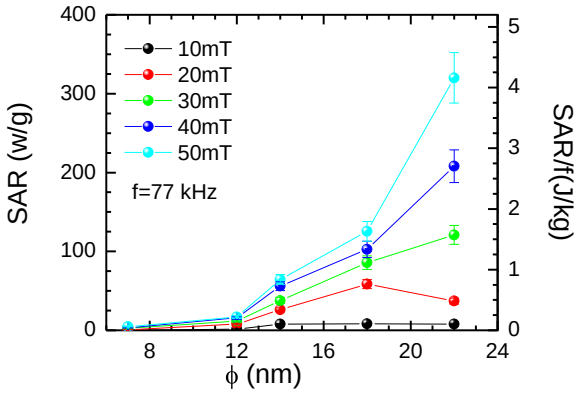

Figure 1: SAR and SAR/f values for IONP measured in water dispersions as a function of particle size and magnetic field amplitudes at f=77 kHz.

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STRUCTURAL MODIFICATION AND SELF-ASSEMBLY OF NANOSCALE MAGNETITE SYNTHESISED IN THE PRESENCE OF AN ANIONIC SURFACTANT

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INTRODUCTION

Many biological and industrial processes are crucially dependent upon the absorption of surfactants from an aqueous phase onto a solid surface. At the heart of this physical chemical process is the alteration of the interface properties caused by the adhesion and aggregation of the surfactant molecules at the solid surface.

Synthesis of magnetite (Fe_3O_4) in the presence of the surfactant sodium dodecyl sulphate (SDS) gives rise to a variety of nanoscale morphologies, some of which look remarkably similar to magnetite found in organisms, suggesting that similar processes may be involved**.** So, taking our inspiration from biology, where templates produce magnetite of defined shapes and sizes, we have been interested in investigating how surfactant molecules can similarly influence nanoscale magnetite formation e.g. Figure 1.

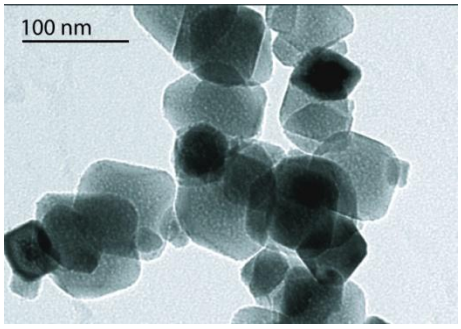

Figure 1. Mesoporous nanocrystallites form with diameters of 40-100 nm and a morphology similar to the widely reported truncated dodecahedral shape seen in certain magnetotactic bacteria [1]. In addition to its “biogenic signature” this mesoporous nanomagnetite could be useful for targeted drug delivery [2].

In this paper, we report structural modification and self-assembly of magnetite in the presence of the anionic surfactant SDS. SDS is commonly used to mimic hydrophobic binding environments such as cell membranes [3], and has recently been used to study the folding and thermal stability of cytochrome c (cyt c) a biologically important electron transfer system [4].

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PHOTOTHERMAL MICROSCOPY AND MAGNETOPHORESIS OF SUPERPARAMAGNETIC IRON OXIDE NANOPARTICLES IN CELLS

Lara K Bogart, Arthur Taylor, Anita Peacock, Patricia Murray, Raphäel Lévy and Matthew Rosseinsky

The development of a range of biomedical applications depends upon the ability to track cells *in vivo*. Long-term cell tracking requires cells to be labelled with an appropriate probe to allow for the precise monitoring of the *in vivo* behaviour of cells. Functionalised core-shell superparamagnetic iron oxide nanoparticles (SPIONs) have been proposed as suitable probes since they allow the possibility for long-term tracking *via* magnetic resonance imaging (MRI). The effects of cellular internalisation on SPION integrity has important implications in terms of material design and are by no means fully understood as yet. Such knowledge is only attainable by the development of new techniques that directly probe the iron-oxide core within cells.

We have developed two microscopes - photothermal microscopy and cell tracking velocimetry - which together provide a fully quantitative and non-destructive approach to the study of SPIONs on a single cell level. A systematic investigation into the kinetics of SPION uptake in different cell types is presented and the evolution of the magnetic properties over time will be discussed. Both the uptake and integrity of commercially available nanoparticles will be compared to nanoparticles that have been synthesised 'in-house'. The effect of different iron oxide core material, as well as both shell material and diameter on the chemical and biological stability of SPIONs within cells will be presented. This work is an important preliminary step required for the optimisation of biologically, chemically and magnetically stable particles in MRI tracking based applications.

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BLOOD PRESSURE SENSOR BASED ON FERROMAGNETIC RESONANCE OF MAGNETIC MICROWIRES

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SUMMARY

Available techniques for pressure monitoring include either direct measurement using catheter-based techniques or indirect measurement requiring implantation of a pressure sensor. None of these methods is without limitations. The present works shows the possibility of using an amorphous magnetostrictive microwire [1] to be used as sensor element to detect changes in blood pressure. These materials possess superior mechanical, electrical, magnetic, and chemical properties [2]. Previous research work has shown the possibility of modulation an electromagnetic wave in the GHz range by the presence of a magnetic microwire [3].

A prosthesis and / or artery, as shown in Figure 1, has been tagged using a ring of magnetoelastic amorphous magnetic microwire. Simultaneously said element has been subjected to a magnetic field of low frequency, maximum amplitude of 120 A/m generated by Helmholtz coils, and an electromagnetic wave of 1.29 GHz from a transmitter antenna connected to a vector network analyzer. We have designed an hydraulic system connected to to a pulsatile ventricular assist system (Abiomed/AB5000) which produce different degrees of stenosis in PTFE graft, bovine artery and arterial anastomosis. Fluid pressures (0.33 %o agar-agar) were registered using a catheter and compared with those obtained by the wireless device (Figure 2). It has been possible to find a correlation between the pressure in the prosthesis / artery and the signal generated by the electromagnetic system (50 mmHg-2.25 dB signal variation / 14 mmHg-variation 3.97 dB / 170 mmHg-variation 6.78 dB). It has been possible the registration of measurable changes in the electromagnetic signal a function of stenosis severity and position.

Figure 1. Bypass between tagged artery and prosthesis

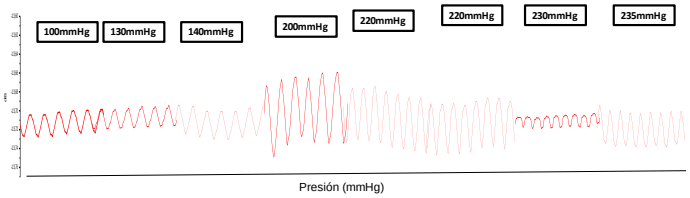

Figure 2. Electromagnetic signal as a function of artery pressure

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COMPARATIVE EVALUATION OF AC MAGNETIC HYPERTHERMIA EFFICIENCY OF FERRITE-BASED MAGNETIC NANOPARTICLES

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INTRODUCTION

In this study, Mn and Co ferrite nanoparticles were synthesized by a facile, low-cost, environmentally friendly and high yield methodology based on the aqueous coprecipitation of proper salts and evaluated as AC magnetic hyperthermia agents. Firstly, structural, morphological and magnetic characterizations were performed to determine crucial factors for optimizing their heating potential (such as size, polydispersity, saturation magnetization, coercivity). In order to study the impact of medium properties on heating mechanisms (Brownian and/or Néel relaxation, hysteresis losses) and consequently on AC magnetic hyperthermia, synthesized nanoparticles were dispersed in different solvents with varying concentration and viscosity, namely water and Agar. Eventually, nanoparticles with optimum features were, directly injected in three different cell lines: (a normal one and two cancer ones) to check their performance in-vitro. The quantifiable measure of heating efficiency i.e. the Specific Loss Power (SLP) was strongly affected by the dispersion medium and its properties. The comparative results of the AC hyperthermia efficiency of ferrite nanoparticles in combination with the in-vitro study coincide with the magnetic features and their tunability may be further exploited for AC magnetic hyperthermia driven applications.

SYMPOSIUM 2.4

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MAGNETIC VORTEX-ANTIVORTEX DIPOLES IN SPIN-TRANSFER OSCILLATORS

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Periodic motion of vortices in the GHz range induced by spin-transfer-torque gives rise to spin-transfer-oscillators (STO). We assume a current with in-plane spin-polarization which acts on a vortex-antivortex (VA) pair where the vortex and the antivortex have opposite polarities. This vortex dipole has the structure of a skyrmion. Using the Landau-Lifshitz-Gilbert-Slonczewski equation we show that the dipole is set in steady rotational motion. This is induced by two independent forces: the interaction between the two vortices and an external in-plane magnetic field. The nonzero skyrmion number of the vortex dipole is responsible for both forces giving rise to rotational motion. The spin-torque acts to stabilize the motion.

Simple rotational dynamics (steady-state rotation) is obtained if we consider exchange interaction and easy-plane anisotropy. We find three types of VA pairs, which may even coexist for the same parameter values (as in Figure 1). This indicates hysteresis, as observed in experiments.

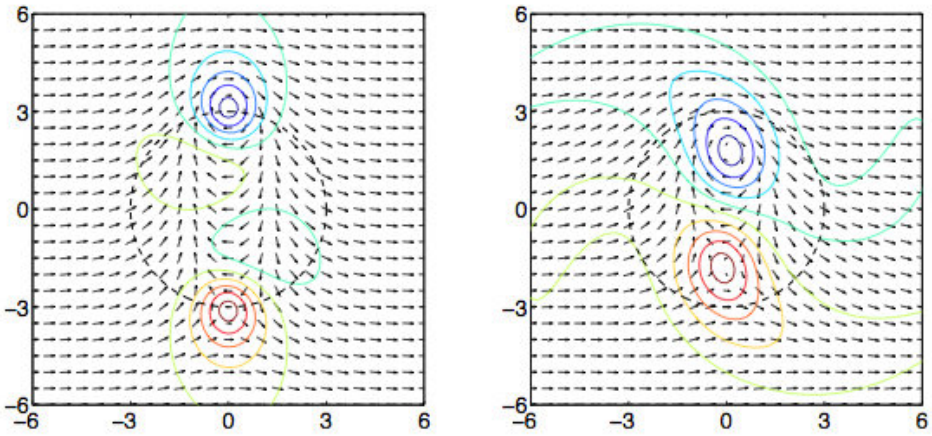

Figure 1. Two VA pairs which correspond to the same parameter values, but their frequencies of rotation are significantly different.

We derive an exact (virial) relation which quantifies the effect of various factors to the rotation frequency. The external magnetic field can tune the frequency, while the spin-torque affects the frequency indirectly by tuning the distance between the two vortices.

The present results could be used as a framework for the description of frequency generation by various topological solitons under spin-polarized current.

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CONTRIBUTION OF MAGNETIC CIRCULAR DICHROISM IN HELICITY-DEPENDENT ALL-OPTICAL MAGNETIZATION SWITCHING

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Direct demonstration of all-optical light helicity-dependent magnetic switching (AO-HDS) was observed in ferrimagnetic GdFeCo alloys in the absence of an external magnetic field [1], which became subject of intense discussion in modern magnetism. The most obvious explanation via the inverse Faraday effect (IFE) [2,3] could only very qualitatively account for the previously observed features. What is the origin of the helicity dependence in the all-optical switching?

We show that all-optical switching with circular polarized (CP) femtosecond laser pulses in ferrimagnetic GdFeCo is related to the collinear sub-lattice magnetization and not with the net magnetization. Furthermore, we present an explanation of the AO-HDS based on magnetic circular dichroism (MCD). Using magneto-optical microscopy in combination with femtosecond pulsed light, we measured the composition dependency (X:22~27) of AO-HDS in $Gd_x(Fe_{87.5}Co_{12.5})_{100-x}$. The relation between the direction of reversed net magnetization and helicity of the light changed sign by going across the magnetization compensation composition ratio C_M (X~24.5). We also found that the sign of MCD changed at C_M. It was hypothesized that CP light acts as a strong effective magnetic field pulse H_{OM} on the spins of the medium through the IFE. The direction of H_{OM} is then defined by the helicity of the light. The above results do not match with the description based on the IFE. We already reported that ultrafast heating can act as a sufficient stimulus for magnetization reversal in a ferrimagnet with taking into account the multi-sublattice nature [4], and the intensity window in AO-HDS can be explained quantitatively based on MCD [5]. The above results show that the helicity-dependent absorption in a multi-sublattice magnetic layer exactly matches the helicity-dependent features in switching experiments.

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FERROMAGNETIC RESONANCE RESPONSE OF THIN FILMS WITH ONE- AND TWO-DIMENSIONAL PATTERNED ARRAYS OF PERIODIC PERTURBATIONS

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We present an analytical theory focused on the description of the ferromagnetic resonance (FMR) response of thin films in the case that periodic surface perturbations are introduced [1]. These perturbations can be any kind of one- or two-dimensional rectangular arrays of defects patterned onto one surface of the magnetic film. Our theory allows us to describe their influence in such a way that the periodic defect structure can have any given shape. We calculate the response functions that are the components of the frequency and wave-vector dependent dynamic susceptibility tensor of the film exposed to the FMR microwave excitation. These allow us to obtain the resonant response of the system, trough relevant quantities as the microwave absorption, the FMR linewidth, and resonance field. We show examples where the periodic defects have the shape of stripes, dots, and rectangles. In our framework the perturbations may be considered either as bumps or pits. Finally, we compare our results with recent experimental results obtained with broadband FMR, which manifest a very good agreement with the theory, demonstrating at the same time that FMR is capable to measure key features of Magnonic Crystals.

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CONTRIBUTION OF PEIERLS RELIEF TO THE DYNAMICS OF DOMAIN WALLS IN METAL-ORGANIC COMPOUNDS

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Peierls potential relief contributes to the domain walls dynamics in the thin films [1]. Sensitivity of the domain walls dynamic to the Peierls potential was estimated by relative change of the critical temperature of maximum of AC susceptibility $\Delta T/T$ in chiral crystals in comparison with racemic crystals. Sensitivity of the domain walls mobility to the Peierls relief is controlled by the ratio of domain wall width W to the lattice parameter a. Analysis of the of AC susceptibility in the series of chiral and racemic crystals [2-7] allowed us plotting the $\Delta T/T$ as function of ξ = W/a (Fig.1). It is clear distinguishable on the Fig.1 that $(W/a)_c$ ~ 4.2 threshold value which below domain walls is mainly controlled by Peierls relief [2]. Thus, domain walls dynamics manifests universal regularity possessing sharp transition from Peierls regime to the regime limited by structural defects.

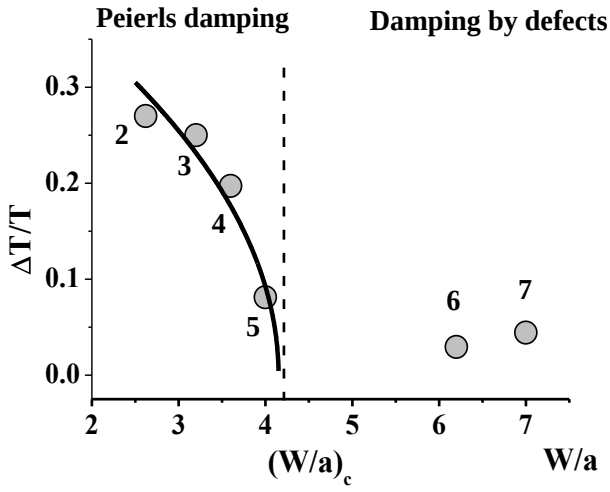

Fig.1. Experimental dependence of the shift of AC magnetic susceptibility maximum $\Delta T/T$ as function of relative width of the domain wall W/a. Solid line is approximation by scaling function $(1-\xi)^{0.5}$ (ξ = $(W/a)_c/(Wa)$. Points are numbered correspondently to the referencies [2-7] which data were used for the analysis.

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JILES-ATHERTON THEORY FOR SYSTEMS WITH FIRST ORDER PHASE TRANSITION

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The phenomenological Jiles-Atherton model is widely used to describe normal hysteresis loops in ferromagnetic materials [1]. Recently, this model was extended to describe hysteresis loops at different temperatures, where the dependence of model parameters on temperature was introduced by adding second order phase transition temperature (Curie temperature T_{2nd}) as a parameter [2].

The situation becomes more complex in systems exhibiting a magnetic-structural (MS) first order phase transition (FOPT). Magnetocaloric $Gd_5(Si_xGe_{1-x})_4$, in region ($0.4 \le x \le 0.503$), is an example of such a system where, at a specific temperature ($T_{1stORDER}$) a MS FOPT from orthorhombic ferromagnetic phase to monoclinic paramagnetic phase occurs [3]. At higher temperatures ($T>T_{1stORDER}$) this FOPT can be induced by application of magnetic field (see Fig. 1).

In order to describe M(H,T) dependences for such systems, the total magnetization was calculated as a sum of magnetizations of monoclinic (paramagnetic with $T_{2ndMONO}$) and orthorhombic (ferromagnetic with $T_{2ndORTHO}$) phases weighted by the amount of the monoclinic phase, which is a function of temperature and applied magnetic field (see Fig. 1).

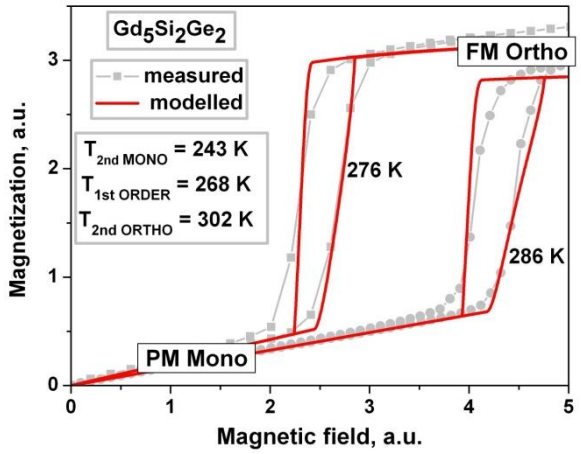

Figure 1. Magnetization curves showing the induced MS FOPT.

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THERMAL TRANSPORT BY RECIPROCAL AND NON-RECIPROCAL MAGNONS

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The interaction of spins with heat currents in a magnetic medium leads to a variety of spin-dependent thermoelectric effects and it is the keystone for the field of spin caloritronics. Spin-caloric effects have been discovered in magnetic insulators, where a spin is transported via magnetic excitations (magnons). The understanding of spin-caloric effects for these materials requires the investigation of the interplay between temperature and spin waves through the magnon-phonon interaction.

We have studied magnon mediated caloritronic effects in yttrium iron garnet films using the infrared thermography technique in combination with Brillouin light scattering spectroscopy. The experimental results have shown an energy transfer from the magnonic system to phonons leading to the formation of thermal gradients, which depends strongly on the energy of the magnons. We show that the heating by artificially excited magnons follows the character of non-reciprocal propagation with respect to the excitation antenna of surface magnons, while for backward volume magnons a symmetric thermal distribution was seen. Furthermore, at relatively low excitation microwave powers, a thermal gradient yielding an increase in temperature from the antenna to the end of the sample was observed in the case of surface magnons. This effect was understood as a result of the non-reciprocal nature of the surface magnons that drastically dissipate their energy in the process of reflection at the end of the sample.

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ULTRAHOT BOSE-EINSTEIN MAGNON CONDENSATE IN A PHASE SPACE

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Bose-Einstein condensation (BEC) of quasi-particles (QPs) such as magnons [1] or photons [2] can be achieved even at room temperature by increasing density of a QP gas. It was assumed (see for example [1]) that due to the huge number of thermal QPs at 300 K the QP temperature remained constant and a small quantity of additionally injected particles changed only the chemical potential of the gas. Our observations show the paramount importance of thermal effects in this process.

The transient dynamics of a magnon gas was measured in a phase space by means of Brillouin light scattering spectroscopy [3] in a single-crystal ferrimagnetic film (yttrium iron garnet) at room temperature. Magnons were injected to the narrow spectral area at 7 GHz by parametric electromagnetic pumping**.**

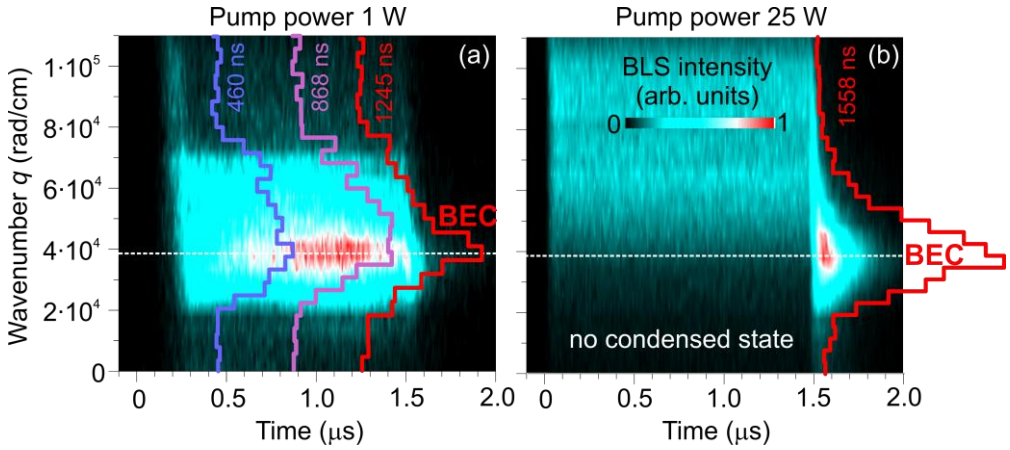

Figure 1. Evolution of gaseous magnons and magnon BEC at the bottom of QP spectrum.

At low pumping power of 1 W, corresponding to moderate heating of the magnon gas, the clearly visible spontaneous concentration of magnons at the global energy minima (5 GHz, 3.93×10^4 rad/cm) occurs (Fig.1a). The increase of the pumping power results in depopulation of the lowest energy state. At pumping power of 25 W the magnon gas is drastically (up to 30'000 K) overheated and no condensation developed during the pump pulse (from 0 to 1.5 μs). The BEC appears as a result of a local spectral cooling of the free-relaxing magnon gas after the pump is switched off (Fig.1b). Thus, the magnon BEC evolves in a narrow spectral region which temperature significantly (thousands kelvins) exceeds the temperature of the thermal bath.

Support by the DFG within the SFB/TRR 49 is gratefully acknowledged.

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SWITCHING OF THE SPIN CIRCULATION IN LINEAR ARRAYS OF TAPERED MAGNETIC NANODISKS

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INTRODUCTION

Magnetic vortices are curling magnetization structures which represent the lowest energy state in sub-micron size magnetic disks or polygons. The vortex core, a singularity at the vortex center, features magnetization pointing either up or down perpendicular to the disk plane. The binary character of the direction of the circulation of the magnetization and the polarity of the vortex core leads to four possible stable magnetization configurations that can be utilized in a multi-bit memory cell.

We demonstrate ultrafast switching of spin circulation in magnetic nanodisks using nanosecond magnetic field pulses by imaging the process with full-field x-ray transmission microscopy. The dynamic reversal process is controlled by far-from-equilibrium gyrotropic precession of the vortex core and the reversal is achieved at significantly reduced field amplitudes when compared to quasi-static switching. Controlled switching of the spin circulation requires removing the vortex core out of the disk and then reforming the vortex with opposite circulation. This can be achieved by using a static or dynamic magnetic field and exploiting a geometric asymmetry [1]. Furthermore, we discuss the magnetostatic interaction of the neighboring disks in linear arrays. Magnetic nanodisks in the vortex state exhibit almost perfect flux-closure, however, during the switching of the spin circulation where the vortex core must be annihilated and the disk is saturated into almost uniform state the magnetostatic interaction between two disks in proximity is non-negligible. We show how the interplay between the distance of the disks in arrays and their geometric asymmetry can influence the switching process.

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SYMPOSIUM 7.2

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REVISITING THE VORTEX PHASE DIAGRAM OF $Bi_2Sr_2CaCu_2O_{8+\partial}$

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The highly anisotropic superconductor $Bi_2Sr_2CaCu_2O_{8+\partial}$ (Bi2212) is one of the most studied of all the cuprates. The highly two dimensional character and susceptibility to disorder via pinning and thermal fluctuations leads to a very rich magnetic phase diagram, with both experimental and theoretical support for the existence of a Bragg-glass, a vortex-glass and a vortex-liquid phase.

Muon-spin rotation (μSR) measurements, which measure the local field distributions of the vortex system in the bulk of the material in order to probe local spatial correlations, were among the first experiments to observe a local microscopic rearrangement of vortices with increasing temperature and field. Only recently, however, has an adequate theoretical framework been developed to interpret such experiments. This makes it timely to revisit the magnetic phase diagram from the perspective of μSR data, to explore what new insight may be revealed.

Data will be presented from experiments on two representative samples of Bi2212, one over doped and one optimally doped. Quantities directly related to two- and three-body spatial correlations of vortices are used to construct a novel magnetic phase diagram. Our studies reveal an unusual glassy state at intermediate fields, which appears to freeze continuously from the equilibrium vortex liquid but differs significantly both from the lattice and the conventional high-field vortex glass state in its local structure. The existence of this glassy state, which it is argued should be especially sensitive to perturbations, reconciles a number of prior observations and simulation results for pancake vortices in this field and temperature regime.

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QUARTETS OF ORDER PARAMETERS IN DOMES PREVENTING QUANTUM CRITICAL POINTS AND IN CORRELATED NANOSTRUCTURES

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A multitude of quantum ordered states is accessible in correlated systems. This mainly includes superconducting and particle-hole condensates the second category including as well all the magnetic phases when magnetism is considered in the itinerant limit. For example, if we consider the possibility of coexistence and competition of Density Waves with Superconductivity, we may construct an eight-dimensional spinor theory that defines 63 different accessible order parameters, among which 31 are different particle-hole condensates from which the 26 have a magnetic character [1]. In many of the systems of interest, like for example manganites exhibiting the phenomenon of colossal magnetoresistance (CMR), we were the first to point out that the coexistence and competition of four order parameters: Charge and Spin Density Waves, Ferromagnetism and the particle-hole asymmetry term or chemical potential, is crucial for the melting of large insulating density waves by small magnetic fields and the sudden emergence of metallic ferromagnetism [2]. However, the coexistence and competition of multiple condensates is a much more generic phenomenon that we argue manifests fully in the so called “domes” areas .

Indeed, we have demonstrated a general rule [1] that predicts hidden symmetries and induced order parameters. We identify a universal interaction between the order parameters that have tendency to aggregate into *quartet*s of order parameters. We have verified the relevance of the rule on dozens of examples, and we conclude that the quartets of order parameters constitute the building blocks of quantum complexity. Indeed, overlapping quartets form patterns of condensates. Many of these quartets involve magnetic order parameters. The quartets may be in the *hierarchy* regime where usually one order parameter dominates, or in the *equity* regime where all members fully develop. The equity regime defines domes preventing the expected quantum critical points of dominating orders and we argue that such domes seen in various materials, in some cases delimited by first order double step metamagnetic transitions, have a common characteristics, reflecting in fact the transition from the hierarchy regime to the equity regime [1,3].

However, our quartets are not only relevant in the dome areas of phase diagrams of materials. We were first to notice that a competition of CDW and SDW of similar magnitude when they coexist with particle-hole asymmetry and ferromagnetism may lead to the CMR phenomenon [1] something that can be understood only if the full quartet is considered on the same footing. More importantly, our quartets can be engineered at interfaces and in nanostructures [4] and produce extraordinary new phenomena of great interest for technologic applications. We will discuss some characteristic examples of engineered quartets, proposing a novel picture of the phenomenology of $LaAlO_3/SrTiO_3$ and other oxides interfaces. The potential implications of our engineered quartets range from topological error-free quantum computation to topologically protected spin current devices and other spintronics applications.

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CHARGE ORDER AND MAGNETIC EXCHANGE BIAS ASSOCIATED WITH PHASE SEPARATION IN UNDERDOPED La_2CuO_{4+x}

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INTRODUCTION

The low magnetic field magnetization and the dielectric permittivity of underdoped La_2CuO_{4+x} single crystals has been studied in this report. Local minimum is observed for in-plane magnetization while a frequency dispersive peak is obtain for the dielectric permittivity, suggesting that charge ordering occurs below 40K. Besides, when samples are cooled in a static magnetic field, the low magnetic field magnetization hysteresis loops exhibit both vertical and horizontal shifts, suggesting the existence of magnetic exchange bias effect. Both charge ordering and magnetic exchange bias are well interpreted in terms of the phase separation exhibited in this system.

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IRREVERSIBILITY, REMANENT MAGNETIZATION, AND GRIFFTHS PHASES IN $Sm_{0.1}Ca_{0.9}MnO_3$ NANOPARTICLES

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In electron doped $R_{1-x}Ca_xMnO_3$ manganites (R is a rare earth), the largest ferromagnetic (FM) moment appears for doping $x \sim 0.9$. At this doping level, the low temperature magnetization reaches values of 0.5 ÷ 1 μ_B/f.u. [1], and the compound exhibits glassy behavior stemming from phase separated state with FM component immersed in a *G*-type antiferromagnetic matrix.

In this paper we report on magnetic properties of $Sm_{0.1}Ca_{0.9}MnO_3$ particles with 25 and 60 nm average size. We have concentrated on magnetization dynamics by investigating temperature dependence of ac-susceptibility, temperature and field dependence of thermoremanent (TRM) and isothermoremanent (IRM) magnetization, and on time decay of the remanent magnetization. The thermomagnetic irreversibility found in $Sm_{0.1}Ca_{0.9}MnO_3$ particles has been linked to the martensitic strain effects. Temperature dependence of TRM and IRM of 25 nm nanoparticles, is shown in Fig. 1. Relative gap between TRM and IRM, quantified as (TRM – IRM)/TRM decreases from 0.49 at 10 K and H =10 kOe to 0.28 at 10 K and H = 40 kOe, indicating a significant suppression of metastability by increasing magnetic field.The magnetic relaxation associated with glassy features was found to be much more pronounced in smaller particles, where formation of collective states may take place. The inverse magnetic susceptibility of the $Sm_{0.1}Ca_{0.9}MnO_3$ nanoparticles exhibits Griffiths-like features linked to the presence of short range ferromagnetically correlated spin clusters at $T > T_C$.

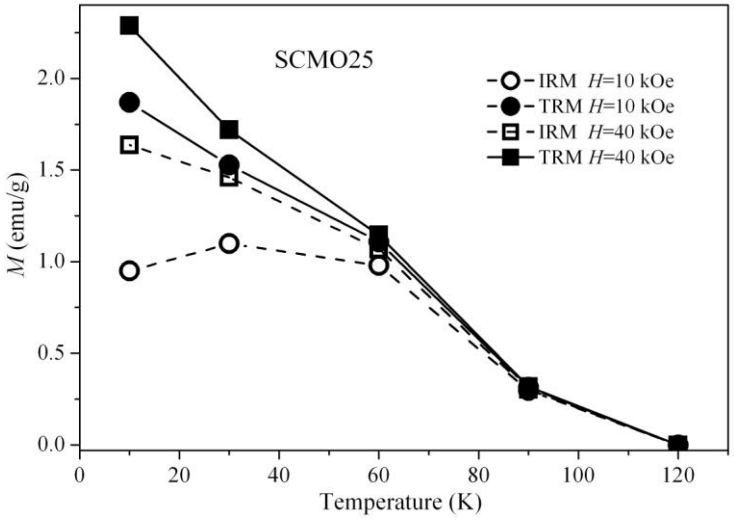

Fig. 1 The temperature dependence of TRM and IRM of 25 nm sample measured at H =10 and H = 40 kOe.

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Co-Nb-Co TRILAYERS AS EFFICIENT CRYOGENIC SUPERCURRENT SWITCHES

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INTRODUCTION

Nowadays Ferromagnetic-Superconducting-Ferromagnetic (FM-SC-FM) trilayers (TLs) are intensively studied [1-2]. Here, based on Co-Nb-Co TLs, we propose a supercurrent switch that could be utilized in cryogenic applications.

METHODS

The TLs were sputtered on Si [001] substrates under high-vacuum base-pressure ($5x10^{-8}$Torr) and an ultrapure (99.999%) Ar environment ($3x10^{-3}$Torr). The transport properties were measured in the four-point straight configuration for parallel magnetic fields inside a SQUID device [Quantum Design].

RESULTS

The upper-critical field line, $H_{c2}(T)$ of Co-Nb-Co TLs with thick/thin FM/SC layers (that is, above/below 60/20 nm) is recorded in detail. Interestingly, in the low-field regime (H<5000 Oe) the critical temperature $T_c(H)$ increases upon field application (reentrance behavior of $H_{c2}(T)$). Isofield R(T) curves obtained in the reentrance regime effectively demonstrate a pronounced critical temperature increase of order 100 mK upon application of 2000 Oe (in respect to zero field). Practicaly, this refers to complete restoration of superconductiivty upon application of a magnetic field.

CONCLUSIONS

The Co-Nb-Co TLs presented here operate as absolute supercurrent switches in analogy with a binary "0"-"1" memory device. These results could serve as technical guidelines for the construction of cryogenic supercurrent switches.

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AKNOWLEDGMENTS

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FIELD-INDUCED LONG-RANGE ORDER IN THE SPIN-SINGLET GROUND STATE SYSTEM $YbAl_3C_3$

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The 4*f*-electron system $YbAl_3C_3$ with a non-magnetic spin-dimer ground state has been studied by neutron diffraction in zero and applied magnetic field. It has been found that without field the system exhibits a first order structural phase transition from hexagonal $P6_3/mmc$ to orthorhombic *Pbca* symmetry at T_S~80K. The primary order parameter driving the transition involves displacements of Al and C ions along the hexagonal *c*-axis. The structural distortions renormalize the exchange parameters promoting the formation of isolated dimers but the orthorhombic symmetry does not fully release the frustration. Suppression of magnetic ordering by the remanent frustration stabilizes the non-magnetic singlet ground state. Application of a magnetic field above H_C~6T induces long-range magnetic order at T=0.05K (Fig. 1). The magnetic structure involves a homogeneous ferromagnetic component along the orthorhombic *c*-axis and an antiferromagnetic component along the *b*-axis. The latter is likely to be disordered on half of the Yb sites. In the magnetic field H=12T, both the ferromagnetic and antiferromagnetic components persist up to 50K indicating that the long-range order is not directly related to the singlet-triplet excitation. A field-induced intermediate disordered phase is likely to exist as the first excitation from the non-magnetic singlet ground state. This opens the primary question whether the long-range magnetically ordered phase in $YbAl_3C_3$ really displays similar physics to that of a Bose-Einstein condensation of magnons and how the Kondo effect interplays with the magnetic frustration.

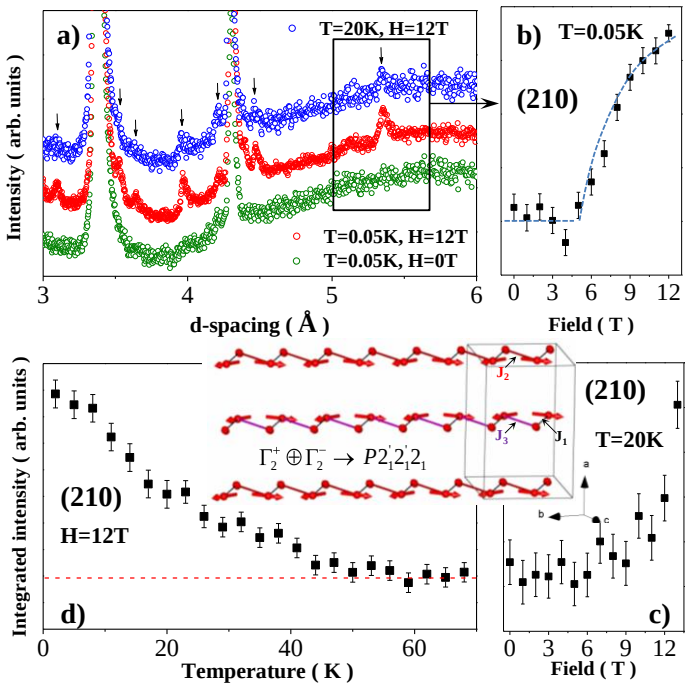

Figure 1. (a) Neutron diffraction patterns collected at different temperatures and magnetic fields. (b) and (c) Integrated intensity of the antiferromagnetic peak (210) as a function of the magnetic field. (d) This peak as a function of temperature. Inset shows the field-induced magnetic structure of $YbAl_3C$

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ELECTRONIC STRUCTURE AND CHEMICAL BONDING OF URANIUM DIOXIDE WITHIN THE HUBBARD I APPROXIMATION

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The electronic structure and elastic constants of uranium dioxide (UO_2) have been calculated by means of a combination of density functional theory and dynamical mean-field theory (DMFT) [1]. The impurity problem occurring in DMFT was solved using the Hubbard I approximation (HIA), including spin-orbit effects [2]. The simulations were performed by means of a full potential linear muffin-tin orbitals (FP-LMTO) code.

Density functional theory within the standard local density approximation predicts an incorrect itinerant character of the 5f electrons, which leads to a metallic solution and an underestimation of the equilibrium lattice parameters. We show that the Hubbard I approximation corrects these deficiencies and leads to an equilibrium volume much closer to the experimental value.

A Mott insulating state is obtained, with spectral features in good agreement with measured high-resolution X-ray photoemission and Bremsstrahlung Isochromat spectra [3], as well as other DMFT results [4]. The calculated bulk modulus and elastic constants will also be presented.

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POLARONS IN METALLIC LOW-SILICA X ZEOLITES

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Zeolites are nanoporous materials with periodic nanospaces (cages), which can accommodate various atoms and molecules. The zeolites filled with alkali metal atoms display intriguing low-temperature magnetic orderings ranging from a ferromagnetic, antiferromagnetic, even ferrimagnetic orderings. The appearance of magnetic moments and their ordering is surprising as all the individual components are nonmagnetic. Most recently, insulator-to-metal transition has been reported in sodium-doped low-silica X (LSX) zeolite [1].

The confined geometry of alkali-metal nanoclusters imposed by framework cages may enhance coupling between the electronic and lattice degrees of freedom leading to the formation of polaron states [1]. These polarons may be either localized (small polarons), or form extended states over several cages (large polarons). How the interplay between different polaron states accounts for the insulator-to-metal transition and the origin of unquenched spin in alkali-metal loaded zeolites are the two main questions that we are trying to address.

We present a ^{23}Na and ^{27}Al nuclear magnetic resonance (NMR) investigation of LSX zeolite filled with sodium atoms. Our results [2] suggest strong electron-phonon coupling in support of the proposed polaron model. In addition, we are trying to interpret the observed temperature dependences of resistivity, spin susceptibility and spin-lattice relaxation in terms of a simplified single-band Hubbard-Holstein model [3].

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SYMPOSIUM 9.2

SPIN-ORBITAL SEPARATION IN THE QUASI-ONE-DIMENSIONAL MOTT INSULATOR SR_2CUO_3

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When viewed as an elementary particle, the electron has spin and charge. When binding to the atomic nucleus, it also acquires an angular momentum quantum number corresponding to the quantized atomic orbital it occupies. Even if electrons in solids form bands and delocalize from the nuclei, in Mott insulators they retain their three fundamental quantum numbers: spin, charge and orbital. The hallmark of one-dimensional physics is a breaking up of the elementary electron into its separate degrees of freedom. The separation of the electron into independent quasi-particles that carry either spin (spinons) or charge (holons) was first observed fifteen years ago. Here we report observation of the separation of the orbital degree of freedom (orbiton) using resonant inelastic X-ray scattering on the one-dimensional Mott insulator Sr2CuO3. We resolve an orbiton separating itself from spinons and propagating through the lattice as a distinct quasi-particle with a substantial dispersion in energy over momentum, of about 0.2 electronvolts, over nearly one Brillouin zone [1].

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ORIGIN OF STRAIN-INDUCED FERROMAGNETISM IN DOMAIN WALLS OF MULTIFERROIC $TbMnO_3$ THIN FILMS

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Strain-engineering of multiferroic (ferroelectric-antiferromagnetic) $TbMnO_3$ thin films grown on (100)-$SrTiO_3$ show ferromagnetic behavior with magnetic moments of 1.5 μ_B/f.u. at 15 K [1], inconsistent with homogeneous magnetism, but scaling with the domain walls (DW) density.

Aberration-corrected Scanning Transmission Electron Microscopy (STEM) and Electron-Energy Loss Spectroscopy (EELS) is performed to analyze the domain nanostructure of $SrTiO_3$-grown $TbMnO_3$ thin films. Annular-dark-field (ADF) imaging evidences the presence of DWs characterized by the presence of spatially-ordered Tb-deficient planar defect perpendicular to the substrate. Atomic-resolution STEM-EELS chemical mapping demonstrates that Tb vacancies are filled with Mn, giving rise to a local decrease of the Mn oxidation state below the nominal value (+3). Theoretical models support the microscopic scenario where Tb-by-Mn substitution gives rise to the onset of local ferromagnetism by inducing local magnetic frustration between the antiferromagnetically-coupled Mn^{3+} ions.

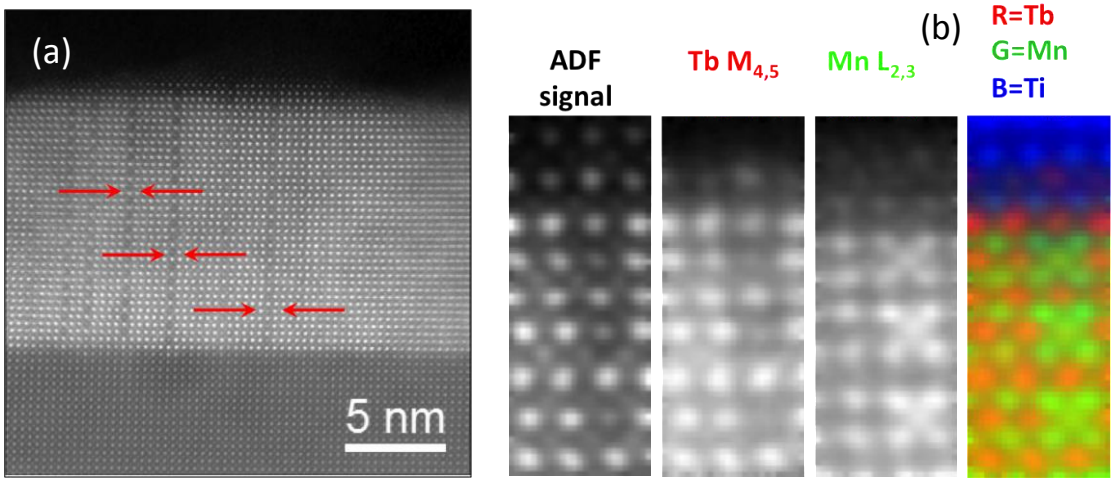

Figure 1. (a) ADF-STEM image of $TbMnO_3$ thin film (defects marked with arrows). b) STEM-EELS mapping of Tb and Mn around the defect.

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DOUBLE-LAYERED MONOPOLAR ORDER IN TH $Tb_2Ti_2O_7$ SPIN LIQUID

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In geometrically frustrated pyrochlore magnets, the magnetic interactions cannot be simultaneously satisfied, leading to short-range magnetic orders called spin ices or spin liquids (see recent review [1]). We focus on a comparison of Tb2Ti2O7 spin liquidand the canonical spin ice Ho2Ti2O7. Using a magnetic monopole picture [2], we show that under a field applied along a [110] direction, Tb2Ti2O7, having finite local susceptibility perpendicular to ternary axis [3], orders as a three dimensional arrangement of monopole and antimonopole double layers [4]. In contrast, Ho2Ti2O7 spin ice orders in so called X-structure and behaves as a monopole free state. We briefly present the symmetry analysis of (Jahn-Teller) distortions compatible with the observed magnetic modes. Finally, diffuse scattering in Tb2Ti2O7 at 160 mK will be presented which seems to corroborate the model of local symmetry breaking in Tb2Ti2O7.

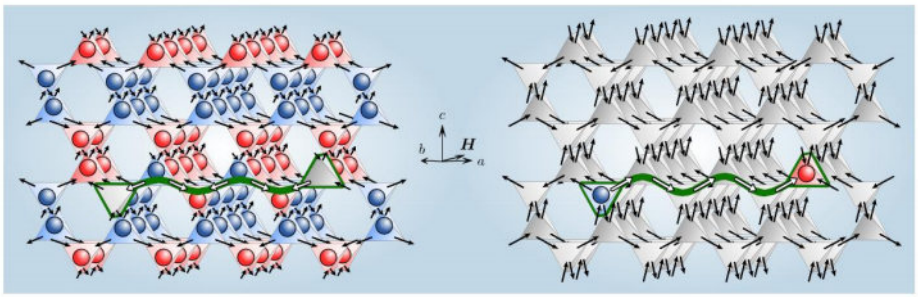

Fig. 1. Magnetic structures of Tb2Ti2O7 (left) and Ho2Ti2O7 (right) in [110] field.

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SOLITONS IN A COMPOSITE MULTIFERROIC CHAIN

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Soliton transport properties in multiferroic system are examined. Particularly, we are interested in soliton motion through ferroelectric-ferromagnetic interface when the soliton carrier frequency is located within the linear band of the ferroelectric and in the band gap of ferromagnet. For a proper choice of the soliton parameters there exist a critical amplitude above which the interface becomes transparent and the band gap soliton penetrates into the ferromagnetic array, while below the threshold the soliton is fully reflected. If one works slightly below the transmission threshold, then even small perturbations can cause the soliton transmission. Indeed, we show via numerical simulations that increasing the noise level there is a clear evidence of stochastic resonance like behavior, particularly, for low noise level there is no soliton (signal) transmission, for intermediate noise level the soliton transmission is stimulated, while for large noise levels transmission is again suspended.

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arXiv:1301.3802. Submitted in Phys. Rev. Lett. (2013)

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SINGLE DOMAIN SPIN MANIPULATION BY ELECTRIC FIELDS IN STRAIN COUPLED ARTIFICIAL MULTIFERROIC NANOSTRUCTURES

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The continuously increasing demand for data storage systems that exhibit both high-speed and low energy consumption has encouraged researchers to look for novel ways of manipulating and recording information. One promising and viable solution is to couple a magnetostrictive ferromagnet to a ferroelectric piezoelectric creating an artificial multiferroic, a material whose magnetization configuration can be manipulated by applying an electric field [1, 2]. In this work we demonstrate the first experimental evidence of an electric field-induced 90° uniform magnetization reorientation between two single domain states in 200×100 nm^2 Ni nanoislands. Artificial magnetoelectric coupling is achieved depositing the Ni nanoellipses on a $Pb(Mg_{1/3}Nb_{2/3})_{0.68}Ti_{0.32}O_3$ ferroelectric single crystal [3]. Imaging of the magnetic domain configuration was obtained by photoemission electron microscopy (PEEM) using the X-ray magnetic circular dichroism (XMCD) effect at the Ni L_3 edge. By applying an electric field that drives the polarization reversal of the ferroelectric, the magnetization in the nanoislands rotates uniformly from the in-plane easy axis defined by the shape anisotropy, to the perpendicular in-plane easy axis, defined by the converse magnetoelectric interaction. Our experimental findings correlate well with micromagnetic simulations and the observed electric field-induced magnetization reorientation can be explained by strain mediated magnetoelectric coupling which causes the magnetization to reorient as a result of the competition of shape anisotropy and magnetoelastic contributions induced by the ferroelectric distortions. We believe that our results constitute an important step not only towards the realization of magnetoelectric memory devices containing an artificial multiferroic film stack with low power consumption and high switching reliability but also for a greater understanding of the physics related to strain coupled nanostructured artificial multiferroics.

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LOCAL PROBING OF MULTIFERROICS BY FIRST-PRINCIPLES CALCULATIONS OF HYPERFINE PARAMETERS

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INTRODUCTION

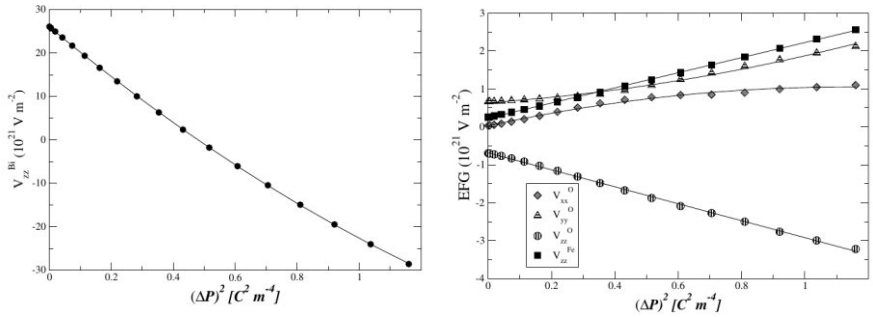
Multiferroics are known for its complex interplay of different interactions, which must be understood at the microscopic level to disentangle its fundamental mechanisms and predict new materials with potential for applications. In this regard the hyperfine properties are an interesting probe of atomic scale physics.

METHODS

We present density functional calculations results for the electric field gradient (EFG) and magnetic hyperfine field in multiferroics, in order to show its changes induced by magnetoelectric or ferroelectric transitions.

RESULTS AND DISCUSSION

The EFGs at different sites or atoms of manganites, ferrites and nickelates show very different variations with the ferroelectric transition, depending on the local charge density changes. The magnetic hyperfine fields are also very sensitive to local changes in magnetism. These calculations serve as a guide for experiments and to quantify or understand the symmetry changes in the local electron density. The figure shows the variation with the polarization amplitude of the main EFG component at all the atoms of $BiFeO_3$.



ACKNOWLEDGMENTS

Work supported by FCT grant SFRH/BPD/82059/2011, project CERN/FP/123585/2011 (financed by FCT and COMPETE/FEDER program) and PEst-C/CTM/LA0011/2011.

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MULTIFERROICS UNDER PRESSURE STUDIED BY NEUTRON DIFFRACTION

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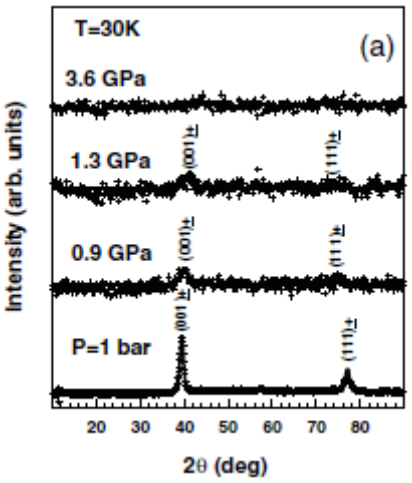
$RMnO_3$ multiferroics exhibit a large variety of frustrated magnetic structures, studied here by high pressure neutron diffraction. Pressures around 1-5 GPa change the delicate balance of the magnetic interactions, inducing new magnetic orders without changing the crystal symmetry. This allows checking the interaction scheme at play.

In hexagonal $YMnO_3$ frustration comes both from the triangular Mn lattice and from a critical threshold tuning the competing interactions along ***c*** [1]. Under pressure, the ordered Mn moments reorient and spin liquid correlations are enhanced [2]. Replacing Y by the smaller In ion cancels the short range interactions along ***c,*** doubling the magnetic periodicity [1].

Monoclinic $BiMnO_3$ a rare ferromagnetic multiferroic, whose ordering temperature strongly depends on pressure. Above 1 GPa an antiferromagnetic order settles, induced by competing antiferromagnetic interactions [3].

In orthorhombic $TbMnO_3$ Mn and Tb incommensurate orders are suppressed under pressure, and a commensurate order appears. The Mn ordering temperature decreases and the Tb one increases. It suggests a change in the relative magnitudes of the Mn-Mn interactions, and a strengthening of the Tb-Tb or Tb-Mn ones [4].



Magnetic diffraction pattern of $TbMnO_3$ showing the suppression of the Mn magnetic order under pressure.

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STRONGLY DISORDERED HEISENBERG SPIN-1/2 CHAINS: AN NMR APPROACH

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Although the physical properties of spin-½ chain materials have been thoroughly investigated, the influence of disorder on them is not well understood. Qualitatively, the non-magnetic ground state of a spin-½ Heisenberg chain can be seen as a linear combination of states representing all the possible ways of forming singlets. While quantum fluctuations suppress the long-range order (hence preserving translational symmetry), any amount of disorder in the exchange parameters is predicted to dominate at large length scales (low-energies) over both quantum and thermal fluctuations. The disorder, therefore, leads to an inhomogeneous ground state by associating a unique way of forming singlets to every random configuration of exchange paths. This new type of ground state is termed the random-singlet (RS) phase.

To demonstrate the existence of the random-singlet phase in a real material, we studied the spin-chain compound $BaCu_2SiGeO_7$, where the substitution of Ge for Si induces random variations in the exchange couplings. Magnetic resonance experiments (^{29}Si NMR) proved to be a key tool for investigating both the inhomogeneous static magnetism and its low-energy dynamics. The combined results of NMR and magnetometry measurements, together with Quantum Monte Carlo calculations provide compelling evidence for the formation of a random-singlet phase in this compound.

FRIDAY MORNING

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FUTURE TRENDS IN HDDS AND MAGNETIC RECORDING MEDIA

Olav Hellwig

San Jose Research Center, HGST a Western Digital company, San Jose CA, USA

In the first half of my talk I will give an introduction to today's non-volatile re-writable data storage landscape, consisting of flash or solid state memory (SSD), hard disk drives (HDDs) and tape. I will highlight the importance that rotatable storage in the form of HDDs will also maintain in the future and point out recent trends and emerging opportunities for HDD technology resulting from a still exponentially growing demand of increasingly diversifying storage specifications. Looking into the intermediate and far future I will introduce possible technologies, such as heat assisted magnetic recording (HAMR) and bit patterned recording (BPR) [1,2] that have the potential to drive HDD technology beyond the currently used perpendicular magnetic recording (PMR) regime [3,4] and therefore will allow reaching area densities well beyond 1 Tb/in^2.

In the second half of my talk I will present selected magnetic recording media studies that illustrate the complexity of current PMR media and the challenges that the industry is currently facing while developing new recording technologies, such as HAMR and BPR. In this context close scientific collaborations between industry and universities as well as public research facilities are essential to reach critical mass for pioneering new characterization techniques in order to better understand and optimize such more advanced recording technologies. Various examples will be presented.

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Superconducting Levitation on a Permanent Magnet Track – The SupraTrans Test Facility –

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New means of urban transportation and logistics will become realistic with superconducting magnetic bearings. The advantage of superconducting magnetic levitation is that it works passively stable without any electronic control but with attracting and repelling forces to suspend a vehicle pendant or standing upright from zero to high speed - perfect conditions for the idea of rail-bound individual transport with cabins for 4 - 5 passengers requested call by call. They will levitate noiseless over the track made of RE permanent magnets to the chosen destination. Cabins can form chains of cars on their route and release single cabins by magnetic switches. This saves energy and travel time. A big step forward to this vision has been made in Dresden. The world largest research and test facility for transport systems using HTS bulk material in the levitation and guidance system in combination with a permanent magnet track was put into operation. A vehicle for 2 passengers, equipped with linear drive propulsion, non-contact energy supply, second braking system and various test and measurement systems is running on an 80 m long oval driveway.
In the presentation the principle of superconducting levitation by flux pinning in high temperature superconductors will be described. Based on this an overview of the SupraTrans II research facility, the current status of this project, as well as future directions of superconductivity-based magnetic levitation and bearing for automation technology and transportation will be given.

MAGNETIC MATERIALS BY DESIGN

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Magnetic materials are ubiquitous in our daily life. Energy conversion and data storage are among the most common applications. Among the permanent magnets, materials with rare-earth elements such as $Nd_2Fe_{14}B$ or Sm_2Co_{17} dominate the applications, where a large saturation magnetization and energy product is essential.

Steep rise of prices of rare-earth elements motivated world-wide efforts to develop cheap replacement materials, which should contain a little or none of the rare-earth elements. A number of promising candidate materials have been already identified, such as tetragonal Fe/Co alloys [1], $L1_0$ FeNi (tetrataenite) [2], MnAl [3], FeCoB alloys [4], tetragonal Heusler alloys [5], $Fe_{16}N_2$ [6] and efforts are continuing.

By focusing on cheap and abundant elements, we are rather restricted in optimizing the microscopic properties that could lead to excellent permanent magnets. By limiting ourselves to transition metals, the magnetic moments will rarely exceed 3 Bohr magnetons per atom – providing some fundamental limits on achievable saturation magnetization. Furthermore, the spin-orbital coupling in 3*d* transition metals is of limited strength, therefore a demand of large magneto-crystalline anisotropy (that would lead to high coercivity) leads to quite specific requirements on the band structure of replacement materials.

In this talk some recent efforts in finding new, rare-earth free magnets with large anisotropy will be presented. This materials investigated cover a large class of compounds, involving, e.g., Heusler alloys, and 3d based carbides, borides and phosphides.

ACKNOWLEDGEMENTS

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SYMPOSIUM 5.7

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IMAGING MAGNETIZATION REVERSAL OF INTERFACIAL EXCHANGE COUPLING

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We present a direct view of interfacial exchange-coupling in antiferromagnetic/ferromagnetic FM/AFM systems by exploiting the capabilities of soft x-ray magnetic holography imaging [1], i.e., element-selectivity, immunity to external magnetic field, and can image deeply buried layers. We have investigated $[Co/Pt]_n$ multilayers with perpendicular anisotropy exchange-coupled with FeMn and IrMn films. Spectroscopy and element-selective hysteresis loops reveal and quantify two types of interfacial uncompensated AFM moments (UAFM), which behave differently. The majority rotate during FM reversal (*unpinned*-UAFM *moments*) whereas a small amount (10%) stays aligned antiparallel to the field-cooling direction (*pinned*-UAFM *moments*). Holography imaging gives direct views of both FM and UAFM magnetic structures. FM reverses via nucleation, propagation and annihilation of magnetic domains, and shows its asymmetric behavior. Co magnetic domain structure is replicated in the AFM during the whole hysteresis loop, which proves that the FM moments locally drag the unpinned-UAFM moments during reversal. In addition, different nucleation sites and domain wall propagation directions are found in both field branches, pointing out the deterministic nature of the reversal and the spatial distribution of the pinned-UAFM moments.

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COMBINATORIAL EPITAXIAL STRAINED FE-PD FILMS ON CU-AU LAYERS FOR TUNING MAGNETIC PROPERTIES

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ABSTRACT

Tuning functional properties by straining the crystal lattice is of great interest for semiconductors, multiferroics, ferroelectrics, ferromagnets, data storage and shape memory materials [1].
A combinatorial thin film preparation was used to systematically change the composition over a full 4 inch wafer resulting in a variation of magnetic properties. With this approach more than 300 samples can be deposited on one substrate [2].
We will demonstrate that a variation of the Cu-Au composition allows a continuous tuning of the lattice parameter of the epitaxial buffer. This fixes the in-plane lattice parameter of the strained Fe-Pd film grown on top. A variation of the Fe-Pd composition perpendicular to Cu-Au gradient allows examining both, variation of tetragonal distortion and film composition in one sample (Fig. 1).

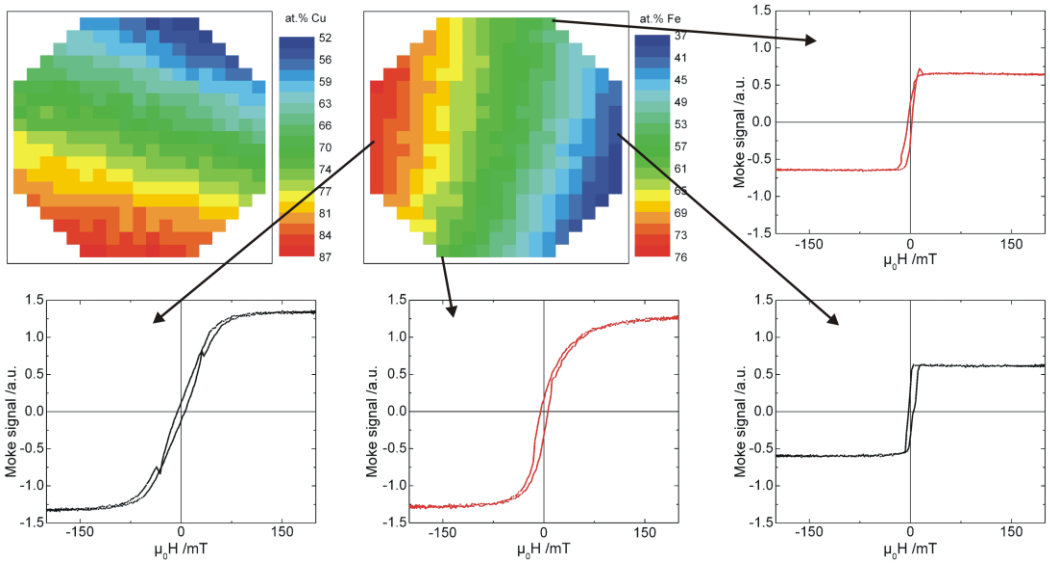

Fig. 1: In-plane composition and hysteresis loops of $Fe_{100-x}Pd_x$ films on $Cu_{100-x}Au_x$ buffer.

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ACKNOWLEDGEMENTS

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XAS/XMCD STUDIES OF GA^+ IONS IRRADIATED PT/CO/PT TRILAYERS

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New effect of Ga^+ ion irradiation induced changes of magnetic and magneto-optical properties was reported recently in [1] where two branches of perpendicular magnetic anisotropy (PMA) were discovered on the 2D maps (d_{Co}, F) of magnetic and magneto-optical parameters driven by ion fluence F and Co thickness. We report here the results of studies performed on Pt/(Co(d_{Co}= 3.3nm)/Pt samples: one non-irradiated and two irradiated ones with fluences corresponding to the first (F_1= $2.8*10^{14}$ ions/cm^2) and second (F_2= $6*10^{15}$ ions/cm^2) PMA branches using XANES and XMCD techniques on Co K-edge and Pt $L_{2,3}$ edges. XANES studies for both irradiated samples showed: (i) changes of the shape of spectra and (ii) big changes of the spectra amplitude for the fluence F_2 what is related with ion irradiation induced modifications of the local environment of Co(Pt) atoms and the etching process, respectively. XMCD Co spectra for the irradiated samples had similar shape as for $Co_{50}Pt_{50}$ alloy. XMCD Pt $L_{2,3}$-edge study revealed the induced magnetic moment of Pt atoms for both irradiated samples.

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MAGNETIC PROPERTIES OF SELF-ORGANIZED Cr OXIDE MONOLAYERS ON Fe(001)

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Thin chromium layers have been extensively studied in recent years due to their application as anti-ferromagnetic spacers in Giant MagnetoResistive (GMR) devices [1]. Especially, the growth mechanism of Cr thin films onto Fe(001) substrates has been widely investigated (see e.g. [2]) owing to the bidimensional nature of the Cr film, which presents different morphological and magnetic characteristics than bulk Cr.

We demonstrated [3] that a sharp Cr/Fe interface can be obtained if the Fe substrate has been previously passivated by oxygen. In this way a layer-by-layer growth for Cr is possible. We recently observed by means of Scanning Tunneling Microscopy (STM) and Low Energy Electron Diffraction (LEED) a transition from the *c*(4x2) phase to the (√5x√5)*R27*° when the growth is performed at 400°C at submonolayer coverages and detalied the atomistic structure by Density Functional Theory calculations [4].

Here we report on the magnetic properties of Cr thin films deposited on Fe-*p*(1x1)O substrates in the submonolayer regime at 400°C and room temperature: X-ray Magnetic Circular Dichroism (XMCD) and Resonant PhotoEmission Spectroscopy (RPES) were employed to this purpose. All the experiments were performed at the beamline BACH of the Italian Synchrotron Elettra in Trieste.

The results show an antiparallel alignment of Cr magnetic momenta with respect to the Fe substrate, even for the submonolayer-thick Cr film. These outcomes are supported by first-principles DFT calculations.

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STRAINING EPITAXIAL FE-CO THIN FILMS TO INCREASE MAGNETOCRYSTALLINE ANISOTROPY

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ABSTRACT

The demand on permanent magnets is increasing and alternatives to the common rare-earth based alloys lack. Fe-Co alloy is a promising candidate as it provides a very large intrinsic magnetic moment. High magnetocrystalline anisotropy is expected for tetragonal distortions with $(c/a)_{bct}$ between 1.2 [1] and 1.25 [2].

Different buffer layers may provide the required in-plane lattice parameter a_{bct}. As the unit cell volume should remain constant, the out-of-plane lattice parameter c is expected to adapt accordingly. Alloyed buffers such as Au_xCu_{1-x} are advantageous as they allow continuous tuning of lattice parameters.

Here, we will present our recent work on epitaxial Fe-Co films with varying thicknesses d. RHEED was used to monitor the strain relaxation in Fe-Co during film growth which begins at a critical film thickness d_C. Out-of-plane magnetic hysteresis measurements demonstrate that high magnetocrystalline anisotropy is only achieved when $d \leq d_C$. Additional approaches that may stabilise the growth of distorted Fe-Co with higher thicknesses are discussed.

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TUNING THE MAGNETIC COUPLING OF FePc/Co(001) BY ADLAYERS

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The demand for new electronic devices, which overcome the limits of conventional electronics, has brought molecules into focus. A challenge is to tune the magnetic properties between molecules and substrate. For porphyrin molecules, ligands and surface adlayers can be used to manipulate the magnetic coupling and the spin state [1,2].

Here, we present a combined state-of-the-art density functional theory (DFT) and X-ray absorption spectroscopy study of a submonolayer Fe phthalocyanine (Pc) film on Co(001) showing that the magnetic coupling can be tailored by surface oxidation.

In presence of oxygen the coupling between the Fe center and the Co surface switches from ferromagnetic to antiferromagnetic. Simultaneously, the coupling strength is reduced due to screening effects. Notably the coupling mechanism is also completely different with O. On the bare Co substrate a mixture of direct coupling between Fe and Co and an indirect coupling via the benzene rings is obtained from the DFT calculations whereas on the oxidized surface, an 180º coupling between Fe and Co via O dominates.

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DOMAIN STRUCTURE AND CONDUCTING PROPERTIES OF THIN NiFe FILMS DEPOSITED ON YIG AND Si INSULATORS

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Anisotropic magnetoresistance (AMR) effect is a telltale sign of a ferromagnet metal. Recently Pt thin films deposited on FM insulator $Y_3Fe_5O_{12}$ (YIG) have demonstrated a sizable MR [1]. It was shown that FM properties of Pt films are attributed to a strong magnetic proximity effect in close proximity of an FM insulator [2]. Similar MR was revealed in soft ferromagnet Permalloy (Py = $Ni_{80}Fe_{20}$) thin films deposited on YIG.

To clarify the influence of a domain structure evolution in YIG on conducting properties of thin NiFe films deposited on polycrystalline YIG substrates, details of the Py/YIG magnetization reversal process was studied by the magneto-optical indicator film technique.

It was established that a domain structure in Py during magnetization reversal is controlled by the stray field created by a non-homogeneous magnetization distribution in YIG. It was revealed that this one determines the non-saturated AMR behavior in Py/YIG exhibited during longitudinal and transverse magnetoresistance measurements. It was shown that AMR and the domain structure in Py deposited onto a non-magnetic Si substrate are cardinally distinguished from these ones in Py/YIG.

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SYMPOSIUM 7.3

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SINGLE CRYSTAL GROWTH AND CHARACTERIZATION OF SUPERCONDUCTING LIFEAS AND ITS DOPING VARIANTS

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INTRODUCTION

LiFeAs is considerably different from other iron-pnictides as the magnetically ordered spin density wave state, which is suppressed upon either chemical doping or external pressure and is considered as an important ingredient for superconductivity in all iron-pnictide superconductors, is not present in LiFeAs.

RESULTS

We have grown high quality single crystals of LiFeAs and its substitution variants $Li_{1-\delta}Fe_{1-x}TM_xAs$ (with TM=Co,Ni,Rh,Cr) variants by a self-flux technique [1,2]. As an example, the superconducting transition temperature was found to decrease in $LiFe_{1-x}Co_xAs$ [2,3]. Apparently, charge doping in LiFeAs suppresses superconductivity, in contrast to the effects of charge doping in other iron-pnictides, where charge doping suppresses the spin density wave and establishes superconductivity.

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FERROMAGNETISM IN COMPLEX TRANSITION-METAL-OXIDE STRUCTURES

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Transition-metal oxides are known to have complex phase diagrams and often exhibit ferromagnetism. Thin films grown epitaxially on different substrates, which impart varying degrees of strain, may exhibit magnetic properties that are quite different from those of the bulk materials. Quite often, a thin film may be ferromagnetic, but ferromagnetism is suppressed in the interfacial region ("dead magnetic layers"). The origins of ferromagnetism or its suppression at interfaces are difficult to determine. Here we describe explorations of ferromagnetism in complex transition-metal-oxide structures using a combination of density functional theory and aberration-corrected scanning transmission electron microscopy – we determine the origin of room-temperature, defect-mediated ferromagnetism in Co-doped TiO2 [1]; elucidate the origin of magnetic dead layers in heterostructures [2]; and demonstrate that oxygen-vacancy ordering causes spin ordering in nanopockets of $La_{0.5}Sr_{0.5}CoO_{3-\delta}$ thin films [3] and is responsible for ferromagnetism in insulating $LaCoO_3$ thin films [4]. In all cases, long-standing issues and controversies are resolved in a conclusive way.

Primary collaborators: Stephen J. Pennycook, Maria Varela, and Albina Borisevich. The work was supported in part by Department of Energy grant DE-FG02-09ER46554, by the Department of Energy Basic Energy Sciences, Materials Science and Engineering Directorate, and by the McMinn Endowment at Vanderbilt University.

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THERMOELECTRIC PROPERTIES OF THE KONDO INSULATOR $CeRu_4Sn_6$ UNDER MAGNETIC FIELD

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Kondo insulators are materials in which an energy gap in the electronic density of states (DOS) opens at the Fermi level as a consequence of strong electronic correlations. The gap arises from a half-filled conduction band hybridized with the almost localized *f*-levels (*cf* hybridization). Since correlations renormalize energy scales the gap width of Kondo insulators is of the order of 1 to 10 meV [1].

A particularly interesting situation arises when the *cf* hybridization is strongly anisotropic or develops nodes along certain directions in *k* space [2, 3]. The tetragonal compound $CeRu_4Sn_6$ shows pronounced anisotropy between the crystallographic *c* axis and the directions within the tetragonal plane (*a* and *c'* directions) [4,5]: characteristics of a Kondo insulator are seen within the tetragonal plane but heavy fermion behaviour dominates along the *c* axis [5].

Thermopower is extremely sensitive to details in the electronic DOS near the Fermi level. Thus, measurements on single crystals along different crystallographic axes may shed light on the underlying electronic correlation phenomena. Here we present our investigations of the thermoelectric properties of single crystalline $CeRu_4Sn_6$ at low temperatures and under high magnetic fields. Our aim is to reveal the topology of the Fermi surface and its relation to the anisotropy of the energy gap.

This work was supported by the Austrian Science Fund (project I623-N16) and the European Commission (contract N° 228043-EuroMagNET II).

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MAGNETIC CONTRIBUTION TO THE HEAT CAPACITY OF $CeNi_4Cr$

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Recently the thermomagnetic and XPS properties of the intermetallic compound $CeNi_4Cr$ were studied [1]. The expected antiferromagnetic order was not present. The measurements of heat capacity up to 2 K and in an applied magnetic field of 9 T revealed the enhanced Sommerfeld coefficient γ (below 100 $mJ.mol^{-1}K^{-2}$), which classifies the compound studied as being on the border of the heavy-fermion behaviour. We present the analysis of the magnetic contribution to the heat capacity taking into account the presence of the spin fluctuations and the Schottky anomaly. In order to subtract the phonon contribution to the heat capacity we have used $LaNi_5$ as the nonmagnetic reference compound crystallizing, like $CeNi_4Cr$, in the $CaCu_5$–type crystal structure.

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THE INFLUENCE OF MAGNETIC INGOMOGENEOUS STATE ON MAGNETOTHERMOPOWER OF $Sm_{0.55}Sr_{0.45}MnO_3$ MANGANITES

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The research of $Sm_{05.5}Sr_{045}MnO_3$ have shown [1] that there's a magnetic inhomogeneous state consisted of three types clusters: ferromagnetic, A- and CE- types antiferromagnetic with T_{NCE}=240K.

In our work we've investigated the thermopower α and longitudinal effect of magnetothermopower $\Delta\alpha/\alpha=(\alpha_H-\alpha_{H=0})/\alpha_{H=0}$ of the $Sm_{0.55}Sr_{0.45}MnO_3$ single crystal. Figure 1 shows the temperature dependences of α(T) with the broad maximum includes T_{NCE} temperature (a) and $\{\Delta\alpha/\alpha\}$(T) with the sharp giant minimum located near the T_{NCE} (b). As it shown in [1] the imposition of magnetic field H>8 kOe at $T>T_C$ on this sample transfers CE-type AF state in F state in the jumplike fashion.

Sharp decrease of α in T_{NCE} under the action of field is connected to destruction of CE-type AF phase. Electrical current, flowed in sample, causes Peltier effect on boundary of CE-type AF cluster and a temperature overall ΔT arises on this cluster. Internal thermopower is caused by influence of ΔT and is equals to $(\alpha_1-\alpha_2)\Delta T$, where α_1 is the thermopower of clusters and α_2 is the one without clusters. Sharp decrease of crystal's thermopover in T_{NCE}-region (Fig.1b) shows big contribution in α from the AF CE-type clusters.

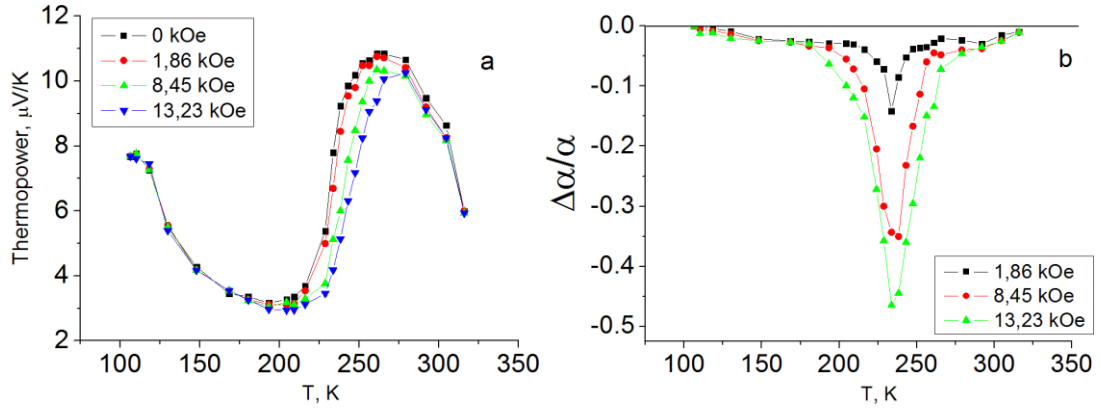

Figure 1. Temperature dependence of the thermopower α(T) of $Sm_{0.5.5}Sr_{0.55}MnO_3$ (a) and magnetothermopower $\{\Delta\alpha/\alpha\}$(T) in H=13.23 kOe (b).

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HIGH PRESSURE ELECTRICAL RESISTIVITY OF THE KONDO INSULATOR COMPOUND $CERU_4SN_6$

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In the past two decades, the unusual physical properties of Kondo insulators (KIs) have attracted a lot of attention [1]. The electronic structure of KIs is thought to derive from the hybridization of conduction electrons states with 4*f* orbitals situated on a periodic lattice. In the special case of a Kondo lattice at half filling, the Fermi level is situated within the small gap/pseudo-gap that develops at low temperatures.

The compound $CeRu_4Sn_6$ is a rare example of a KI that crystallizes in a tetragonal structure (space group *I – 4 2m* [2]). Recent electrical transport measurements on $CeRu_4Sn_6$ single crystals showed pronounced anisotropy between the *c* direction and directions within the tetragonal plane *(a* and *c´* directions) perpendicular to it which might be attributed to the formation of a nodal gap [3]. Optical conductivity measurements showed metal-like character along *c* but semiconductor-like behavior within the tetragonal plane [4]. LDA + DMFT could attribute this anisotropy to a band crossing along $X \rightarrow \Gamma$ (*c* axis), but direct gaps elsewhere [4]. Electrical resistivity measurements under high pressure have so far only been performed on polycrystalline samples [5].

Here, we present electrical resistivity and magnetoresistance measurements on single crystalline CeRu4Sn6, under hydrostatic pressures up to 15 kbar and at temperatures down to 0.05 K, to shed further light on this unusual state.

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SYMPOSIUM 2.5

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DOMAIN-WALL DYNAMICS IN FERROMAGNETS AND ANTIFERROMAGNETS

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Ferromagnets (FMs) and antiferromagnets (AFMs) can be used to store and manipulate spin information, and new developments have created opportunities to use them as active components in spintronic devices. We study current-induced domain-wall (DW) dynamics in thin ferromagnetic and AFM nanowires. We derive effective equations of motion describing the dynamics of the DW soft modes associated with topological defects. Because the DWs are topological objects with a rigid spin structure, these equations are rather universal. The DW rigidity makes the microscopic details irrelevant and allows us to solve the DW dynamics for a very general class of spin Hamiltonians. We show that the DW dynamics in FMs is described by simple equations with only four parameters. Based on these equations, we study DW dynamics in a ferromagnetic wire with Dzyaloshinskii-Moriya interaction (DMI) [1]. We obtain spin spiral DW structure and how the critical current required to move the domain wall depends on DMI. We also investigate the DW dynamics driven by time-dependent currents. We find the most efficient (with the lowest Ohmic losses) way to move the DWs by resonant current pulses [2]. In addition, we propose a procedure to unambiguously determine the DW dynamics parameters by all-electric measurements of the time-dependent voltage induced by moving DW [3]. Furthermore, based on the derived DW dynamics equations for the translationally non-invariant nanowires [4], we show how to make prospective magnetic memory nanodevices much more energy efficient.

In AFMs, the dynamics is described by coupled equations of the staggered field and the magnetization. These equations are very complex and have many degrees of freedom. We present a theory which is conceptually much simpler and which uses collective coordinates to describe staggered field dynamics in antiferromagnetic textures [5]. The theory includes effects of dissipation, external magnetic field, as well as reactive and dissipative current-induced torques. We derive the equations of motion for the collective modes, equivalent to the classical motion of a massive particle subjected to dissipation-induced friction and external forces. We conclude that, at low frequencies and amplitudes, currents induce collective motion in AFMs by means of dissipative rather than reactive torques.

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HIGH ENERGY SURFACE SPIN WAVES OF ULTRA-THIN FERROMAGNETIC FILMS

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Electron energy loss spectroscopy has been established as a valuable tool for studies of the dispersion of spin waves at ferromagnetic surfaces. Using our recently developed spectrometer with unprecedented high energy resolution, we have studied spin waves of Co and Fe films on Cu(100).

For fcc cobalt films standing spin wave modes in addition to surface spin waves are discovered in the region of small wave vectors $q_{||} < 0.35 Å^{-1}$ [1]. An example is shown in Figure 1 for the case of 6ML Co/Cu(100).

The spin wave dispersion of ultrathin iron films grown on Cu(100) surfaces was found to be nearly identical to the dispersion reported for bcc Fe(110) layers grown on W(110). We therefore conclude that the spin wave signal stems from the “nanomartensitic” phase of Fe/Cu(100) [2].

The limited mean free path of low energy electrons allows us to furthermore look at the spin waves localized at the interface between cobalt and a capping layer. Compared to the free cobalt surface, the interface spin waves are downshifted in frequency. The effect is attributed to a reduced exchange interaction between cobalt atoms at the interface [3].

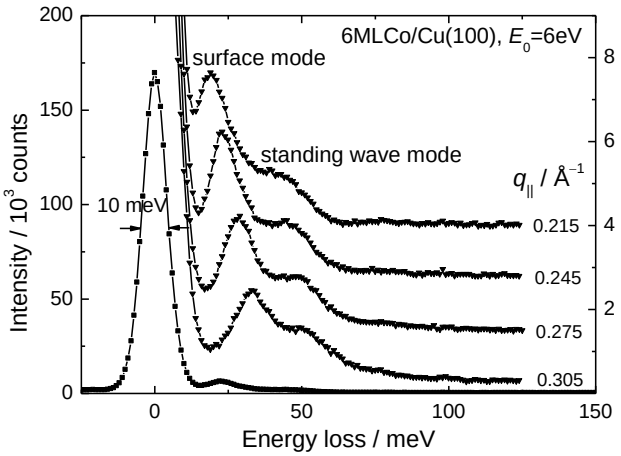

Fig. 1: Series of spin wave spectra measured on 6ML Co/Cu(100) with 10 meV resolution.

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EFFECT OF THE ANNEALING TEMPERATURE ON DYNAMIC AND STRUCTURAL PROPERTIES OF Co_2FeAl THIN FILMS

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Co_2FeAl (CFA) Heusler alloys have a high Curie temperature and, therefore, are promising for practical spintronic applications. However, an annealing process is required to initiate their crystallization and to induce their atomic ordering. Therefore, it is of great interest to investigate the annealing temperature (T_a) effects on the structural and dynamic properties of CFA thin films. 10 nm and 50 nm thick CFA thin films have been deposited on Si(001) substrates by magnetron sputtering using a Tantalum cap layer and, were then ex-situ annealed at 415°C, 515°C and 615°C during 15 minutes in vacuum. X-rays diffraction indicates that the [011] CFA axis is normal to the substrate and that all the CFA films exhibit in-plane isotropy. Ferromagnetic resonance measurements using a microstrip line (MS-FMR) reveal huge interfacial perpendicular magnetic anisotropy and small in-plane uniaxial anisotropy, both Ta-dependent. The MS-FMR data also allow concluding that the gyromagnetic factor remains constant and that the exchange stiffness constant increases with T_a. Finally, the FMR line-width decreases with increasing T_a and allows deriving a very low intrinsic damping parameter ($1.13x10^{-3}$ at 615°C).

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SPIN-TORQUE FERROMAGNETIC RESONANCE STUDY IN CO/NI MULTILAYERS

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Recent experiments on current induced domain wall motion (CIDWM) [1-3] invoke various physical interests on new mechanisms of the domain wall motion. Especially, it has been attracting attentions on effects of non-magnetic layers beneath and above the active magnetic layer, which even reverse the translational motion of the domain wall with respect to the current flowing direction [2]. Spin Hall effect, Rashba effect, and Dzyaloshinskii-Moriya interaction have been employed to give a qualitative explanation for this phenomenon. However, it is not clear which of the effects are actually dominant.

We perform spin-torque ferromagnetic resonance measurements to quantitatively estimate various properties relevant to the dynamics of the domain wall motion, such as Gilbert damping constant, spin torques, and effective fields upon application of an electric current. The samples are Co/Ni multilayers capped with and without MgO which are often used in CIDWM experiments [2]. We found that these samples exhibit distinctive differences in spin Hall torque and the effective field. In the talk, we will discuss the results to clarify the dominant effect.

We thank Dr. T. Tanigawa at Renesas Electronics Corporation for providing Co/Ni multilayer samples.

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INFLUENCE OF THE DZYALOSHINSKII-MORIYA INTERACTION ON THE SPIN-WAVE SPECTRA OF THIN FILMS

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We have developed a theory that describes the spin wave spectra of ferromagnetic films with Dzyaloshinskii-Moriya interactions. In agreement with recent experiments [1], we demonstrate that, in the case that a bias field saturates the film magnetization, the spin wave dispersion relation is asymmetric with respect to wave vector inversion for a variety of ferromagnetic films with Dzyaloshinskii-Moriya interactions and different crystallographic classes [2]. It is also predicted that, for non-zero wave vectors, the resonance frequency and resonance field can increase or decrease depending on the spin wave vector orientation. We provide explicit formulae for the spin wave dispersion relation and its asymmetry, as well as for the dynamic susceptibility for a film under microwave excitation, that can be used to understand Ferromagnetic Resonance (FMR) as well as Brillouin Light Scattering (BLS) experiments in these classes of magnetic thin films.

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SIMULTANEOUS STXM IMAGING AND RESISTANCE MEASUREMENTS OF TRILAYER VORTICES

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We investigate a trilayer vortex system by simultaneous scanning transmission X-ray microscopy (STXM) and *in*-situ giant magnetoresistance (GMR) measurements. Our aim is to correlate the magnetic configuration of both magnetic layers with the corresponding magneto-resistance effects.

The sample is a Co/Cu/$Ni_{80}Fe_{20}$ cylindrical trilayer, with 2 µm diameter [1]. Top and bottom contacts allow to apply a perpendicular DC current to measure the resistance. Simultaneously the magnetic configuration of each element of the disc is imaged using STXM. This is performed at the Paul Scherrer Institute. The vortex core formation in both magnetic layers and the position of the vortex core can be controlled by applying an in-plane external magnetic field. When the cores are at the edge, and the magnetization state resembles that of two in-plane magnetized disks, the GMR is low, as both cores move towards the center. With decreasing field the resistance increases, as the cores move beyond the center and towards the opposite side, the resistance decreases again. We investigate the resistance at different DC currents in dependency on the swept magnetic fields.

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MAGNETIZATION DYNAMICS OF MULTILAYERED RARE EARTH (RE) – TRANSITION METAL (TM) STRUCTURES

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ABSTRACT

It was recently demonstrated that femtosecond laser pulses can manipulate the magnetic order [1] and even result in a full magnetization reversal of metallic samples [2]. The latter was first shown in GdFeCo, a RE-TM ferromagnetic alloy near its magnetization compensation point, which happens at a certain temperature T_M. This temperature is a function of the alloy chemical composition and plays a crucial role in its magnetization dynamics. It was in fact demonstrated that the ultrafast demagnetization efficiency strongly depends on $(T-T_M)$ [3].

Mixing different RE-concentrations in one sample consisting of RE-TM layers could reveal an atypical behavior of the net magnetization dynamics, different from those for each separate alloy. We investigated the relative influence of the layers and possible interface effects by means of static magneto-optical measurements and time-resolved pump-probe spectroscopy. Temperature and fluence dependent measurements demonstrated the possibility of magnetization reversal. Pump-probe spectroscopy allows distinguishing the contributions from the different RE-TM layers. Note that a proper engineering of such a stack could lead to the expansion of the all-optical switchability to a more extended range of compositions due to the interlayer coupling.

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SYMPOSIUM 9.3

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MAGNETOELECTRIC RESPONSE OF MULTIFERROIC THIN $YbMnO_3$ FILMS MEASURED BY LOW-TEMPERATURE ELECTROSTATIC FORCE MICROSCOPY

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Magnetoelectric (ME) coupling in multiferroic materials results in the appearance of an electric polarization upon applying a magnetic field. Using low-temperature, high-magnetic field electrostatic force microscopy, we have studied the ME response of $YbMnO_3$ films. Thin films of $YbMnO_3$ with thickness of 150 nm were grown epitaxially by RF magnetron sputtering on conducting Nb:$SrTiO_3$ substrates.

The applied magnetic field results in the appearance of distinctive electrostatic domains with typical dimension of about 0.2 μm (see Figure). No motion of the domain boundaries or coalescence of domains was observed.

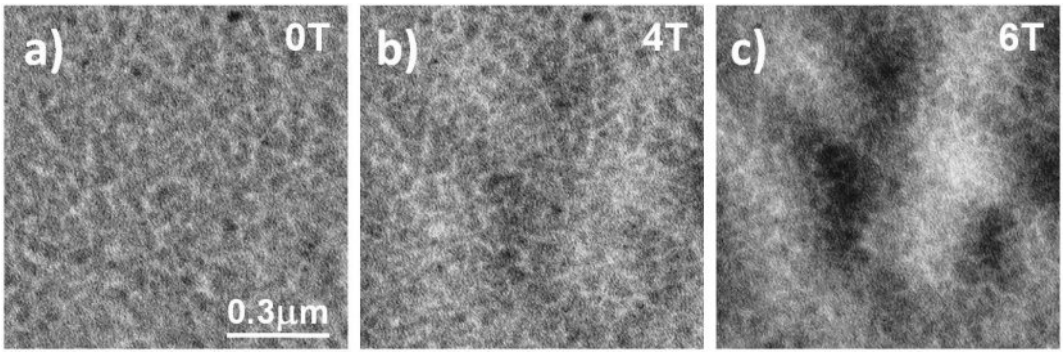

Figure: (a) Electrostatic force microscopy images of a $YbMnO_3$ sample acquired at 4.3 K under in-plane magnetic fields of B = 0 T (a), B = 4 T (b) and B = 6 T (c).

The formation of the domains can be attributed to the appearance of surface charges due to a magnetic-field induced change in the electrical polarization. This magnetic-field induced polarization variation can be considered as a consequence of the existence of a cycloidal magnetic order in the $YbMnO_3$. The observed electrostatic field domain pattern can be associated with the crystalline domains in our $YbMnO_3$ films.

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NON-EQUILIBRIUM DYNAMICS IN THE INHOMOGENEOUS SPLAYED FERROMAGNETIC PHASE OF THE QUANTUM SPIN ICE $YB_2SN_2O_7$

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INTRODUCTION

The pyrochlore Yb2M2O7 (M = Ti, Sn) has been recently reported to be an experimental realization of quantum liquid behaviour [1], arising, as in the case of Tb2Ti2O7, from quantum spin ice physics. Although some controversy remains regarding the low temperature ground state in these materials, both the Ti [2] and the Sn [3] compounds have been recently shown to undergo a transition into a long-ranged ferromagnetic state at ca. 130-140 mK. The instability of this phase seems to be linked to the proximity of a quantum critical point (QCP) separating the ferromagnetic and the 'paramagnetic' quantum spin liquid [2,4].

Despite the onset of an ordered ferromagnetic phase, both the Ti and Sn systems are found to remain dynamic as T → 0 [3]. Here we present results from μSR and ac-susceptibility measurements of Yb2Sn2O7 that confirm this instance and shows the system to behave as cluster glass with glassy dynamics that extend over several decades of time. Further confirming this view, we found aging and rejuvenation non-equilibrium behaviour, characteristic of glassy systems with slow dynamics. We suggest that the cluster-like behaviour is related to the proximity of the QCP. The power law dependence of the spin-lattice relaxation rate $1/T_1T$ vs T seems to support this view.

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Ref # : 467.1367850938

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ELECTRICAL SWITCHING OF THE MAGNETIC ORDER AT THE Fe/$BaTiO_3$ INTERFACE

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Exploiting the interfacial magnetoelectric coupling to electrically control the magnetization of ferromagnetic electrodes is a viable path to achieve the electrical writing of magnetic information in spintronic devices. For the paradigmatic Fe/$BaTiO_3$ (BTO) system some studies reporting sizable magnetoelectric effects exist, mainly based on inverse magnetostriction on bulk BTO substrates [1], while only indirect evidence for purely electrical magnetoelectric effects has been inferred from measurements on magnetic tunnel junction including a thin BTO barrier [2].

In this paper, by X-ray Magnetic Circular Dichroism measurements performed on patterned Co/Fe/BTO/$La_{0.7}Sr_{0.3}MnO_3$//$SrTiO_3$(001) fully epitaxial heterostructures we show that, at RT, the average magnetization of the iron oxide interface layer disappears when the dielectric polarization vector of BTO points away from the iron oxide layer.

DFT+U calculations show, indeed, that the switching from ferromagnetic to the antiferromagnetic ordering within the interface iron oxide layer can be driven by the BTO polarization reversal.

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HEXOGANAL AND PEROVSKITE-LIKE MULTIFERROIC THIN $YbMnO_3$ FILMS

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Thin films of $YbMnO_3$ (YbMO) with thickness of 50-100 nm were grown epitaxially by RF magnetron sputtering on different substrates. The hexagonal modification h-YbMO (the same as in the bulk) was obtained on $SrTiO_3$(111) and Al_2O_3(001) with Pt buffer layers, while the orthorhombic (perovskite-like) modification o-YbMO was epitaxially stabilized on $NdGaO_3$ (001), $SrTiO_3$ (001), $SrTiO_3$ (110) and $LaAlO_3$ (001). The surface topography of the films was studied by atomic force microscopy. Piezoresponse force microscopy was used to investigate the ferroelectric response of the hexagonal films.

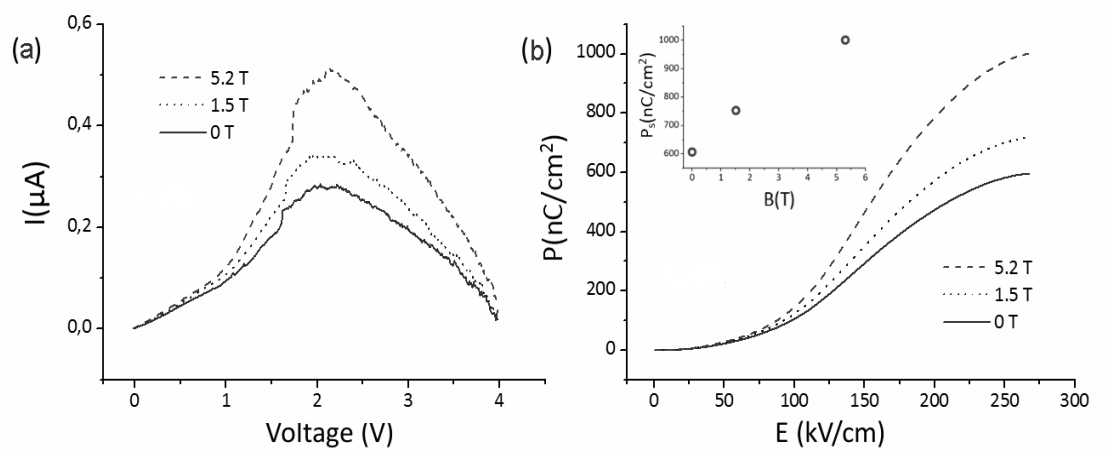

Figure 1. (a) Current I vs. voltage V and (b) polarization P vs. electric field E measured at 4.5K for o-YbMO at different magnetic fields. The insert presents the magnetic field dependence B(T) of polarization P.

o-YbMO films revealed ferroelectric behavior at low temperature with saturation polarizability ~ 300 nC/cm^2. Application of an external magnetic field led to enhancement of the polarization (see Figure), demonstrating the real multiferroic nature of the films (Fig.1). The enhancement is in agreement with the existence of a cycloidal [1] magnetic order in $YbMnO_3$.

This work was supported in part by the RFBR Grants #12-02-00717_a and #12-02-92607_a.

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MAGNETOSTRUCTURAL PHASE SEPARATION INDUCED BY GEOMETRICAL FRUSTRATION

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Complex electronic-phase inhomogeneities are often encountered in transition metal oxides with simultaneously active multiple degrees of freedom. In insulating spin systems they are rare, though predicted, and can be born out of geometrical frustration leading to competition of different states.

The triangular lattice antiferromagnet α-$NaMnO_2$ is intriguing in this respect as it features unexplained coexistence of long- and short- range magnetic correlations below the Néel ordering and anisotropically strained crystal structure above it [1]. Here, we review our comprehensive structural and magnetic studies, including high-resolution synchrotron X-ray diffraction, local-probe NMR and μ^+SR, which in a complementary fashion provide a new insight to α-$NaMnO_2$ [2]. The current experiments reveal an unprecedented magnetostructurally inhomogeneous ground state, with nanoscale regions of competing monoclinic and triclinic structures (Figure 1) entailing different magnetic order. This intriguing state that stems from the near-degenerate structures and is endorsed by the inherent geometrical frustration of the triangular spin lattice, provides a paradigm of nanoscale inhomogeneity in an insulating spin system coupled to phonons.

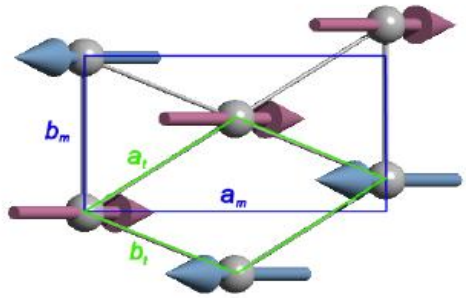

Figure 1. Schematic of the lattice-distortion in α-$NaMnO_2$ at the transition (Néel ordering) from the monoclinic (m) to the triclinic (t) phase. The Mn-Mn antiferromagnetic spin-2 chains shift along b_m-axis.

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MAGNETIC AND FERROELECTRIC TRANSITIONS IN $Mn_{1-x}Co_xWO_4$ MULTIFERROICS WITH CONICAL ANTIFERROMAGNETIC ORDER (x>0.15)

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$MnWO_4$ exhibits gigantic magnetoelectric effects and belongs to the new class of frustrated multiferroics in which magnetic and ferroelectric order coexist and mutually interact [1]. Addition of Co^{+2} ions (S=3/2) modifies the overall magnetic interactions, produces changes in the magnetic anisotropy and stabilizes the multiferroic behavior [2-5].

Collinear and non-collinear spin orders strongly compete in $Mn_{1-x}Co_xWO_4$ multiferroics for Co dopings around 0.15, and eventually coexist. The interval of coexistence progressively reduces increasing the cobalt content. The competing commensurate collinear (AF4) and incommensurate cycloidal (AF2) spin structures in $Mn_{0.80}Co_{0.20}WO_4$ multiferroic were studied by neutron diffraction, magnetic, and pyroelectric characterization measurements. In contrast to pure and slightly Co doped $MnWO_4$, the antiferromagnetic AF4 collinear phase with wave vector $\mathbf{k}_1$=(0.5, 0, 0) inherent to the pure $CoWO_4$ was observed below $T_N \approx 20$ K in $Mn_{0.80}Co_{0.20}WO_4$. This collinear order survives down to the lowest temperature reached in the experiments (2 K) even after the appearance of the second (cycloidal AF2) spin order below $T_{FE} \approx 8.5$ K [$\mathbf{k}_2$=(0.211, 0.5, 0.452)] [4,5]. Ferroelectric polarization along *b*-axis was revealed below T_{FE} in the low temperature transverse conical phase resulting from the superposition of the AF4 and AF2 spin structures. The arrangement of the spins after the two successive magnetic transitions has been thoroughly described [4]. We found that spins in the AF4 phase are aligned along the easy direction in the ac-plane (~142^o with respect to the c*-axis), while the cycloidal AF2 spin order is developed in the magnetically hard directions, perpendicular to the easy one, and consequently the T_{FE} decreases compared to the pure $MnWO_4$. The effect of the magnetic field strongly depends on the applied direction.

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SPIN DYNAMICS IN THE SPIN-1/2 TRIANGULAR-LATTICE ANTIFERROMAGNET CS_2CUBR_4.

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Magnetic excitations in Cs_2CuBr_4, a spin-1/2 spatially anisotropic antiferromagnet with a distorted triangular lattice, are probed by means of high-frequency electron spin resonance (ESR) spectroscopy in magnetic fields up to 25 T. A substantial zero-field gap, Δ = 9.5 K, is observed in the magnetically disordered state. Surprisingly, the ESR excitation spectrum is not appreciably affected by the ordering at T_N = 1.4 K, leaving the gap size almost unchanged. No critical behavior of the ESR linewidth in the vicinity of T_N was observed. These results are consistent with that obtained for quasi-1D $KCuCl_3$ and Cs_2CuCl_4 suggesting that the spin dynamics in Cs_2CuBr_4 is dominated by strong short-range order correlations (presumably of the quasi-1D nature) . On the other hand, contrary to Cs_2CuCl_4 the size of the gap cannot be explained solely the Dzyaloshinskii-Moriya interaction revealing the important contribution of frustrated interchain interactions. Peculiarities of the spin dynamics in Cs_2CuBr_4 are discussed.

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Spintronics – Implications for Energy, Information and Medical Technologies*

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ABSTRACT

Spintronics encompasses the ever-evolving field of magnetic electronics.[1,2] Fields such as spintronics hold the potential to extend the information technology revolution as the semiconductor roadmap reaches its end. A major issue with present day electronics is in its demand for increased power. Spintronics offers the possibility to communicate via pure spin currents as opposed to electric charge currents. The talk provides a brief perspective of recent developments to switch magnetic moments by spin-polarized currents, electric fields and photonic fields (see Fig. 1). Developments in the field of spintronics continue to be strongly dependent on the exploration and discovery of novel nanostructured materials and configurations. An array of exotic transport effects dependent on the interplay between spin and charge currents have been explored theoretically and experimentally in recent years. The talk highlights promising areas for future investigation, and, features recent work at Argonne, [3,4] including, most strikingly, in the realm of medical applications.[5]

ACKNOWLEDGEMENT

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