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My research topic is magnetism and spintronics of low-dimensional structures, with a special focus on magnetization dynamics of domain walls. I am concerned with fundamental processes investigated in model systems. This led me to acquire expertise at the frontier of several areas : experimental and theoretical micromagnetism ; surface magnetism; epitaxial growth and chemical synthesis, particularly for self-organization, and associated material science. My main current focus is fundamental issues related to the prospects for a 3D race-track memory using dense arrays of cylindrical magnetic nanowires. I coordinated a European project on the topic (http://mem3d.eu).
I am the creator and general chair of the European School on Magnetism (2007-), and co-funder of the European Magnetism Association (EMA), for which I am managing communication (http://magnetism.eu).
I am also presently acting as deputy director for SPINTEC.

Opportunities and challenges for nanomagnetism and spintronics

Abstract

Magnetism is a topic with a long history. Yet, an incredible number of new fundamental phenomena have been uncovered during the past three decades, making magnetism a key actor of modern condensed matter physics. Most new phenomena are intrinsically related to the nanoscale, and pertain to two categories: either new ways for magnetization to behave in statics or dynamics, a field called nanomagnetism; or the interplay of the localized moments underlying a magnetic order with conduction electrons and their spin, a field called spin electronics or in short: spintronics. Foundation events for this golden area are the discovery of interlayer exchange coupling and most notably the giant magnetoresistance effect in the 1980's. The former is singular example of a quantum phenomenon robust at room temperature, while the latter motivated the Nobel Prize for Physics to Peter Grünberg and Albert Fert in 2007. The physics side of this Nobel Prize is the discovery that ultrathin magnetic layers can act as very efficient filters for conduction electrons depending on their spin; the societal side is their application to the development of so-called electronic spin valves and highly sensitive sensors of magnetic field. This played a key role in boosting the storage capacity of hard disk drives, underlying our modern communication network. Many other effects share this balance between new physics and high impact or prospect for applications: interfacial magnetic anisotropy (resulting from the broken symmetry of solids at interfaces, and use again in hard disk drives), precessional magnetization dynamics (the text-book case of a moment precessing around a magnetic field however applied to magnetization, with prospects in compact RF antennas and energy harvesting), the spin-transfer torques (the reverse effect of giant magnetoresistance: however spin-polarized conduction electrons set magnetization into motion, key to the current emergence of magnetic random access memories), the Dzyaloshinskii-Moriya interaction (an indirect exchange favoring non-colinear magnetization states) etc.
A clear trend is also expansion towards interdisciplinarity, in physics such as with the ultrafast interaction between light and magnetism, engineering with neuromorphic computing, health and medicine making use of magnetic nanoparticles etc. At a time of rising expectations to address societal concerns, magnetism has key assets however also challenges in terms of high-performance and low-power computing, sustainability, material criticality etc.

Keywords: nanomagnetism, spintronics, condensed matter physics

Session Nanomagnetism & Spintronics
Keywords: 2D materials, WS_2, MTJ, spin valve

Title: Introducing CVD WS_2 in Magnetic Tunnel Junctions

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Spintronics has opened a new paradigm through the use of the spin variable as the vector of information and has been largely applied from harddrives read-heads to the STT-MRAMs. While very recent, the introduction of 2D materials in Magnetic Tunnel Junctions (MTJ) has already shown some promising properties (atomic thickness control, diffusion barrier, spin filtering…)[1]. Graphene and the 2D insulator h-BN have been the first 2D materials to show strong impact on spin transport in MTJs. It was shown that strong spin filtering occurred with the creation of an insulating spin channel in metallic graphene and metallic channel in insulating h-BN[2]. The recent advent of the wide TMDC family of 2D semiconductors (MoS_2, WS_2…) opened new opportunities for further tailoring of spintronics properties. Preliminary results highlighted that maintaining interfaces and materials quality (such as preventing ferromagnets oxidation) remains a crucial issue. While initial focus has been on MoS_2[3], we will present results on the scarcely studied WS_2. We will detail a protocol using laser lithography technology to fabricate spin valves based on CVD grown WS_2, with step by step characterizations in support (Raman spectroscopy, photoluminescence, AFM measurements…). In particular our approach aims at avoiding interface oxidations. We will finally show our first spin transport measurements obtained in a CVD WS_2 based MTJ. Our measured MR signals, above state of the art for 2D semiconductor based MTJs, validates our integration approach. Our work opens the way to the integration of different members of the very large TMDCs family, in order to reveal their spin transport properties in MTJs.

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Nanaomagnetism & Spintronics

Key words: graphene, nanoparticle, spintronics, spin orbit, single electron transistor.

Anisotropic magneto-Coulomb properties of 2D-0D nanospintronic devices.

L.D.N. Mouafo [1], F. Godel [2], G. Melinte [1], S. Hajjar-Garreau [3], B. Dlubak [2], D. Halley[1], Y. Henry[1], O. Ersen [1], B. Doudin [1], L. Simon [3], P. Seneor [2], J.-F. Dayen [1].

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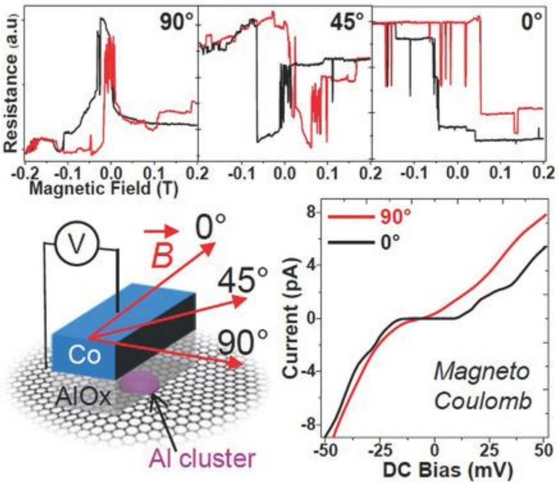
We report a simple and scalable fabrication route of new 2D material/0D clusters heterostructures, exploiting the self-organized growth over graphene of epitaxial flat aluminium based nanoclusters assemblies. We provide experimental evidence that 2D materials are unique promising alternative to skirt the challenging issue of contacting the nanoparticles one by one with external leads in the sake of developing single electron transport devices [1].

Finally, the spintronics properties of 2D–0D heterostructures are unveiled [2]. An anisotropic magneto-Coulomb effect, mediated by spin–orbit coupling within a single ferromagnetic electrode, provides tunable spin-valve-like magnetoresistance signatures and controllable magnetic modulation of the device's single-electron charge states, without need of spin coherent tunnelling transport. These heterostructures pave the way towards scalable nanospintronics device architectures at the crossroads of 2D material physics and spin electronics.



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Congrès 2018, Toulon

11, 12 & 13 septembre

Session: Nanomagnetism & spintronics

Keywords: Perovskite oxides – Spin-to-charge conversion – Spin-Pumping – Thin Films - PLD

Towards Spin-Orbitronics integrating perovskite oxides

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Among the numerous functionalities displayed by perovskite oxides such as superconductivity at the interface [1], multiferroism [2] or colossal magnetoresistance in manganites…, they may also be very useful materials for generating spin currents with weak relaxations.

Moreover, thanks to the Rashba spin-orbit coupling appearing at interfaces, spin currents can generate charge currents and *vice versa* through the Edelstein effects [3]. The aim of my thesis would be to exploit the combinatorial character of perovskite oxides for obtaining high spin/charge current conversion, as observed on recent studies in our lab. [4]

In our study, we focus on heterostructures based on $La_{2/3}Sr_{1/3}MnO_3$ (LSMO), grown by pulsed laser deposition. We investigate the role of strain, thickness and temperature on the magnetization dynamics in order to estimate the ideal parameters to integrate LSMO as spin injector into heterostructures. We observe that the damping depends on the thickness of the layers, the strain imposed by the substrate, but also varied with temperature. Above all, thin films obtained have better damping values than the benchmark for spin injection, the permalloy (Py).

To confirm the potential of inserting LSMO as spin injector, we looked at the effect of Pt capping on LSMO thin layers. We study the dependence of spin-mixing conductance $g_{\uparrow\downarrow}$ for these materials with temperature and the thickness of the compounds. And, by performing a FMR-Spin Pumping experiment, we observe an Inverse Spin Hall Effect (ISHE) signal with a very good conversion rate, confirming interests in LSMO as platform material for Spin-Orbitronics.

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Session: Nanoelectronics, Nanomagnetism & Spintronics
Keywords: 'Magnetic Tunnel Junction, Spinterface, Magnetoresistance, Molecular, Monolayer

Spin-dependent transport in aromatic self-assembled monolayers

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Molecular spintronics, an emerging research field at the frontier between organic chemistry and spintronics, has opened novel and exciting opportunities in terms of functionalities for spintronics devices. Among those devices, Magnetic Tunnel Junctions (MTJs) have attracted a growing interest over the years. MTJs are made of two ferromagnetic electrodes separated with an insulating layer. Depending on the applied field, the magnetization of the electrodes can be parallel or antiparallel, modifying the resistance of the device. Our group focuses on replacing the insulating spacer, usually made of an oxide, with an organic self-assembled monolayer (SAM).

Indeed, it was shown that spin dependent hybridization at the metal/molecule interface could lead to a radical tailoring of spintronics properties [1]. To achieve this, SAMs appear to be very promising candidates thanks to their impressive molecular scale crafting properties and easy-processing. Previous works were done with basic molecules such as linear alkanethiols [2]. We now focus on more complex molecules integrating aromatic moieties to study how the modification of the tunnel barrier impacts the magnetic and electronic behaviour of the devices.

We will firstly present the fabrication procedure of our magnetic tunnel junctions, including a recently found method to recover the surface of an oxidized ferromagnet and graft a SAM ontop [3]. We will then present the transport experiments realized on our devices, including tunneling transport and tunnel magnetoresistance experiments. We will particularly try to underline the main similarities and differences between alkanethiols and oligophenyls MTJs.

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Session Nanomagnétisme et Spintronique

Key words: Nanoparticules, Nanoalliages, Nanomagnet

Size and Interface Effects on Magnetism of chemically ordered FeRh clusters prepared by MS-LECBD

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The major importance of surface atoms in small nanoparticles (NPs) offers the opportunity to tailor their magnetic properties by playing with the interface between nanomagnet and its surrounding. The systems FeRh has attracted a lot of attention because, in bulk phase when they are chemically ordered in B2 phase, they present an antiferromagnetic to ferromagnetic order (AFM-FM) transition close to room temperature.

This paper deals with structural and intrinsic magnetic properties of such nanomagnets, prepared using Mass-Selected Low Energy Cluster Beam Deposition (MS-LECBD) embedded in carbon matrix, at the PLYRA platform of Institut Lumière Matière at Lyon[1].

Very recently B2 FeRh clusters have been deposited on a crystalline BaTiO3 (BTO) layer epitaxially grown on Nb-doped SrTiO3 (STO) layer and on a BTO crystal. Their physical properties will be compared to their intrinsic ones taken into account both size and interface effects.

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Session (Nanomagnetism & Spintronics)
Keywords: 2D materials; spintronics; MoS_2; spin valve; magnetoresistance

Spin valves with exfoliated 2D materials: MoS_2

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In the last years 2D materials have attracted a huge attention thanks to the amazing properties that arise when thickness approaches the single layer level and thanks to the large number of functionalities that they offer. Recently, they started to appear as high potential candidates for spintronics devices since, thanks to their intrinsic two-dimensional nature, they create thin, tuneable and free of defects barriers with sharp interfaces. Despite this potential, investigation of 2D materials for spintronics is still at the beginning. Only very recently few works started to appear using other 2D materials beyond graphene[1]. In particular, concerning the family of transition metal dichalcogenides (TMDCs), promising theoretical calculations were first reported predicting an extremely large magnetoresistance (MR) signal up to 300% in Fe/MoS_2/Fe MTJs[2]. However, experimental results are still far from these expectations. Indeed, most of experimental works have to face the main technological issue of avoiding bottom FM electrode oxidation during fabrication process, limiting in turn MR signals.
Here we will show an in-situ fabrication approach to avoid oxidation of the FM electrodes during the device fabrication process that tackles this fundamental problem. This allowed the successful fabrication of NiFe/MoS_2/Co MTJs with multilayer MoS_2 flakes showing MR signal above state of the art. Our results demonstrate the high interest of MoS_2 for spintronic devices and prove the efficiency of our easy and general fabrication method for incorporating mechanically exfoliated flakes of 2D materials in spintronic devices with high quality and non-oxidized interfaces.

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Session: Nanomagnetism & spintronics
Keywords: TEM, electron holography, domain wall, magnetic nanowire

Magnetic configurations in complex magnetic nanowires studied by off axis electron holography

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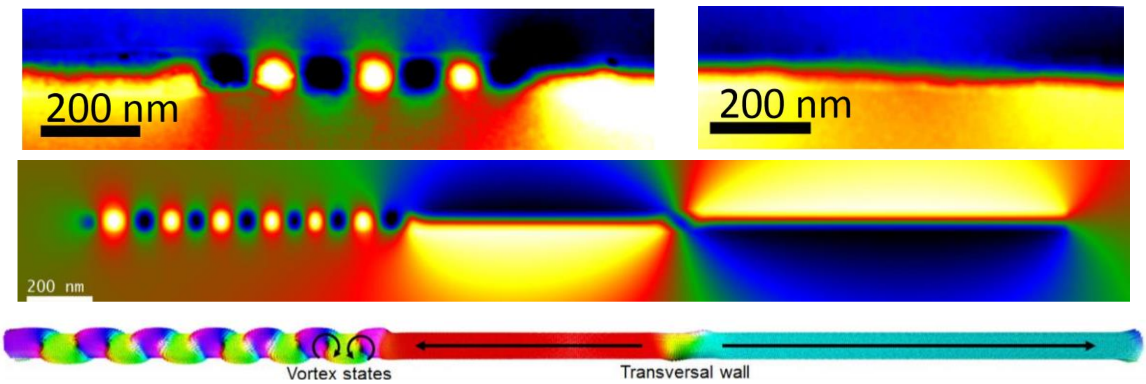
Understanding the magnetic configurations in cylindrical nanowires (NW) is a current topic for the development of future spintronic devices. In such ferromagnetic systems the equilibrium state is defined by minimizing the magnetic energy, where shape, crystal structure and composition are contributing factors. This study aims to analyze the complex magnetic structure and the domain wall structures in CoNi nanocylinders displaying grains of both fcc and hcp structures. Electron holography (EH) combined with classical TEM have been used to determine the magnetic configuration of these NWs and to analyze the local crystallographic structure and chemical composition. Micromagnetic simulations have been carried out to support the experimental results.

EH evidences two distinctly different types of configurations within a single nanowire: periodical vortices in regions with perpendicular easy axis orientation, and another with magnetization parallel to the nanowire axis. These vastly different domains are found to be due to variations in the crystalline orientation and/or structure along the nanowire axis, which give rise to changes in the crystallographic and uniaxial anisotropies. Micromagnetic simulations have confirmed this complex magnetic configuration.



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Session (Nanoelectronics, Nanomagnetism & Spintronics)

Keywords: ultrathin ferromagnetic layers, domain wall velocity, electric field effect, ferromagnet electrolyte interface

Electric field effect on domain wall motion in Co ultrathin films in direct contact with an electrolyte: comparison between different substrates

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Domain wall (DW) motion in perpendicularly magnetized ferromagnetic layers is the subject of intensive research. DW may be displaced by applying an external magnetic field or by injecting an electric current. One means to assist the DW motion is to apply electric field which allows modifying the magnetic anisotropy energy (MAE) of the ferromagnet. In experimental investigations of this electric field effect (EFE), the potential between the ferromagnetic nanostructure and a gate electrode is generally applied either across a dielectric layer. A common problem related to the presence of the latter is electric field induced oxidation of the ferromagnetic layer yielding irreversible effects with long time constants. Applying high electric fields without such side effects is therefore highly desirable.

In this work, we investigate the influence of EFE on DW velocity of Co layers in direct contact with an electrolyte. We developed a dedicated experimental procedure for contacting in situ Co ultrathin epitaxial layers with an electrolyte avoiding any transfer in air and surface oxide formation. In addition, this configuration allowed us to reach large and uniform electric fields (> 1 V/nm). The magnetic samples were either grown in situ by electrodeposition or by sputtering with the deposition of a capping layer which is then removed in situ. Both preparation procedures prevent surface oxidation of the ferromagnet by keeping it under potential control throughout the entire experiment. The samples were studied by in situ magneto-optical Kerr effect (MOKE) and in situ MOKE imaging.