Korea-UK Workshop on Spintronics

February 6~8, 2012

Korea Institute of Science and Technology (KIST),
Seoul , Korea

Supported by UK Global Partnerships Fund,
UK-Korea Focal Point Programme &
KIST Institutional Programme

Scope

Spintronics has emerged from studying the properties of magnetic materials, and become an important field of research in condensed matter physics, leading to remarkable scientific and technological breakthroughs. The aims of this workshop are to bring scientists from the UK and Korea, who are active in the field, and forge long-term collaborations in this fast moving field of research. Topics that will be covered include: spin transport and magnetism, magnetic multilayers, magnetic tunnel junctions, semiconductor spintronics, the electrical control of magnetism, spin FET, spin Hall effect, domain wall motion, vortex dynamics, topological insulators, and the entanglement of spin waves, to name only a few. We are going to highlight some of latest developments in the field of experiments and theories. This special Korea-UK workshop is sponsored by UK government through the Global Partnerships Fund, by Korean government through the UK-Korea Focal Point Programme and KIST Institutional Programme.

Invited Speakers

Prof. Gabriel Aeppli (LCN)
Prof. Simon Bending (Bath)
Prof. Russell Cowburn (Cambridge)
Dr. Adidan Hindmarch (Durham)
Prof. Sean Langridge (RAL)
Prof. Christopher Marrows (Leeds)
Dr. Andrew Rushforth (Notts)
Dr. Yeong-Ah Soh (Imperial)
Prof. Robert Stamps (Glasgow)

Dr. Hyun-Cheol Koo (KIST)
Prof. Chunghee Nam (Hannam Univ.)
Prof. Chun-Yeol You (Inha Univ.)
Prof. Hyun-Woo Lee (POSTECH)
Dr. Sung-Chul Lee (Samsung Advanced Institute of Tech.)
Prof. Sang-Ho Lim (Korea Univ.)
Prof. Myung-Hwa Jung (Sogang Univ.)
Prof. Jae-Ho Chung (Korea Univ.)
Dr. Kyung Soo Choi (KIST)
Prof. Sug-Bong Choe (Seoul National Univ.)

Organizing Committee

Byoung-Chul Min (KIST) & Sean Langridge (RAL)

Advisory Committee

Kyung-Ho Shin (KIST) & Je-Geun Park (Seoul National University)

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The Global Partnerships Fund (UK government)
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Information

http://cscmr.snu.ac.kr/spin/Korea-UK.html

Program

Monday, 6 February 2012

09:30-09:50 **Registration** ***&*** ***Coffee***

09:50-10:00 **Welcome address**

(Long talk 35 min + 5 min & Short talk 15 min + 5 min)

Session I

Chair: Prof. Hyun-Woo Lee (POSTECH)

10:00-10:40 Prof. Gabriel Aeppli (LCN)
„The title of the 1st talk“

10:40-11:20 Dr. Kyung Soo Choi (KIST)
„A Quantum Circus with Acrobatic Photons, Floppy Spins, and Vibrant Phonons“

11:20-11:40 Dr. Hyun-Cheol Koo (KIST)
„Spin transport in a strong Rashba system“

11:40-14:10 **Lunch break and lab tour (KIST)**

Session II

Chair: Prof. Myung-Hwa Jung (Sogang Univ)

14:10-14:50 Dr. Adidan Hindmarch (Durham)
„Magnetic anisotropies in hybrid magnetic nanostructures“

14:50-15:30 Prof. Sang-Ho Lim (Korea Univ.)
„Magnetic Unit Structures for Perpendicular Magnetic Random Access Memory“

15:30-16:00 **Coffee break**

Session III

Chair: Prof. Sang-Ho Lim (Korea Univeristy)

16:00-16:40 Prof. Russell Cowburn (Cambridge)
„Towards fully 3-dimensional MRAM“

16:40-17:00 Prof. Chun-Yeol You (Inha Univ.)
„Optimization of the Gilbert Damping Constant Measurements with General Susceptibility“

Program

17:00-17:20 Prof. Myung-Hwa Jung (Sogang Univ.)
„Magnetic noise spectra and spin transfer torque in symmetric MgO-based magnetic tunnel junctions“

17:20-17:40 Dr. Sung-Chul Lee (Samsung Advanced Institute of Tech.)
„Current Driven Magnetic Damping in Dipolar-Coupled Spin System“

Tuesday, 7 February 2012

08:50-09:00 **Registration** ***&*** ***Coffee***

(Long talk 35 min + 5 min & Short talk 15 min + 5 min)

Session IV

Chair: Dr. Jun Woo Choi (KIST)

09:00-09:40 Prof. Jae-Ho Chung (Korea Univ.)
„Long-Range antiferromagnetic interlayer exchange couplings in GaMnAs/GaAs diluted ferromagnetic semiconductor multilayers“

09:40-10:20 Prof. Sean Langridge (RAL)
„Observing the subtle magnetism of surfaces and interfaces in nanoscale systems“

10:20-10:40 **Coffee break**

Session V

Chair: Dr. Jung Hoon Lee (KIST)

10:40-11:20 Dr. Andrew Rushforth (Notts)
„Controlling Ferromagnetism with Electric Fields“

11:20-12:00 Prof. Hyun-Woo Lee (POSTECH)
„Rashba spin-orbit coupling, domain wall motion, and spin motive force in ultrathin magnetic nanostructures“

12:00-13:30 **Lunch break**

13:30-13:50 **Group photo**

Program

Tuesday, 7 February 2012

Session VI

Chair: Prof. Chun-Yeol You (Inha Univ.)

13:50-14:30 Prof. Robert Stamps (Glasgow)
„Domain Growth in Coupled and Frustrated Patterned Magnets“

14:30-14:50 Prof. Sug-Bong Choe (Seoul National Univ.)
„Spin-transfer-torques-induced domain-wall motion in ferromagnetic Pt/Co/Pt nanowires with perpendicular magnetic anisotropy“

14:50-15:30 Prof. Simon Bending (Bath)
„Resistivity and Current-driven Motion of Domain Walls in Artificial Magnetic Domain Structures“

15:30-16:00 **Coffee break**

Session VII

Chair: Dr. Hyun-Cheol Koo (KIST)

16:00-16:40 Prof. Christopher Marrows (Leeds)
„Spintronics at Magnetic Domain Walls“

16:40-17:20 Dr. Yeong-Ah Soh (Imperial)
„Magnetic Force Microscopy of Magnets with Competing Interactions“

17:20-17:40 Prof. Chunghee Nam (Hannam Univ.)
„Magnetic domain walls in circular and elliptical rings“

17:40-17:50 **Concluding remark**

18:00- **Banquet**

The title of the first talk

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Abstract of the first talk

A Quantum Circus with Acrobatic Photons, Floppy Spins, and Vibrant Phonons

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Quantum networks are composed of quantum nodes that interact coherently through quantum channels, and open a broad frontier of scientific opportunities [1]. For example, a quantum network can serve as a 'web' for connecting quantum processors for quantum computation and communication, or as a 'simulator' allowing investigations of quantum critical phenomena arising from interactions among the nodes mediated by the channels. The physical realization of quantum networks generically requires dynamical systems capable of generating and storing entangled states among multiple quantum memories, and of efficiently transferring stored entanglement into quantum channels for distribution across the network [1,2]. By extension, one can envisage a 'quantum circus,' a macroscopic quantum system which provides an exciting playground for strongly interacting photons, (atomic) spins, and phonons. In this talk, I will discuss a series of recent experiments [3-6], where single collective spin excitations (analogous to magnons) in ultracold atomic ensembles are strongly coupled to optical modes, and provide efficient means for the coherent control of entangled states between matter and light. Finally, I will also describe recent results of trapping and interfacing a 1D array of cold atoms in a state-insensitive two-color evanescent wave guided by a dielectric nanofiber, and discuss future prospects of connecting quantum systems with nano-mechanical interfaces.

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Spin transport in a strong Rashba system

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In order to realize spintronic device, we have to understand and utilize the spin-orbit interaction in a semiconductor system. The spin-orbit interaction is the fantastic phenomenon in the field of spintronics because the electric field can be converted to the magnetic field. The mechanism of spin-orbit interaction is that moving electrons in a perpendicular electric field experience an effective magnetic field. In a strong spin-orbit interaction system, we observed several fascinating phenomena.

Spin field effect transistor suggested by Datta and Das is a new paradigm of electronic device [1]. The operation mechanism is the gate field dependence of spin orientation. In an InAs-based quantum well system, the spin polarized current injected from a ferromagnetic source is modulated by the gate voltage and sensed by the ferromagnetic drain [2]. Another observation is that we can obtain spin Hall voltage from the in-plane magnetic source using spin-orbit interaction field. Usually, to detect the spin Hall effect, the perpendicularly magnetized source is necessary. However, in a strong spin-orbit interaction channel spin precession occurs and therefore the spins, initially polarized in the longitudinal direction, can be perpendicularly aligned at the Hall probe. This work clearly shows the spin precession and spin Hall effect at the same time.

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Magnetic anisotropies in hybrid magnetic nanostructures

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Interface magnetism in hybrid nanostructures is important in the functionality of a broad range of spintronic devices. In this talk we will describe studies of magnetic anisotropies induced due to designed interfaces in magnetic nanostructures relevant for spintronics.
In the first part we will discuss magnetic anisotropies in ferromagnetic thin-films on III-V semiconductor substrates. The origin of the uniaxial magnetic anisotropy which arises in prototypical epitaxial Fe thin-films on GaAs(001) has remained enigmatic despite over 25 years of investigation: using amorphous CoFeB films on (Al,Ga)As we show that the uniaxial magnetic anisotropy may be related to the spin-orbit coupling in the III-V substrate.
We also demonstrate how this interface anisotropy can be combined with additional anisotropy terms to created novel magnetic anisotropies in these hybrid structures.
The second part will concentrate on structures which model the lower-electrode/barrier interface in CoFeB/MgO magnetic tunnel junctions. We show how the structural quality and interface magnetism may be modified by designing structures with ultra-thin insert layers of Mg and Zr added to the device structure. We demonstrate how Mg and Zr insert layers improve the crystallinity of the MgO barrier and CoFe(B) electrode, respectively, with concomittant influences on the interfacial magnetism in the CoFe(B) electrode.

Magnetic Unit Structures for Perpendicular Magnetic Random Access Memory

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Recently, magnetic thin films with a strong perpendicular magnetic anisotropy attracted a lot of research interest. This is mainly because the magnetic tunnel junctions with a perpendicular magnetic anisotropy (perpendicular MTJs) have the important advantage of a smaller critical current density for current induced magnetization switching (CIMS) over MTJs with an in-plane anisotropy (in-plane MTJs). This renders perpendicular MTJs more suitable for high density magnetic random access memory. In this presentation, several magnetic thin films showing a strong perpendicular magnetic anisotropy, which were fabricated by using a UHV sputter, are discussed. Examples include unit structures of MgO/CoFeB/Pd and Pd/MgO/CoFeB with a thick CoFeB layer (~2 nm) and TM/Pd and TM/Pt multilayers (TM is the transition metal) with a very small layer thickness (~1 ML). The former type of materials is important because they are suitable for MgO-based magnetic tunnel junctions that are known to exhibit a very large tunneling resistance. The latter structures are also of significant importance because they are likely to form the L11 structure, an important group showing a very high perpendicular anisotropy energy density. Furthermore, the interlayer exchange-coupling between two perpendicular magnetic structures separated by a very thin spacer layer is also investigated. As the exchange-coupled magnetic structure radiates small stray fields, it should be suitable for the pinned layer structure.

Towards fully 3-dimensional MRAM

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3-dimensional nanoelectronic devices offer a potential route to overcoming the current limitations of scaling and lithography feature size. There may be a major opportunity for metallic spintronics if the magnetic part of the system allows vertical stacking of bits in way that is not possible with traditional CMOS or Flash. The key unsolved physics problem to enable this is finding ways of copying the magnetic state of one layer to that of a neighbouring layer to form a vertical shift register, potentially allowing serial streams of bits to be pumped up into the volume of a 3-dimensional MRAM-style device. In this talk I present progress to date on solving this problem. I show three experimental systems, all of which comprise alternating layers of magnetic / non-magnetic materials in which the RKKY interaction is used to couple neighbouring layers anti-parallel to each other. Importantly, in one of these systems the magnetic layers are less than 1nm thick, offering near-atomic stacking of data bits in the vertical direction. I demonstrate how data can be coded into stable frustrations in the anti-parallel ordering and how these frustrations can be injected into the stack from the bottom layer, propagated unidirectionally up the stack under the action of an oscillating magnetic field and then detected at the top layer.

Optimization of the Gilbert Damping Constant Measurements with General Susceptibility

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The measurement of the Gilbert damping constant α becomes important because α governs the performances of the many spintronics devices such as spin transfer torque magneto-resistive random access memory, domain wall motion memory, spin torque nano oscillators, etc. It is well-known that the Gilbert damping constant α can be extract from the line-width of the ferromagnetic resonance (FMR) measurements in frequency domain, or decaying time from the real-time measurements such as time-resolved magneto-optical Kerr effect (TR-MOKE). There have been great achievements in the measurement of α for various systems, however, there are only a few success have been reported in the measurement of α for perpendicular magnetic anisotropy (PMA) systems. In this study, we will discuss the reasons of difficulties in the α measurement for PMA systems. We derive the general susceptibility for arbitrary magnetization and field directions, and show the signal strengths strongly depend on the directions of the magnetization and field in spite of the various measurement methods. We confirm our derived results with the micromagnetic FMR simulations for typical PMA materials.

Magnetic noise spectra and spin transfer torque in symmetric MgO-based magnetic tunnel junctions

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We investigate the bias dependences of in-plane and out-of-plane spin-transfer torque by employing magnetic noise measurement in symmetric MgO-based magnetic tunneling junction devices. The measured power spectra densities of magnetic noise are successfully analyzed by the fluctuation-dissipation theorem with an imaginary part of transverse susceptibility including spin-transfer torque contributions. We find that the inplane component has a linear dependence of the bias voltage, while the out-of-plane component has a quadratic dependence. These results are well consistent with the noise amplitude analysis, neglecting the Joule heating effect with small bias voltage.

The basic structure of the examined magnetic tunneling junction is PtMn/F3/Ru/F2/MgO/F1, where F1,2,3 are ferromagnetic layers. F1 acts as a soft free layer, while PtMn/F3/Ru/F2, an exchange biased synthetic ferrimagnet structure, serves as a fixed reference layer. With the assumption of rigid fixed reference layer, the magnetic thermal noise is only related with the thermal motion of the free layer spins. However, we find additional resonance peaks in the magnetic noise spectra, which correspond to the thermal motion of the reference layer spins. Furthermore, the magnetic noise spectra show intricate field dependences, which are related with the spin dynamics of the reference layer induced by spin transfer torque.

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Current Driven Magnetic Damping in Dipolar-Coupled Spin System

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The damping of the spin, the decay rate from the initial spin state to the final spin state, can be controlled by the spin transfer torque driven by the current. Such an active damping control has given birth to novel phenomena like the current dri-ven magnetization reversal and the steady state spin precession, which are very im-portant in modern spintronic devices. Though the active damping on the single spin system has been intensively studied, the effect of the spin transfer torque on the coupled spin system has never been addressed. Here we report the current driven spin oscillations on the dipolar-coupled magnetic layers. The damping of the coupled spins was enhanced at a specific field, which could not be understood if the spin dynamics in each layer was considered separately. The observed anomalous magnetic damping has been analyzed by the micromagnetic calculations. Our result gives a way to switch on or off the transfer of the energy between the coupled spin layers by controlling an external magnetic field.

Long-Range antiferromagnetic interlayer exchange couplings in GaMnAs/GaAs diluted ferromagnetic semiconductor multilayers

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One of the best known spintronics phenomena is the giant magnetoresistance (GMR), in which electrical resistivity changes greatly when relative magnetizations of adjacent ferromagnetic layers switch between being parallel to antiparallel. Such switching can readily be performed using external magnetic field when the FM layers are coupled via spontaneous antiferromagnetic (AFM) exchange. The GMR effect of metallic FM multilayers is already widely exploited for magnetic read-heads in high-density data storage devices. It is expected that realization of similar GMR effects in semiconductors will open up new possibilities for highly integrated electronic circuits utilizing the GRM effect. One of the most promising semiconductors is GaAs, which becomes diluted FM with p-type conductivity when Mn^{2+} ions replace Ga^{3+} sites. Since the RKKY interaction is known to produce exchange oscillations between FM and AFM in metallic systems, similar effect may be achieved by controlling multilayer parameters such as carrier concentrations in the spacers. [1,2]

In this work, we present experimental evidence that the GMR effect is realized in GaMnAs/GaAs multilayers by controlling interlayer exchange coupling. Step-like changes in magnetoresistance was observed in multilayers in which GaMnAs layers with 3% Mn doping is separated by Be-doped GaAs spacers. Polarized neutron reflectivity confirmed that robust spontaneous AFM coupling between ferromagnetic layers indeed exists in these multilayers. Surprisingly, these stabile AFM interlayer coupling is observed when the thickness of the nonmagnetic spacers is 3.5 nm or larger, which corresponds to 12 GaAs monolayers or more. [3,4] Careful inspection of the magnetoresistance also suggests that the FM layers couple beyond the nearest layers. These results indicate that the interlayer exchange couplings in GaMnAs/GaAs multilayer are much longer-ranged than ever expected.

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Observing the subtle magnetism of surfaces and interfaces in nanoscale systems

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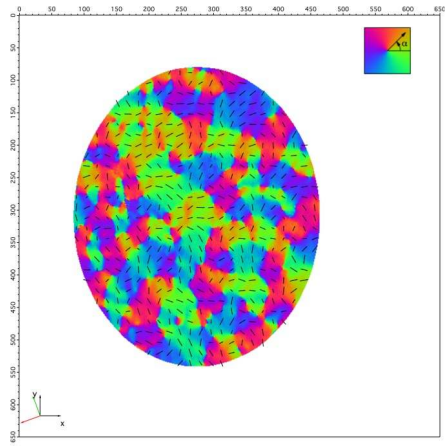
The understanding of electron behaviour in systems with reduced dimensionality and length scale is a central theme of contemporary condensed matter physics. Nanomagnetic (and superconducting) systems allow us to rigorously test our understanding of electronic phenomena with much of the interesting physics and functionality residing within nanometres of the interface. Providing an atomic understanding of such phenomena presents a significant experimental challenge. The interfaces of interest are often buried and not readily accessible to more conventional techniques. Neutron and resonant x-ray scattering and absorption techniques are ideally suited to the study of such systems.

We shall demonstrate the interface and surface sensitivity in two cases: that of induced proximity magnetism [1] in a transition metal multilayer and in a system exhibiting a complex phase transition [2] coupling structural, electronic and magnetic ordering at room temperature. To fully understand these systems, in particular their functional behaviour, a detailed knowledge of the relevant macroscopic and microscopic length scales is required



A x-ray photo-emission micrograph of the near-surface ferromagnetic structure in a binary alloy. The field of view is 20μm.

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Controlling Ferromagnetism with Electric Fields

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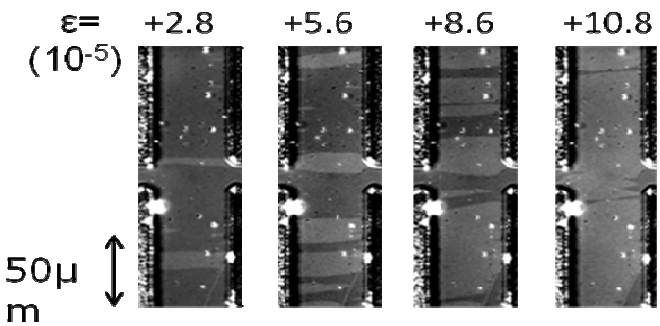
Many applications of ferromagnetic materials in information and communications technologies rely on the control of the magnetic state by magnetic fields or electrical currents. These approaches face challenges such as the difficulty in addressing specific device elements, or energy dissipation due to Joule heating, both of which place limitations on the packing density of memory and processing devices. A promising alternative approach is to use electric fields to control the magnetisation, either directly by electrical gating or indirectly via an induced strain in a hybrid ferromagnet/piezoelectric device.

In Nottingham we investigate ferromagnetic material systems that allow the magnetic properties to be tuned by electric fields or mechanical strain. For example, the magnetic properties of the dilute magnetic semiconductor (Ga,Mn)As are very sensitive to both electric fields and mechanical strain due to the low carrier density and strong spin-orbit coupling present in the valence band. Another promising material system is Galfenol, an alloy of Fe and Ga. For Ga concentrations in the range 19% - 28% this system possesses a magnetostriction that is an order of magnitude higher than for pure Fe and higher than any other transition metal system, rivalled only by rare earths. We have studied epitaxial thin films of Galfenol which we find to have a magnetostriction enhanced above that of the bulk material, whilst retaining the large moment and spin polarisation found in pure Fe films. These properties make epitaxial thin Galfenol films very promising for spintronic applications.

I will discuss experiments and recent results on these and other material systems studied in Nottingham.



MOKE images showing the motion of ferromagnetic domain walls under the application of a uniaxial strain ε applied to an epitaxial $Fe_{19}Ga_{81}$ thin film.

Rashba spin-orbit coupling, domain wall motion, and spin motive force in ultrathin magnetic nanostructures

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Recent experiments [1,2,3,4] on nanostructures with ultrathin (~ 1nm) magnetic layers found various anomalous properties such as magnetization swiching by in-plane current, domain wall motion against electron flow, and anomalously high domain wall speed of current-driven domain wall motion. We demonstrate that all these anomalies can be explained naturally if the Rashb spin-orbit coupling is sufficiently strong. We also show that in such a situation, the spin motive force is considerably enhanced, so that it may affect the magnetization dynamics.

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Domain Growth in Coupled and Frustrated Patterned Magnets

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The motion of magnetic domain walls in the creep regime has important consequences for device application. Results from experiments made on single and coupled ultra-thin Co films are summarised, highlighting strong correlations between walls that can appear in coupled films, and also illustrating how domain wall motion can be controlled with patterned magnetic arrays [1]. Magnetisation dynamics within a strongly coupled array of magnetic elements is also discussed. By following the evolution of vertex configurations, we show that magnetisation processes in an artificial spin ice can be described by way of analogy to magnetisation processes in ferromagnets [2]. We discuss effects of disorder [3] and how macroscopic domains can form and evolve through vertex cluster fluctuations.

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Spin-transfer-torques-induced domain-wall motion in ferromagnetic Pt/Co/Pt nanowires with perpendicular magnetic anisotropy

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The spin-current-based electric controllability of ferromagnetic domain walls (DWs) has been of great interest because of its feasible applications such as next-generation memory and logic devices. In particular, nanowires with perpendicular magnetic anisotropy have been predicted as more suitable materials for practical applications. However, the experimental verification with multiple DWs control in such materials has not been explored yet. And also, the physical driving mechanism resulting from the competition between the spin transfer torques (STTs)—adiabatic STT and nonadiabatic STT—and disorders is still controversial. By using Pt/Co/Pt nanowires which exhibit weak and homogeneous microstructural disorders, here we experimentally demonstrate that the purely current driven multiple DWs motion can be obtained at current densities less than 107 A/cm2, allowing random magnetic bits recording and transferring without severe temperature rising (Fig. 1a). Furthermore, based on the DWs motion driven by magnetic field and/or current (Fig. 1b), we can unambiguously distinguish the role of STTs on thermally activated magnetic domain wall motion. The adiabatic STT—resulting in quadratic contribution to effective field—is found to be dominant for large current densities, whereas the nonadiabatic STT—playing the same role as magnetic field—subsisted at low current densities. This finding will provide a step to the complete understanding of STT induced DW dynamics as well as the technological progress in DW based emerging nanodevices.

AUTHORS

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Resistivity and Current-driven Motion of Domain Walls in Artificial Magnetic Domain Structures

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It is well-established that low intensity Ga focussed ion beam (FIB) irradiation can be used to precisely control the 'local' coercivity of perpendicularly magnetized Pt/Co multilayers.[1] We have extended this technique to realise artificial domain wall array structures in Pt/Co/Pt trilayers with various domain widths and number of periods.[2] The scaling behaviour of transport measurements on these model structures confirms the intrinsic domain wall origin of the magnetoresistance. In addition, systematic studies of domains patterned at various angles to the current flow are excellently described by an angular-dependent resistivity tensor containing perpendicular and parallel domain wall resistivities. These are fully consistent with Levy-Zhang theory,[3] and allow us to estimate the ratio of minority to majority spin carrier resistivities, $\rho_{\downarrow}/\rho_{\uparrow}$~5.5, in good agreement with thin film band structure calculations.[4] Current work is focussing on spin transfer torque domain wall motion in such structures with the goal of reducing the critical current density by careful control of the artificial domain structure and coercive fields. The dynamics of wall motion is being investigated by two independent methods; i) via the time-resolved detection of extraordinary Hall effect (EHE) signals in co-planar waveguide structures and ii) by monitoring the domain magnetisation using a fast polar MOKE set-up. Preliminary results will be presented and future prospects discussed.

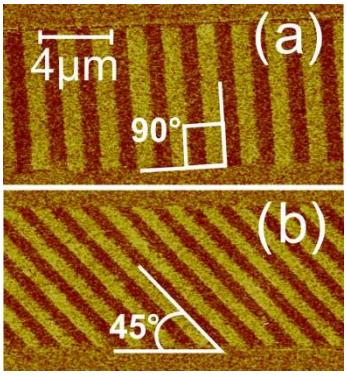

Fig. 1 MFM images of (a) 90° and (b) 45° artificial magnetic domain super-lattices realised by Ga-FIB irradiation.

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Spintronics at Magnetic Domain Walls

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The term spintronics is used to mean the use of the spin degree of freedom of the electron to store and process information, much as charge is used in current microelectronics. Typically ferromagnetic materials are involved where the electrons are spin-polarised: the magnetisation direction of the ferromagnet provides the spin-quantisation axis. Real ferromagnets contain domain walls and other magnetisation gradients and so the spin-quantisation axis can vary spatially over quite short lengthscales, with profound consequences for the interactions between an electrical current and the magnetization [1]. The domain wall can affect the current, giving rise to additional resistance to spin-polarised carriers [2,3]. The current can also affect the wall, with conservation of angular momentum giving rise to so called spin-transfer torques. These result in domain wall motion induced by high current densities, giving rise to a variety of domain wall dynamics including depinning [4,5], deformation [6], resonance [7], and creep [8]. I will discuss our studies of both domain wall resistance and domain wall motion in a variety of ferromagnetic metals and nanostructures, and discuss the ways in which the effects might be optimized for exploitation in future information technologies.

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Magnetic Force Microscopy of Magnets with Competing Interactions

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In this talk I will show the application of temperature-dependent magnetic force microscopy to study magnetic phase transitions in magnets with competing interactions. The probe was applied to study ferromagnetism in colossal magnetoresistive (CMR) films under strain as well as nominally strain free films. The studies on the CMR films under strain revealed an inhomogeneous ferromagnetic ordering temperature due to the local variation of strain (strain is relaxed at the grain boundaries) because of the strong electron-lattice coupling in this class of materials. This is the first time that the transition temperature has been mapped spatially for any ferromagnet (Phys. Rev. B, Rapid Comm. 2001). As a comparison, we have studied nominally strain free CMR films. In this case, magnetic contrast was observed only near the Curie temperature, where magnetization at the step terraces differs from magnetization at the step edges. The difference in the magnetic behavior of the two CMR films demonstrates the important role of strain in their magnetic properties.

Most recently we applied this probe to study iron tin (Fe_3Sn_2), which is a layered ferromagnet, whose building blocks are Kagome planes, with a Curie temperature of 640 K. It has a spin reorientation, where the magnetic moments rotate from the transverse direction towards the planes on cooling, and previously it has been reported to display glass-like phenomena. As the spin reorients, the domain structure evolves from a branched dendritic high temperature state to a less complex structure at low temperatures. The magnetic force microscopy study provides insights to the complex magnetic behavior of this system.

Magnetic domain walls in circular and elliptical rings

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Understanding magnetic domain wall (DW) motion in nanoscale magnetic structures is essential for designing DW based devices for memory and logic. Ring-shaped structures are attractive for these applications because of the existence of several well defined magnetic states. First, the current-driven DW motion was investigated in GMR spin-valves of NiFe/Cu/Co rings in order to see onion-vortex transitions. In the onion state of the ring, two DWs can be moved by the electrical currents at the same time, leading to the specific vortex chirality depending on the injected current polarity. The transition was verified by the electrical measurements and resistance changes. Second, 360 degree DWs were studied in Co material based elliptical rings, where the 360 DWs will be seen in magnetic force microscope (MFM) images. Between the onion and vortex states, the intermediate state can be observed in the ring devices due to high curvature of the elliptical rings. The intermediate states include 360 DWs with a stability of a few mT. Finally, the lateral and vertical interaction between DWs will be shown with MFM techniques. In the later interaction, the controlled vortex chirality in a Co ring was studied by manipulating the specific DW motion in terms of magnetic fields. On the other hand, in the vertical interaction, MFM tip effects on the 360 degree DWs will be discussed.

Monday, 6-Feb	Tuesday, 7-Feb	Wednesday, 8-Feb
Registration	Session IV 09:00-10:20	Lab Tour Korea Advanced Nano Fab. Center & Samsung Advanced Institute of Technology
Welcome address 09:50-10:00		
Session I 10:00-12:00	Coffee break	
	Session V 10:40-12:00	
Lunch break & Lab tour 12:00-14:10	Lunch break & Group Photo 12:00-13:50	
	Session VI 13:50-15:30	Long talks 35'+5' Short talks 15'+5'
Session II 14:10-15:30		
Coffee break	Coffee break	
Session III 16:00-17:40	Session VII 16:00-17:40	
	Banquet	