5th Young Researchers in Magnetism

10-11th November 2021

THE SPANISH MAGNETISM CLUB AND THE SPANISH CHAPTER OF THE IEEE MAGNETICS SOCIETY ANNUAL JOINT MEETING

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5th Young Researchers in Magnetism

The annual meeting of the Spanish Magnetism Club and the Spanish Chapter of the IEEE Magnetics Society will be held in Girona combining ONLINE and PRESENTIAL contributions.

The 5th Young Researchers in Magnetism, the traditional special session devoted to young researchers will take place during this meeting, the 10th and 11th November. This year, it is being organized for and by the young researchers.

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5th Young Researchers in Magnetism

YRM 2021

PROGRAMME

Wednesday, November 10th		
Starts	**Ends**	**Event**
15:30	15:42	Opening ceremony
15:42	17:06	First oral session
17:06	17:20	Poster pitches
17:20	17:50	Coffee break & poster session
17:50	19:15	Second oral session

Thursday, November 11st		
Starts	**Ends**	**Event**
16:15	18:05	Third oral session
18:05	18:20	Awards & closing ceremony

NOVEMBER 10TH

SESSION 1 (15:30 - 17:06 H)

Chair: Darla Mare, Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Spain
Co-chair: Alberto Anadón, Institut Jean Lamour (IJL), France

15:30 Opening ceremony

15:42 **S101** - Microwires optimization for magnetoelastic resonance-based sensors. **Álvaro Peña**

15:54 **S102** - Ultrafast magnetization reversal of ferromagnet using picosecond Spin-Orbit Torque. **Kaushalya Jhuria**

16:06 **S103** - Manufacture of magnetosomes with high power absorption for a thermo-active drug release. **Ana C. Moreno Maldonado**

16:18 **S104** - The collective effect of the FeRh ferromagnetic phase growth during a metamagnetic phase transtion. **Aleksei S. Komlev**

16:30 **S105** - Protected annealing in maghemite-core and iron-core nanoparticles: relating exchange bias to non-saturating magnetization components. **Raúl López Martín**

16:42 **S106** - Stochastic vs. deterministic magnetic coding in designed cylindrical nanowires for 3D magnetic networks. **Elias Saugar**

16:54 **S107** - Development of a sustainable manufacturing process of ferrite permanent magnets by combining recycling and additive manufacturing. **Daniel Casaleiz**

NOVEMBER 10TH

POSTER PITCHES (17:06 - 17:20H)

P01 - Studying the degradation of magnetosomes in tumour cells by magnetometry and XANES spectroscopy. **Alicia Gascon Gubieda**

P02 - Superconductivity assisted change of the perpendicular magnetic anisotropy in V/MgO/Fe junctions. **César González Ruano**

P03 - Excitation and propagation of edge spin waves in ferromagnetic triangles. **Diego Caso**

P04 - Homogenization Of Heating In Magnetic Hyperthermia Through Exploitation Of Magnetisation. **Javier Ortega-Julia**

P05 - Structural and magnetic characterization of nanostructured NiO prepared by mechanical milling. **Jose Luis Garrido Álvarez**

P06 - Nanosensors with spin waves. **Juan D. Aguilera**

P07 - Magnetic analysis: Fe-Co-Mn alloy produced by spark plasma sintering. **Kaouther Zaara**

P08 - Permeability volume distribution in amorphous magnetic microwires: experiment and simulation. **Luliia Alekhina**

P09 - Incommensurate magnetic phases of the multiferroic compound $MnCr_2O_4$ described with the superspace formalism. **Miguel Pardo-Sainz**

P10 - Characterization of Ni-nanoparticles inserted in carbonaceous materials with controlled porosity and morphology. **Mona Fadel**

P11 - Influence of Design Parameters of Core@shell Magnetic Nanoparticles in Magnetic Hyperthermia. **Pelayo García Acevedo**

P12 - Low temperature magnetic force microsocopy characterization of adjustable 3D ferrimagnetic multilayers based on NdCo+GdCo trilayers. **Rafael Delgado-Garcia**

NOVEMBER 10TH

COFFEE BREAK & POSTER SESSION (17:20 - 17:50H)

P13 - Spin-charge interconversion in 111-oriented epitaxial Pt thin films. **Alberto Anadón**

P14 - Spin current generation from incoherent magnon excitation in the multifunctional ferrimagnet Ga0.6Fe1.4O3. **Alberto Anadón**

P15 - From Magnetically Soft to Hard FeNi Nanowires: In the Search of the Cosmological L10-FeNi Phase. **Alonso J. Campos-Hernández**

P16 - Controlling the self-assembly of multicore iron oxide nanoparticles to enhance magnetic properties for biomedical and environmental applications. **Alvaro Gallo-Cordova**

P17 - Synthesis and characterization of magnetocaloric Ni-Co-Mn-Ti Heusler alloys. **Aun N. Khan**

P18 - Exploring the ratchet effect in chemically modulated cylindrical nanowires. **Claudia Fernández-González**

P19 - Hydrothermal synthesis of iron oxide nanoparticles for biomedical applications. **Daniel Arranz**

P20 - Magnetic Hyperthermia of Magnetotactic bacteria doped with Terbium and Gadolinium. **Danny Villanueva-Alvaro**

P21 - Growth stabilization and magnetic response to bending strain in epitaxial ferrite thin films on mica. **Darla Mare**

P22 - 3D Skyrmionic configurations in soft magnetic nanodots with no Dzyaloshinskii-Moriya interactions. **Eider Berganza**

P23 - Study of dipolar collective properties in binary random assemblies of magnetic oxide nanoparticles. **Elena H. Sánchez**

P24 - Antenna resonance of a magnetic microwire applied to anti-theft technology. **Esther Calle**

NOVEMBER 10TH

COFFEE BREAK & POSTER SESSION (17:20 - 17:50H)

P25 - Electric current effects in sensors based on anisotropic magnetoresistance. **Guillermo Gestoso**

P26 - High Anomalous Nernst effect on magnetic multilayers with perpendicular magnetic anisotropy. **Guillermo Lopez-Polin**

P27 - Enhancing the magnetocaloric response of high-entropy metallic-glass by microstructural control. **Hangboce Yin**

P28 - Analysis of the effects of chemical composition and manufacturing conditions of soft nanocrystalline magnetic alloys and composites. **Jason Daza**

P29 - Understanding the initial growth stages in NdFeB films: epitaxial films prepared by molecular beam epitaxy with varying underlayer. **Jimena Soler Morala**

P30 - Synthesis and characterization of Fe3O4@MgO@CoFe2O4 core/shell/shell magnetic nanoparticles. **Jorge M. Nuñez**

P31 - Oersted-field- and current- induced dynamics of Bloch Point in cylindrical Ni nanowires. **Jose A. Fernandez-Roldan**

P32 - Differential refractometry for detection of magnetic nanoparticles. **Jose Luis Marqués**

P33 - Magnetization reversal in rhombohedral Ni nanotubes. **Miguel Méndez**

P34 - Magnetic relaxation in Ɛ-Fe2O3 nanoparticles. **Naureen Khanam**

P35 - Coupled micromagnetic simulations with NEGF-based coherent transport in magnetic tunnel junctions. **Peter Flauger**

NOVEMBER 10TH

SESSION 2 (17:50 - 19:15 H)

Chair: Hangboce Yin, Harbin Institute of Technology, China
Co-chair: José A. Fernández-Roldán, University of Oviedo, Spain

17:50 **S201** - Surface magnons and crystalline electric field shifts in superantiferromagnetic NdCu2 magnetic nanoparticles. **Elizabeth M. Jefremovas**

18:02 **S202** - E-field control of the skyrmion Hall effect in artificial multiferroics. **Mouad Fattouhi**

18:14 **S203** - Cryogenic Magnetocaloric performance of RENiX2 compounds (RE = Er, Ho and Dy, X = Al and Ga). **Dan Guo**

18:26 **S204** - Novel one-pot sol-gel synthesis route of Fe3C/few-layered graphene core/shell nanoparticles embedded in a carbon matrix. **Alberto Castellano**

18:38 **S205** - Real time monitoring of the precipitation of Calcium Oxalate by magnetoelastic resonance sensors. **Beatriz Sisniega**

18:50 **S206** - Global magnetic topology optimization. **Florian Slanovc**

19:02 **S207** - An insight into the structural and magnetic properties of maghemite nanoflowers. **Mariona Escoda-Torroella**

NOVEMBER 11TH

SESSION 3 (16:15 - 18:20 H)

Chair: Peter Flauger, University of Vienna, Austria
Co-chair: Eider Berganza, Karlsruhe Institute of Technology, Germany

16:17 **S301** - Magnetostrictive nanostructured surfaces for antimicrobial applications. **Jorge Marqués-Marchán**

16:29 **S302** - Magnetocaloric effect and critical behaviour in Ni-Mn-Sn Heusler alloys. **Karima Dadda**

16:41 **S303** - Magnetic iron oxide nanocatalyst for the enhanced degradation of organic pollutants. **Carlos Díaz Ufano**

16:53 **S304** - Charge-spin current interconversion in high-quality epitaxial Co/Pt systems. **Adrián Gudín**

17:05 **S305** - Synthesis and characterization of Polyurethane-Magnetite composites for magnetic hyperthermia. **Ángela Arnosa**

17:17 **S306** - Shape anisotropy engineering of V-groove patterned permalloy thin films for sensing and biological applications. **Rafael Delgado-Garcia**

17:29 **S307** - Hysteresis loops of freely rotating nanoparticles in simulations with coupled micromagnetic and mechanical equations. **Santiago Helbig**

17:41 **S308** - Micromagnetics of chemical barriers inserted within Permalloy cylindrical nanowires: towards the control of domain wall motion. **Laura Álvaro Gómez**

17:53 **S309** - Nanolabel optimization for the development of a magnetic immunoserological test for COVID-19. **María Salvador**

18:05 Awards & closing ceremony

5th Young Researchers in Magnetism

BOOK OF ABSTRACTS

Microwires Optimization for Magnetoelastic Resonance-Based Sensors.

Álvaro Peña[1]*, Daniel Matatagui[2], Carlos Cruz[2], Patricia Marcela de la Presa[1],
Mari Carmen Horrillo[2], Pilar Marin[1]

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Magnetoelastic resonance occurs when a device, made of a magnetoelastic material, is subjected to an alternating magnetic field with a given frequency, this being the natural resonant frequency of the said device. As this frequency depends on various factors, such as temperature, the viscosity of the surroundings or changes in the mass of the device, it is possible to create a sensor of such factors that can be operated remotely using magnetic fields. Typically, magnetoelastic ribbons have been used for such devices, and extensive knowledge can be found throughout the scientific literature [1]. On the other hand, microwires, made of an amorphous metallic nucleus with a glass coating, are lesser-known, and fewer examples have been reported.

In previous work, we reported a comparison between magnetoelastic ribbons and microwires, demonstrating that, while ribbons have a better magnetoelastic response, it is negatively affected upon dimensional down-sizing to the scale of microwires. Whereas microwires, while having a not-as-good response, it is lesser affected by their size. Leading to the hypothesis that if microwire's magnetoelastic response were improved, they would be a great alternative to ribbons [2].

In this work, we have studied the magnetoelastic response of microwires with different diameters, thermally treated at temperatures between 200-400ºc, including "as cast" microwires, and, under different bias fields, to find the optimal characteristic for microwires to be used in the aforementioned sensor devices.

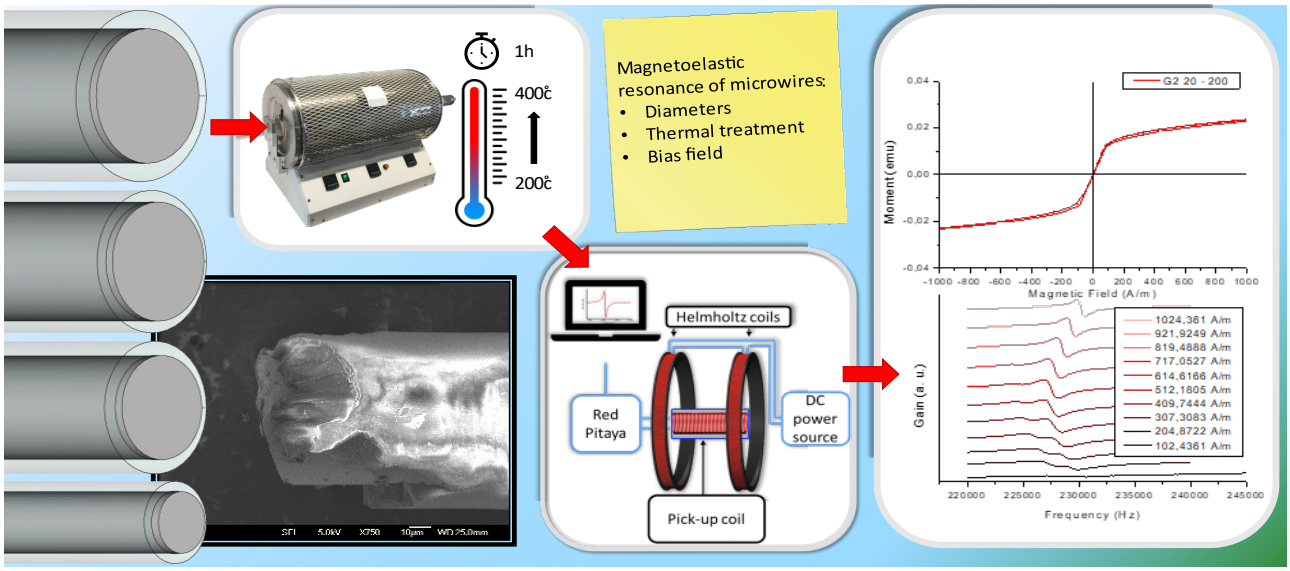

Fig. 1 Graphical abstract.

Acknowledgements

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Index Terms — Magnetoelastic, Amorphous metals, Applied magnetism, Sensors.

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Ultrafast Magnetization Reversal of Ferromagnet Using Picosecond Spin-Orbit Torque

Kaushalya Jhuria[1]*, Julius Hohlfeld[1], Akshay Pattabi[2], Elodie Martin[1], Aldo Ygnacio Arriola Córdova [1,3], Xinping Shi[4], Roberto Lo Conte[2], Sebastien Petit-Watelot[1], Juan Carlos Rojas-Sanchez[1], Gregory Malinowski[1], Stéphane Mangin[1], Aristide Lemaître[5], Michel Hehn[1], Jeffrey Bokor [2,6], Richard B. Wilson[4] and Jon Gorchon[1]

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The need for memory storage has reached enormous heights in the past two years, as a consequence of the pandemic due to COVID-19. Such growth in long-term data storage density has been enabled by the field of spintronics and the constant improvements to magnetic hard disk drives (HDDs) the field has provided. Reducing energy dissipation while increasing speed in computation and memory is a long-standing challenge for spintronics research [1]. In the last 20 years, femtosecond lasers have emerged as a tool to control the magnetization in specific magnetic materials at the picosecond timescale [2–3]. However, the use of ultra-fast optics in integrated circuits and memories would require a major paradigm shift. An ultrafast *electrical* control of the magnetization is far preferable for integrated systems. Here we demonstrate reliable and deterministic control of the out-of-plane magnetization of a 1 nm-thick Co layer with single 6 ps-wide electrical pulses that induce spin orbit torques on the magnetization. We can monitor the ultrafast magnetization dynamics due to the spin orbit torques on sub-picosecond timescales, thus far accessible only by numerical simulations. Due to the short duration of our pulses, we enter a counter-intuitive regime of switching where heat dissipation assists the reversal. Moreover, we estimate a low energy cost to switch the magnetization, projecting to below 1fJ for a $(20\ nm)^3$ cell. Figure provided below shows the MOKE microscopy images of the magnetic sample for different combinations of ps electric pulse and external in-plane magnetic field polarities to verify the symmetries associated with spin orbit torques.

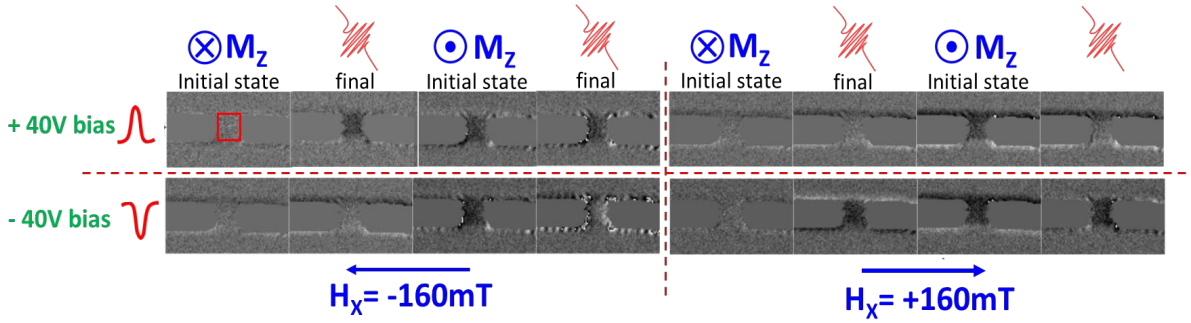

Figure 1. Polar MOKE images of Co (1nm) sample for different combination of polarities of the ps electric pulse and the external In-plane magnetic field to verify the presence of spin orbit torque driven magnetization reversal.

Acknowledgements
This work was supported by the Impact Project LUE-N4S, part of the French PIA project 'Lorraine Université d'Excellence', reference ANR-15IDEX-04-LUE, and the 'FEDER-FSE Lorraine et Massif Vosges 2014–2020', a European Union Programme.

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Manufacture of Magnetosomes with High Power Absorption for a Thermo-Active Drug Release

A. C. Moreno Maldonado[1,2]*, A. Toro- Córdova[1,2†], M. Carmen Jiménez-López [3], Beatriz Sanz[1,4], Ignacio J. Molina[3], M. R. Ibarra[1,2], G. F. Goya[1,2]

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Due to the resilience of neoplastic tissues to traditional therapies, new approaches are based on attacking cancer cells with synergistic therapies such as radiotherapy, chemotherapy, immunotherapy, or hyperthermia [1]. These aim for caring surrounding healthy tissues and maximizing damage to neoplastic cells. Since 2011, in countries such as Germany and the United States [2] magnetic nanoparticles (MNPs), mainly Fe_3O_4 magnetite, are being used in clinical magnetic hyperthermia (HTM) treatments. Some of the advantages of using MNPs include locating, addressing, external control using magnetic fields. These benefits position make them good agents for drug delivery, that is, vectors, transporters and drug distributors in target cells. Currently one of the most studied drug transport system are liposomes [3], which are spherical structures formed by a lipid bilayer with a hydrophilic interior, providing a water-soluble / fat-soluble medium of controlled size.

Exploding the characteristics of both systems, MNPs and liposome, in this work the fabrication and analysis of a thermo-active magnetosome nanosystem is detailed. A structure directed to the target cell that through the local application of an external alternate magnetic field will selectively increase the local temperature, permeabilizing the liposomal membrane, releasing the therapeutic agent in a controlled manner. In this way they would be acting as joint HTM therapies, chemotherapy and immunotherapy.

Thermal decomposition of organometallic precursors in the presence of surfactants is a versatile synthesis route [4], with advantages on the precision and choice of the shape and size of the particles. In this work, a series of MNPs of $Zn_xFe_{3-x}O_4$ were synthesized, with size <15 nm, low dispersion, exhibiting good colloidal stability, necessary requirements for encapsulation in liposomes. Initially, the MNPs have a fat-soluble nature due to their coating of oleic acid, after a 24 hour treatment they are given a hydrophilic character, by coating them with sodium citrate. The specific loss power (SLP) of both systems was studied under alternating magnetic fields (H=23,8 kA/m; f=570kHz) in different media, observing an optimal value around $Zn_{0,2}Fe_{2,8}O_4$ for 13 nm size. With them, multilamellar magnetic vesicles were synthesized by the reversed phase evaporation method, which were extruded at 60ºC to form magnetosomes. A detailed analysis with different techniques of transmission electron microscopy (TEM) shows a stable and repeatable system. In the images it is observed that the MNPs form a linear arrangement covered by a lipid bilayer that rolls up on itself. With a mean size of 900 nm measured by dynamic light scattering. The characterization of the coating was carried out by spectroscopy IR and UV, EDS and Z potential, and as expected, the SLP values for applications in HTM are suitable. Internalization curves of the magnetosome were analyzed in different cell lines BV2, PAN02 and LL2 / LL0. TEM images showed the incorporation of the magnetosomes into the cells.

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The Collective Effect of the FeRh Ferromagnetic Phase Growth During a Metamagnetic Phase Transition

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Earlier in [1] it was shown that the giant magnetocaloric effect is observed in materials near the temperature of the metamagnetic transition. The interaction between the crystal lattice and the spin subsystem manifests itself in a change in magnetization during the phase transition. Such phase transition is responsible for the remarkable thermal properties of materials. Thus magnetocaloric materials to be used in practice need the temperature of the first-order magnetic-structural phase transition to be determined at the stage of material synthesis, and the temperature hysteresis of this transition to be minimal. At the moment, there is no *ab-initio* theory that could be used to predict the magnetocaloric properties of the synthesized material. Therefore, the problem of determining the mechanisms that are responsible for the magnetic structural changes in magnetocaloric materials is worth investigating.

$Fe_{49}Rh_{51}$ alloy was chosen as the object of this study, since it reveals a giant negative magnetocaloric effect of -7÷8 K [2,3] in a magnetic field of up to 2 T near room temperature, it has a binary elemental composition, and its crystal structure does not change symmetry during a phase transition. These peculiarities make it possible to construct a simple descriptive model of a first-order magnetic phase transition. Iron-rhodium alloy has been studied for a long time and its static properties are well described [4]. The authors of this work were interested in the relaxation processes that are observed in this alloy and are described only in several papers [5, Ref. in]. Long-term relaxation of magnetization is associated with a change in the crystal lattice parameter and can provide additional information on the dynamics of the phase transition in such systems. In this work, the structural and magnetic properties of bulk $Fe_{49}Rh_{51}$ alloys were investigated. The samples were synthesized using arc melting and after that they were annealed at 1000 ºC for 48 hours. One of the samples was biphasic. The second phase is paramagnetic and occupies up to 35% of the sample volume (according to EDX data). Elemental analysis was performed with the use of SEM Tescan Vega 3 with EDX. The temperature, field, and time dependencies of magnetization were measured using a Lake Shore 7407 Series vibration magnetometer.

In this work, the mechanisms of the ferromagnetic phase growth were considered. It has been analyzed from the field, temperature (including hysteresis values determination) and time dependencies (time relaxation) of magnetization at different field and temperature values. The relaxation curves of magnetization have clearly visible steps. The presence of steps in the relaxation dependence of magnetization for a bulk alloy is associated with the collective effects of the ferromagnetic phase nucleation and its growth on the alloy surface. To confirm this hypothesis, a numerical simulation of the phase growth process was carried out. The experimental and modeling results are in qualitative agreement. Additional comparison of relaxation dependences of the magnetization for single-phase and two-phase samples makes it possible to separate the process of merging of ferromagnetic clusters from the processes of nucleation and growth.

Acknowledgements

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Protected Annealing in Maghemite-Core and Iron-Core Nanoparticles: Relating Exchange Bias to Non-Saturating Magnetization Components

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Silica coating of magnetic nanoparticles (NPs) is important, for example, in medical applications (e.g., providing biocompatibility) [1] and photocatalysis [2]. Here, we investigate magnetic and structural properties of silica-coated maghemite and silica-coated iron-core NPs of similar (magnetic) core diameters (8 and 9 nm, respectively), studying two different silica shell thickness (t) values for each type of NPs and as a function of post-synthesis thermal treatments (in air). A higher exchange bias (EB) field is found in the Fe-core NPs (~ 1.4 kOe compared to ~ 0.1 kOe in the maghemite) but the field is independent of t. In contrast, non-saturating components (NSCs) observed in the low temperature field dependence (up to 50 kOe) in both NP types are more significant for thicker silica coating. Furthermore, with annealing these components grow while EB field falls. We attribute this behaviour to softening of the spin-disordered shell anisotropy and we contrast the results with the effect of long-term aging (under ambient conditions) in iron oxide NPs [3]. The size of the NSC can be qualitatively correlated with structural disorder in the cores: in the maghemite case, sharper x-ray diffraction peaks are observed in the thinner (t = 4 nm) silica shell NPs than in the thicker (t = 17 nm) particles, while in the case of the thicker shell iron particles (t = 15 nm), *no* diffraction signal (from an Fe-based phase) at all could be detected, indicating highly structurally disordered cores. We suggest that structural disorder gives rise to spin disorder in the Fe-core NPs (as was previously established for the maghemite case [4]) where it acts as the high anisotropy component for EB. Our results suggest that the relative thickness of a spin disordered shell may impact on the size of the NSC without affecting the EB field. The EB properties of the maghemite NPs are observed to be more resistant to annealing, preserved after a 2h treatment at (at least) 600 ºC, compared to only ~ 100 ºC in the case of the Fe-core NPs. Furthermore, this "annealing resistance" is found to be t dependent in the maghemite NPs: the EB properties are preserved to an around 150 ºC higher annealing temperature in the thinner shell than in the thicker shell maghemite particles. We offer speculation on the origin of the t dependence of annealing resistance and of NSC. Magnetic blocking behaviour is also studied. In the thicker silica shell maghemite NPs, blocking temperature follows a similar annealing temperature dependence to that of the EB field, whereas in the thinner shell systems interparticle interactions are no longer negligible, leading to a difference between the annealing dependences of EB field and blocking temperature.

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Stochastic vs. Deterministic Magnetic Coding in Designed Cylindrical Nanowires for 3D Magnetic Networks

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Cylindrical Magnetic Nanowires (NWs) are a promising example of building blocks of 3D nanoarchitectures and nanotechnologies. They have enormous potential for 3D applications involving many types of external stimuli (electrical, magnetic, mechanical, thermal, etc.). Here we address an important novel function, namely the control over the stochasticity of the multivortex state in multisegmented nanowires. This property is very promising for the multifunctional application of NWs in bar coding, data encryption, microwave generation, memristor or reservoir computing, performed on the same nanowire.[1] For this purpose, the micromagnetic simulations are a valuable tool to increase our understanding of these magnetic systems above mentioned.

In this work we perform micromagnetic simulations of multilayer nanowires consisting of short magnetic segments (FeCo) separated by a non-magnetic material (Cu). Typically, for materials with a high saturation magnetization value and sufficiently short segments, each segment is in a single- or two-vortex [2] state with arbitrary polarity/chirality. We show that it is possible to create different magnetic potentials for vortices moving under applied fields by engineering nanowires with interfaces separating different segments which are tilted with respect to the NW axis, thereby breaking the rotational symmetry. Depending on the applied field direction with respect to the interface inclination either stochastic or deterministic switching of the vortex chirality takes place. This property has been also corroborated by the X-ray Magnetic Circular Dichroism combined with Photoemission Electron Microscopy (XMCD–PEEM) [3].

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Development of a Sustainable Manufacturing Process of Ferrite Permanent Magnets by Combining Recycling and Additive Manufacturing

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Ferrite magnets are the most widely used permanent magnets (PMs) due to the availability and low cost of the constituent elements, in addition to a reduced environmental impact compared to that of rare earth elements (REE)-based magnets. A lower magnetic performance than the latter limits the application range of ferrites, however, criticality issues related to REE and the possibility of improving magnetic properties through nanostructuring and optimizing the design by using additive manufacturing are opening the path to new technological applications (e.g. electromobility) [1,2].

Herein, the possibility of 3D-printing PM objects taking as precursor recycled strontium ferrite (SFO, $SrFe_{12}O_{19}$) powder has been studied. Microstructural modification induced through a self-developed recycling process (free of any chemicals) of the SFO residue generated from industrial manufacturing of ferrite magnets has ended with SFO powder with superior magnetic properties [3]. In particular, the recycled ferrite powder shows a 3.5 fold increase in coercivity and 25% higher remanence compared to the brand new commercial SFO powder originally used for the industrial fabrication of magnets [3]. The recycled SFO powder has been used for synthesizing composites (SFO particles/polymer) by the solution casting method [4]. The composites were extruded into meters-long flexible and high-load magnetic filaments. In a next step, Fused Filament Fabrication (FFF) has been used for successfully printing 3D objects with a high particle content (50 wt% and 65 wt%) and, importantly, avoiding deterioration of the properties of the precursor (Fig. 1) [4,5].

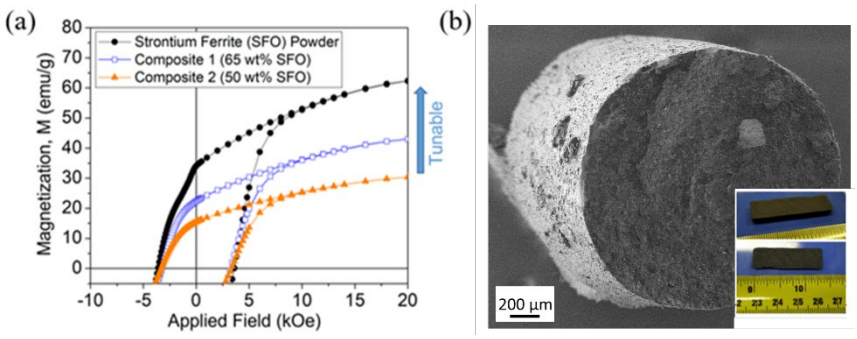

Fig. 1. (a) First and second quadrants of the hysteresis loops of recycled strontium ferrite (SFO) powder and composites with different contents of SFO particles embedded in polymer matrix (magnetization scales with the PM particles content making possible tuning the PM properties). (b) SEM image showing the circular cross section of the filament (65 wt% of SFO). Inset shows pictures of the printed object.

Acknowledgements

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Index Terms — sustainability, permanent magnets, ferrite, recycling, additive manufacturing

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Surface Magnons and Crystalline Electric Field Shifts in Superantiferromagnetic NdCu2 Magnetic Nanoparticles

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Over the last years our group is working on the magnetism in ensembles of 4f metallic nanoparticles (R = Tb,Nd, Gd-M = Cu, Al, Y, La). As a result, we have reported that the existence of an ordered magnetic core and a disordered magnetic shell is regularly found in those ensembles. Depending on the stoichiometry (in our case RX2) it is possible to easily tune the RKKY interactions [1].

As a matter of fact both the collective moment dynamics and the role of the crystalline electric field at the nanoscale have barely been unearthed in ensembles of nanoparticles. Thanks to our previous know-how it is possible to produce very large quantities of NdCu2 nanoalloys. This is achieved by ball milling and allows performing inelastic neutron scattering, which is the key technique to unveil those two effects. We are reporting here those results.

In our NdCu2 nanoparticles, neutron diffraction measurements (Lab. Leon Brillouin) indicate a mean nanoparticle size of ≈ 13 nm, where the bulk commensurate antiferromagnetic structure is retained at the nanoparticle core. Macroscopic magnetic measurements evidence a Spin Glass behaviour at the surface. On the whole, a Superantiferromagnetic state is therefore set for the NdCu2 nanoparticles. Specific heat analyses show a broad Schottky contribution, with a maximum located at T∼25 K, revealing the existence of crystalline electric field. Inelastic neutron scattering (Inst. Laue-Langevin) analyses performed at T = 10 K (paramagnetic state) and T = 1.5 K (magnetic state) reveal the presence of both crystalline electric field and magnon collective excitations. Therefore, the splitting of the crystalline electric field levels associated with the Nd3+ ions, as well as the spin–wave excitations that emerged below the Néel transition (TN ≈ 6 K) in polycrystalline NdCu2 [2] are maintained in the nanoparticle state. Their nature and strengths will be discussed in this contribution [3].

Acknowledgements

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E-Field Control of Skyrmions Hall Effect in Artificial Multiferroics

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In the present work we show a new route to control the skyrmion trajectory and its Hall effect via voltage-controlled strain [1]. Using electromechanical simulations, we investigate the strain distribution created in a Heavy Metal/Ferromagnet/Oxide trilayer on top of a Piezoelectric (PZ) substrate when a voltage is applied between two electrodes that are on top of the PZ but transverse to the trilayer. Later on, we use the strain profile found in our micromagnetic model to investigate the skyrmion dynamics in presence of both longitudinal current along the Heavy Metal and a transversal strain gradient. The magneto-elastic contribution is included in the micromagnetic code by adding the magnetoelastic field to the full effective field in the Landau-Lifshitz-Gilbert equation $\vec{H}_{me} = \frac{1}{\mu_0 M_s}\sigma_{ij}\frac{\delta\varepsilon_{ij}^m}{\delta\vec{m}}$. We also use Thiele's model to support our results. In this model, the equation of motion for the skyrmion is given by $\vec{G}\times\vec{v} + \alpha\bar{\bar{D}}\vec{v} = \vec{F}_{SHE} + \vec{F}_{el}$ where $\vec{G}$ is the gyro-vector, $\vec{v}$ is the skyrmion speed, $\vec{F}_{SHE}$ is the spin Hall effect force and $\vec{F}_{el}$ is the force due to the strain gradient. We find, from both micromagnetic simulations and Thiele's model, that the skyrmion Hall angle for any given value of the current density can be totally suppressed if the appropriate voltage is applied, and also that the skyrmion speed can be enhanced using in-plane strain gradients. We check as well the efficiency of strain gradient to control skyrmion Hall angle in granular films by including a random distribution of magnetic defects in the simulations. To sum up, the results of our study show that strain can be a promising alternative to control skyrmion dynamics in ferromagnetic systems [2].

Acknowledgements

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Cryogenic Magnetocaloric Performance of *RE*NiX_2 Compounds (*RE* = Er, Ho and Dy, *X* = Al and Ga)

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The magnetic refrigeration (MR), which is based on the magnetocaloric effect (MCE), is a new, environmental-friendly and high energy efficient cooling technology [1]. This technology can be implemented for covering a wide temperature range of applications, from cooling system at room temperature to cryogenic liquefaction systems. In recent years, liquid He, H_2, N_2 and O_2 have played an increasingly important role in scientific and research areas. This increasing demand requires better liquefaction systems for gas storage and transport, being the MR one of the most promising alternatives to the traditional gas compression systems.

In this work, we synthesized and characterized a series of *RE*NiX_2 (*RE* = Er, Ho and Dy, X = Al and Ga) compounds. All the samples crystallize in the orthorhombic $MgCuAl_2$-type structure. $ErNiAl_2$ and $HoNiAl_2$ compounds were found to undergo a second-order magnetic phase transition from ferromagnetic to paramagnetic at around 5.1 K (close to He liquefaction temperature) and 7.8 K, respectively [2]. After changing Al to Ga, the transition temperatures were tuned to higher temperatures, yielding: 11.8 K for $ErNiGa_2$ and 24.5 K for $HoNiGa_2$, falling in the H_2 liquefaction temperature range [3]. In order to further increase the transition temperature, the $DyNiGa_2$ was also synthesized and the T_C of 41.0 K was obtained. With respect to their MCE performance, for Al containing samples, the maximum isothermal entropy change ($|\Delta S_{iso}^{max}$ (5 T)|) values are 21.2 and 14.0 J kg^{-1} K^{-1} for *RE* of Er and Ho, respectively. For the Ga containing samples, the $|\Delta S_{iso}^{max}|$ (5 T) values are 11.4, 10.4 and 6.2 J kg^{-1} K^{-1} for *RE* of Er, Ho and Dy, respectively. Although the $|\Delta S_{iso}^{max}|$ values of Ga containing samples are lower than those of Al ones, the higher operating temperature range contributes to obtaining good cooling efficiencies, especially for $DyNiGa_2$, as shown in Fig.1. The studied samples exhibit an outstanding MCE performance in the helium and hydrogen liquefaction temperature ranges, making them potential candidates for cryogenic applications.

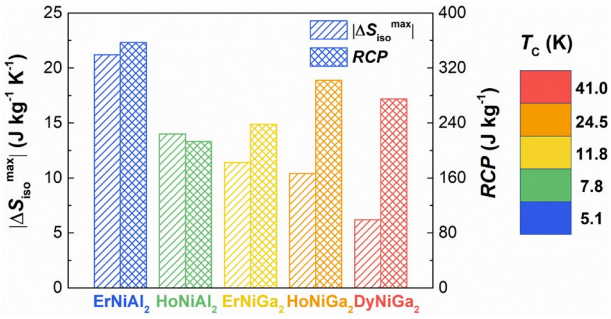

Fig.1 $|\Delta S_{iso}^{max}|$ and the relative cooling power (*RCP*) under ΔH of 0-5 T for the studied compounds

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Novel One-Pot Sol-Gel Synthesis Route of Fe_3C/few-Layered Graphene Core/Shell Nanoparticles Embedded in a Carbon Matrix

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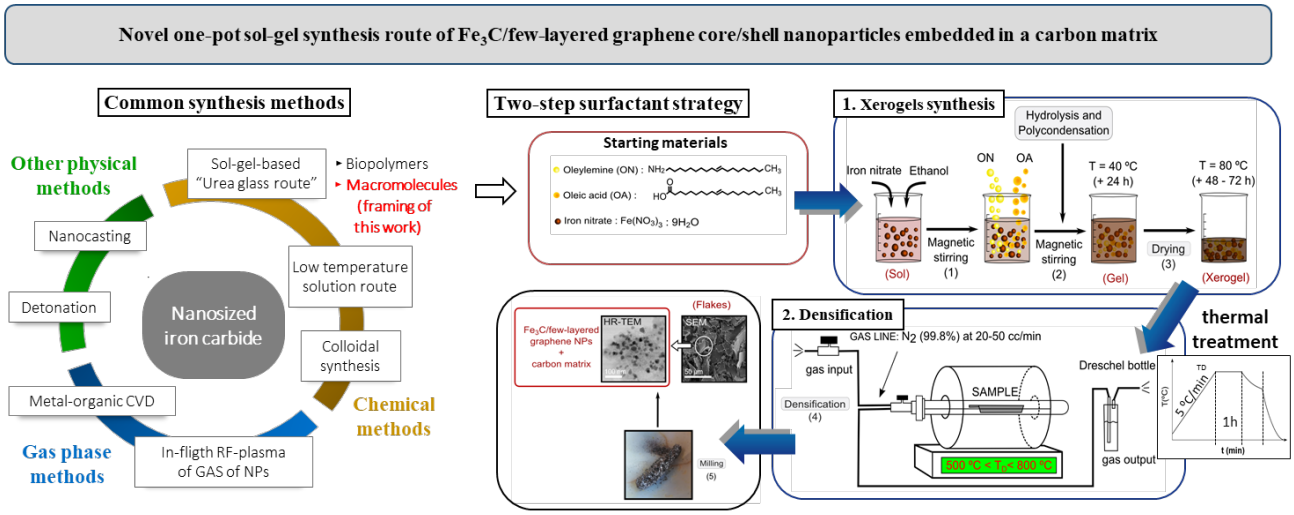
In this work, we propose a novel sol-gel non-aqueous synthesis route replacing the common use of gel-like-network made of organic gelators or biopolymers (urea-glass route) [1], by oleic acid and oleylamine as surfactants. The present approach is based on the combined action of the surfactants, which act sterically on the precursor micelles while a reducing atmosphere is promoted with the densification temperature (two-step surfactant strategy). The structural and magnetic evolution of the formed compounds is investigated, ranging from iron oxides such as Fe_3O_4 and FeO, to the formation of pure Fe_3C/C samples from 700 ºC onwards. Interestingly, Fe_3C nanoparticles with a size of ~20 nm crystallize immersed in the carbon matrix and the surrounding environment form an oriented encapsulation built by few-layered graphene. The nanostructures show a saturation magnetization of ~43 emu/g and a moderate coercive field of ~500 Oe [2]. Thereby, an innovative chemical route to produce single phase Fe_3C nanoparticles is described, and an effective method of few-layered graphene passivation is proposed, yielding a product perfectly competitive and applicable for the whole vanguard proposed applications existent for the nano-sized Fe_3C.



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Real Time Monitoring of the Precipitation of Calcium Oxalate by Magnetoelastic Resonance Sensors

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Magnetoelastic sensors are usually made of amorphous ferromagnetic ribbons. Magnetostriction in these materials provides a strong coupling on their mechanical and magnetic properties, so that an elastic wave can be excited in these materials by the application of an alternating magnetic field and detected by the magnetic changes induced in it. The magnetoelastic ribbon can enter in resonance at certain frequencies of excitation, compatible with the dimension and elastic properties of the material. This resonance behavior is highly sensitive to different external parameters, which have made these materials especially interesting for design different sensing systems [1], in particular, differences in mass loading of the ribbon causes a shift of its resonance frequency and changes its resonance signal.

In the present work, a magnetoelastic ribbon of composition $Fe_{73}Cr_5Si_{10}B_{12}$ was used to monitor the precipitation reaction of calcium oxalate crystals (CaC_2O_4), one of the most common minerals which form calcifications in the urinary track. The formation process of these crystals was measured in real-time by tracking the changes in the resonant frequency of the sensor, which decreases as the precipitate is deposited on its surface, changing its total mass (Figure 1) [2]. In addition, numerical fittings of the obtained resonance curves to a phenomenological expression that describes the resonance behavior were performed (Figure 1.b) [3] in order to improve the detection resolution and allow the study of the different parameters that characterize the response of the sensor with more accuracy (the resonance frequency, the damping parameters or the quality factor Q). These fittings have proven to be more accurate in obtaining the parameters governing the resonance and less sensitive to noise than direct methods, allowing to follow the evolution of the reaction in a more reliable, precise and noiseless way. The results show that the sensor is capable of tracking the precipitation reaction of reactants of concentration as low as 1 mM, with the sensor being able to resolve a mass of precipitate of 2 µg. In addition, it has been found that an intrinsic factor of the magnetoelastic material, its magnetic relaxation under exposure to a magnetic field, influences the measurements, affecting the resonance frequency of the sensor during the process, and therefore masking the effective change caused by the precipitate to be detected. This effect of the relaxation of the magnetization has been evaluated under different conditions, in order to avoid its influence and improve detection.

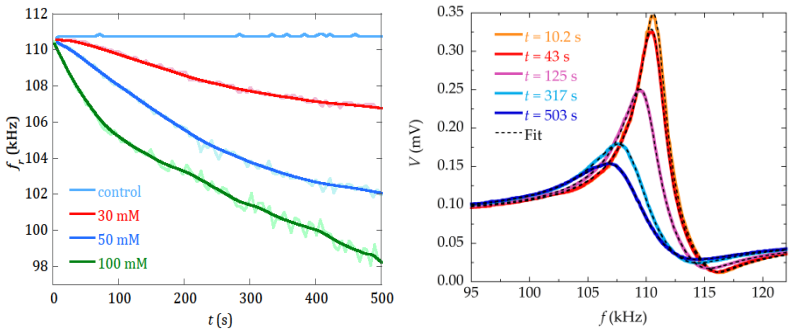

Figure 1: a) Temporal evolution of the resonance frequency of the magnetoelastic sensor as the reaction progresses (for different concentration of reactants in the reaction). **b)** Temporal evolution of the resonance curves during the reaction for 30 mM reactants and corresponding numerical fits.

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Index Terms — Magnetoelastic Sensor, Precipitation Reaction, Mass Sensor, Resonance Curve Fit

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Global Magnetic Topology Optimization

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In various magnetic sensor applications, the profile of the magnetic field (in addition to the sensor properties) has a significant impact on the quality of the sensor system. Therefore, it is reasonable to use magnets with optimized shapes that generate fields that allow simple and robust determination of the measured system variable (position, temperature, pressure, etc.).

A possible way to improve the magnetic field in a desired way is magnetic topology optimization, where the form and shape of magnets is customized by optimization. In the past, several works (e.g. [1, 2]) presented possible optimization algorithms that allow to optimize the magnets with respect to a predefined cost function, that measures the quality of the obtained field. The basic idea is to describe the geometry by a scalar density field describing the presence/absence of magnetic material discretized in a predefined design region (see Fig. 1). This leads to an enormous number of degrees of freedoms, but the majority of algorithms in literature use the adjoint method, which provides a cheap and direct way to calculate the gradient of the cost function. This allows the use of common gradient-based optimization algorithms that provide fast convergence is the very high-dimensional discrete magnetic topology space.

Since gradient-based optimization algorithms tend to converge to nearby local minima, there is no guarantee that the obtained minimum is global. Even simple toy examples show that, in general, multiple local minima can occur, especially with soft magnetic materials and demagnetization effects. To address this problem, we present a hybrid topology optimization algorithm that combines the global cuckoo-search-optimization algorithm [3] with a very efficient binary local on/off optimization algorithm [4]. It is predestined for optimization problems in the case of a very high-dimensional domain (all magnetic cells), only two desirable states (magnetic material or not), available gradient (adjoint method) and the possible presence of multiple local minima.

We show that our algorithm can find significant better solutions than pure local or global optimization methods and exhibit fast convergence properties due to possible parallel computation (see Fig. 1 a) local optimizer b) global optimizer).

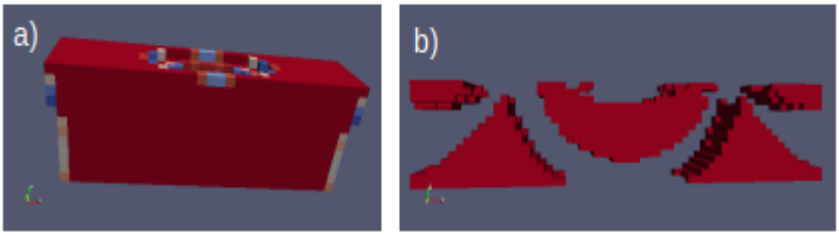

Figure 1: Illustrative result of an optimization where a) is obtained as local minimum with the algorithm in [2] and b) as global minimum (reduction of the same cost function by another 10%) with the hybrid algorithm.

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Index Terms — topology optimization, magnetic sensing, local optimization, global optimization

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An Insight into the Structural and Magnetic Properties of Maghemite Nanoflowers

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Single-core magnetite/maghemite nanoparticles have been extensively studied because of their outstanding properties for biomedical and environmental applications.[1],[2] Recently, great interest has focused on multicore nanoparticles, such as aggregates of cores arranged as nanoflower (NF) -like structures. Nevertheless, there is still a lot to understand about both the structure and magnetic properties of the NFs to achieve good control over their performance in applications. In particular, the origin of the nearly demagnetized remnant state has still to be interpreted. In this work, three different samples synthesized by the polyol method were studied.[3] The size of the NFs (i.e., the overall size of the aggregate) was determined by transmission electron microscopy (TEM), obtaining values of 37 ± 9 nm, 121 ± 13 nm, and 276 ± 55 nm for NF37, NF100, and NF300 samples, respectively. The size of the cores was determined by both TEM and X-ray diffraction to gain a deeper insight into their internal structure. We found that the crystalline size obtained by XRD was about twice the size of the individual cores measured by TEM, showing a crystallographic correlation length that extends well beyond the individual cores. In addition, selected area electron diffraction patterns showed a high degree of texture associated with preferential orientations of the cores within the NF. This complex crystalline structure led to hysteresis loops showing high values of both the saturation magnetization (c.a. 80 emu/g) and the initial susceptibility, but with almost zero remnant magnetization and coercive field at 300K. Therefore, a deeper understanding of the internal magnetic structure of the NFs and the consequent magnetic properties are key to optimize their performance in applications.

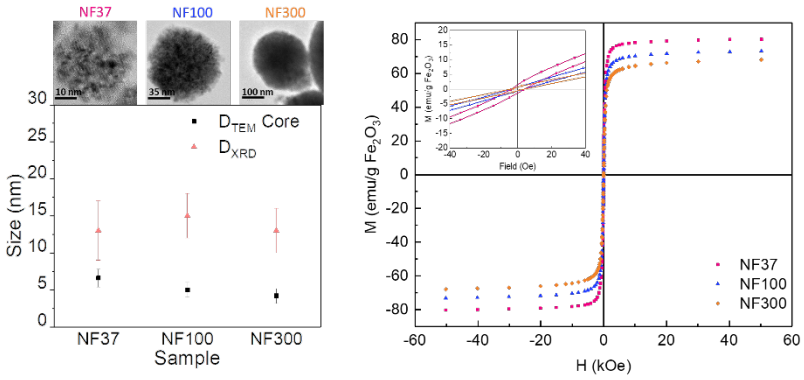

Figure 1. Left panel shows the core diameters obtained from TEM (black squares) and XRD (red triangles) data for the three samples, together with the corresponding TEM images of the NF aggregates at the top of the panel. Right panel shows hysteresis loops at 300K. The inset corresponds to the enlarged region between -40 and +40 Oe.

Acknowledgements

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Index Terms — maghemite, magnetic nanoparticles, nanoflowers

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Magnetostrictive Nanostructured Surfaces for Antimicrobial Applications

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Medical devices such as laboratory or surgical instruments are extensively used. A common problem that may arise from the use of these tools is the proliferation of microorganisms and biofilms formation on their surface, which leads to nosocomial infections in patients [1]. Novel strategies to prevent the adhesion of microorganisms and thus biofilm formation are being developed using physical methods such as the magnetoelectric stimuli [2-4].

In this work, an array of pillars with submicrometer sizes made of highly magnetostrictive material is employed to control and trigger the antimicrobial activity on its surface by applying a magnetic stimulus. Terfenol-D ($Tb_{0.3}Dy_{0.7}Fe_{1.9}$) was deposited by DC magnetron sputtering over a Si substrate using a hexagonal patterned mask with porous diameter of 450 nm, obtaining magnetic pillars of approximately 300 nm in height (Figure 1). In depth characterization of the structures were performed including their morphological and magnetic characteristics.

The antimicrobial activity with Gram-negative (*E. Coli*) bacteria was also assessed by comparing the capability of bacteria killing of Terfenol-D pillars, Terfenol-D thin films and Si substrates. Experiments were performed both under static and dynamic conditions, the latter by applying a varying external magnetic field using a home-made bioreactor [5] to trigger a mechanical stimulus via the magnetostrictive properties of Terfenol-D. Micromagnetic simulations of the pillars were carried out under the same conditions used in the essays to better understand the magnetization dynamics and magnetostrictive effect.

It is shown how the morphology and the application of the magnetic field to the nanostructured surface affects bacteria killing, becoming a proof-of-concept for nanostructured magnetically activated materials for the development of antimicrobial surfaces.

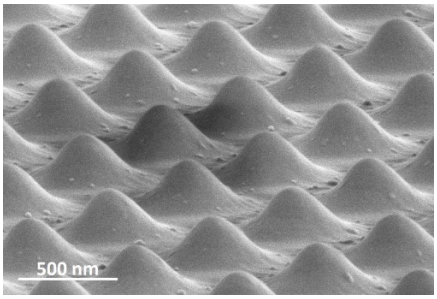

Figure 1. SEM image of the Terfenol-D pillars deposited over a Si substrate.

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Index Terms — Nanostructured surface, magnetostrictive, pillars, antimicrobial activity

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Magnetocaloric Effect and Critical Behaviour in Ni-Mn-Sn Heusler Alloys

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Several experimental and theoretical works [1, 2] have been devoted to study the numerous properties of Heusler alloys and their various applications such as the magnetic refrigeration, MR, near the room temperature [3-6]. MR is equivalent to the magnetocaloric effect that can be estimated from the magnetic entropy, ΔS_M, and calculated *via* the thermodynamic Maxwell relationship, $\Delta S_M(T,H) = \int_{H_2}^{H_1} (\frac{\partial M}{\partial T})_H dH$, from isothermal magnetization $M(H)$ curves, where M, H and T are respectively, the magnetization, magnetic field, and temperature. Heusler alloys might exhibit an inverse magnetocaloric effect, IMCE, around the first order structural transition, MT, and/or a conventional magnetocaloric effect, MCE, around the second order magnetic transition, T_C. The type of the magnetic interactions in materials can be estimated from the critical exponents by using several methods [7] such as the mean field model ($\beta = 0.5$ and $\gamma = 1$), 3D-Heisenberg model ($\beta = 0.365$ and $\gamma = 1.336$), 3D-Ising model ($\beta = 0.325$ and $\gamma = 1.241$), and tricritical mean field model ($\beta = 0.25$ and $\gamma = 1$).

The melt-spun $Ni_{50}Mn_{30}Sn_{20}$ ribbons [8] exhibit a single cubic $L2_1$ structure (lattice parameter $a = 5.994 \pm 10^{-3}$ Å) and undergo a second order magnetic transition at a Curie temperature of $T_c^A = 333\ K$. For an applied magnetic field of 5 T, the maximum entropy change (ΔS_M^{max}) and the relative cooling power (RCP) values are of about $2.43\ J/kg.K$ and $172.88\ J/kg$, respectively. The critical exponents values $\beta = 0.421$, $\gamma = 1.078$ and $\delta = 3.710$ are close to those predicted from the mean field model revealing a dominated long-range order of magnetic interactions. The Heusler alloy can be considered as a good candidate for MR near room temperature.

Acknowledgements

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Magnetic Iron Oxide Nanocatalyst for the Enhanced Degradation of Organic Pollutants

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The use of magnetic iron oxide nanoparticles as catalytic agents for the removal of organic pollutants from wastewater seems a great alternative due to their easy removal and heating capacities. This kind of materials can participate in oxidative processes producing reactive oxygen species needed to degrade organic molecules [1]. In this work, three different nanocatalysts (NCs) based on iron oxide magnetic nanoparticles (Singlecore, Core/Shell made of silica coating and Multicore) were synthesized to compare their efficiency in the magnetic induction heating-assisted degradation of two different dyes, methylene blue (MB) and acid orange 8 (AO8), in aqueous solutions. The efficiency of these NCs depends directly on their surface area to adsorb the organic molecules and degrade them by Fenton reactions. Also, the heating produced under an alternating magnetic field (AMF) can lead to higher degradation yields.

All systems presented higher susceptibility values with zero remanence, which indicates a superparamagnetic behavior at room temperature and ZFC curves with a wide maxima indicating the existence of a blocking temperature distribution and intra- and inter-particle interactions, even for the core/shell structure. Singlecore NC had lower saturation magnetization values than multicore NC because of their smaller size and greater spin canting at the surface, corroborated by surface area measurements. However, the heating efficiency under an AMF is much higher for multicore system than for single core one, according to their magnetic behavior.

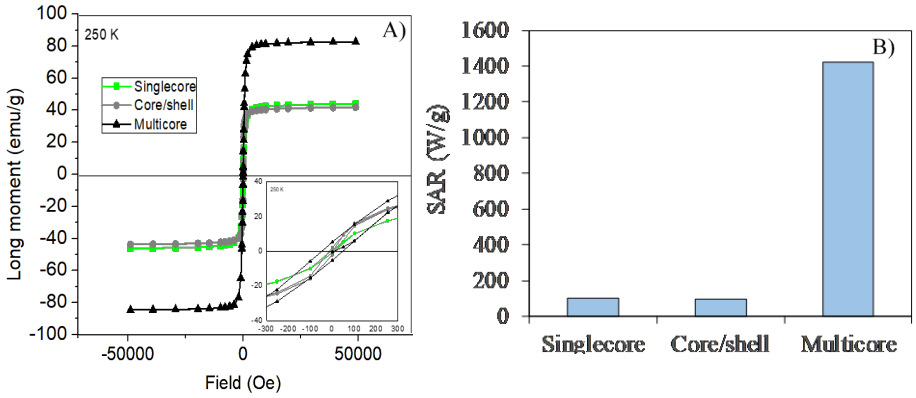

Figure 1. A) Magnetization hysteresis loops at RT in emu/g_{NP} B) optimum SAR values for dyes degradation.

The degradation of MB and AO8 was carried out in the presence of hydrogen peroxide and the nanocatalyst, at 90ºC in thermal reactor and under an AMF (202 kHz and 30 mT). It was concluded that efficiencies were greater when using Singlecore NC (99%) and when the reaction is carried out at 90 °C. Moreover, by subjecting the particles to the AMF, an increase in the degradation of the MB with respect to the degradation at room temperature without the AMF is achieved for the three systems.

Acknowledgements

This research was funded by MAT2017-497 88148-R (AEI/FEDER, UE) and PIE- 201960E062 grants.

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Charge-Spin Current Interconversion in High-Quality Epitaxial Co/Pt Systems

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The conversion of spin current into charge current and vice versa is the main operation in new spintronic devices. In the last years, an active investigation in materials, interfaces and spin injection schemes aims at increasing the efficiency of the spin-to-charge conversion mainly due to the spin-orbit coupling (SOC).

One of the materials widely studied is Pt [1]. We have recently exploited its strong SOC interaction in FM/Pt interfaces for the induction of spin orbit torques in Co [2] as well as the stabilization of chiral spin textures [3]. Nevertheless, there is still an open debate on its efficiency in spin-charge interconversion demonstrated by different techniques in the same material. Interest in the study of the directionality of epitaxial Pt is more recent using different FM layers attached such as Fe [4,5], CoFeB [6], Co[7], etc [8]; finding contradicting results.

In this context, we have evaluated the efficiency of spin to charge conversion in epitaxial [111]Co/Pt deposited on sapphire. Spin torque – ferromagnetic resonance (ST-FMR) method was used to estimate the spin torque efficiency, θ_{DL}, as a function of the thickness of Pt. We find out a strong dependence with Pt-thickness but a bare difference between the two in-plane crystallographic directions, i.e . ΓK and ΓM. This is consistent with our independent results for the resistivity of [111]Pt. The resistivity is the same along the different directions ΓK and ΓM but changes with thickness. These results demonstrate that the main contribution to the spin Hall effect (SHE) in Pt is intrinsic and not skew scattering for our epitaxial [111]Co/Pt.

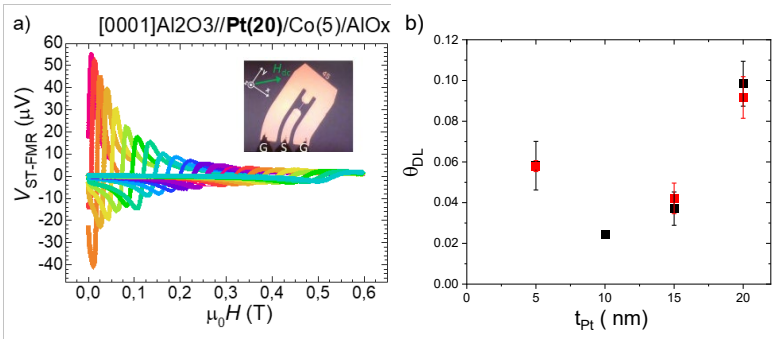

Fig. 1. a). Field sweep ST-FMR spectra. The RF frequency varies from 1 to 22 GHz. The inset shows a ST-FMR device. b) θ_{DL} from Al_2O_3//Pt/Co/AlO_x samples as a function of Pt thickness for both crystallographic directions, ΓK and ΓM.

Acknowledgements

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Synthesis and Characterization of Polyurethane-Magnetite Composites for Magnetic Hyperthermia

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Magnetic hyperthermia is based in the increase of the temperature experienced by magnetic nanoparticles (MNPs) when they are placed in an alternating magnetic field. This procedure is being applied as an antitumour therapy method that induces the death of the tumour cells by heating.[1] In this case, the nanoparticles in solution are carried inside the tumour. Nevertheless, there are different therapy possibilities in which magnetic hyperthermia produced by implantable medical devices constituted by solid materials doped with MNPs can be exploited.

In this work, superparamagnetic composites constituted by a polyurethane matrix were developed as biocompatible and implantable biomedical materials with magnetic hyperthermia. Polyurethane scaffolds containing different types and amounts of magnetic nanoparticles were synthesized (Figure 1) through a wet chemistry procedure. The resulting material can easily cut into different sizes to suit its application requirements.

Figure 1. Polyurethane composites with different magnetic nanoparticles in their composition.

The physicochemical properties of the composites were characterized through different techniques: scanning electron microscopy (SEM), ICP-OES, magnetometry and magnetic hyperthermia. The magnetic behaviour of the scaffolds can be seen with the naked eye when approaching a magnet (Figure 2a) and was then studied by vibrating-sample magnetometry (Figure 2b).

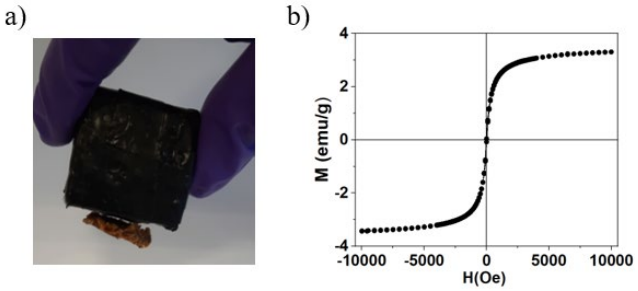

Figure 2. a) Magnetic composite attracted by a magnet. b) Superparamagnetic behaviour of the composite.

Acknowledgements

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Shape Anisotropy Engineering of V-Groove Patterned Permalloy Thin Films for Sensing and Biological Applications

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The magnetic properties of advanced materials, such as soft magnetic-coated nano-undulated films [1], offer innovative possibilities for sensing and biological applications, such as the measuring of perpendicular magnetic fields or the guided control of cell movement [2].

For this purpose, Permalloy (Py) thin films on V-groove (VG) patterned silicon substrates were prepared by a combination of nanostructuration techniques. Firstly, the silicon substrates were patterned through a multistep procedure involving photolithography, laser interference and reactive ion-etching techniques. The resulting pattern (250 nm in periodicity, θ = 55°) was characterized using SEM [Figure 1 (a)]. Secondly, Permalloy thin films were grown on the V-groove substrates by DC sputtering at normal incidence.

The deposited Py-VG thin films were characterized using scanning probe microscopies and vectorial Kerr magnetometry [3]. The measured longitudinal and transversal magnetization components evidence the morphology induced anisotropy of the Py thin films [Figure 1 (b)]. The angular dependance of the critical fields (coercive and switching fields) were studied and compared with the well-established Stoner-Wohlfarth and Kondorsky models. Moreover, micromagnetic simulations were performed to understand magnetization reversal mechanisms in such modulated anisotropic thin films.

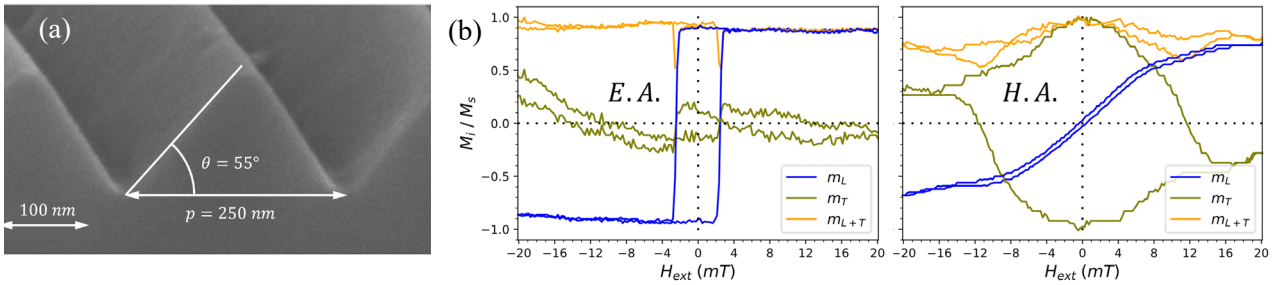

Figure 1. (a) SEM image of nanopatterned V-groove silicon substrate before Py film deposition. (b) Anisotropic behavior of a 15nm width V-groove Py, showing longitudinal (blue) and transversal (green) magnetization in measured hysteresis loops at the easy (left) and hard (right) in-plane magnetization axes of the sample.

Acknowledgements

Rafael Delgado Garcia thanks the UCLM and the Diputación de Toledo for his research grant.

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Index Terms — magnetic thin films, shape anisotropy, micromagnetic simulations

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Hysteresis Loops of Freely Rotating Nanoparticles in Simulations with Coupled Micromagnetic and Mechanical Equations

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In this work, we use a system of mechanical equations coupled with micromagnetic equations to determine the behavior of a magnetic nano-particle in a fluid. The influence of material and field parameters on the behavior can be studied with this model and allows for better understanding of the intrinsic magnetization dynamics and the mechanical response of magnetic fluids under the influence of a magnetic field. An alternating magnetic field is used to stimulate a magnetic particle inside a fluid. The particle accommodates for the change in field by rotation of the intrinsic magnetization and, if allowed to freely rotate, also by mechanical rotation. These two relaxation processes, called the Néel [1] and Brownian [2] relaxation respectively, are responsible for the emerging shape of the hysteresis loop with distinct corners at the point of saturation (see *Figure 1a*). The dissipated energy is thus also the result of both processes. The relaxation processes divide the phase space (see *Figure 1b*) of the field parameters into two regions, which depend on the dominating process. When tracing the particles anisotropy axis during the simulations the trajectory follows an arc. While in the region with the dominating Brownian relaxation (usually at lower frequencies), the zenith (the average angle between anisotropy axis and field axis) of the rotation trajectory is perpendicular to the field, whereas in the region dominated by Néel relaxation the zenith is close to the field axis but will vary depending on the field strength. The amplitude of rotation of the particle is limited at higher frequencies due to friction such that the particle can no longer fully relax in time. The relationship between zenith, amplitude and hysteresis loop will be further discussed in this work.

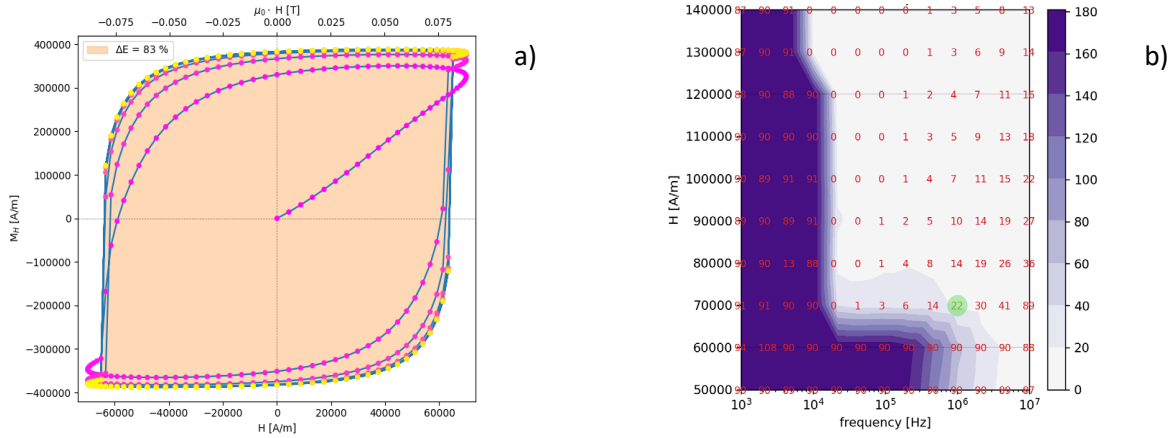

Figure 1. **a)** The hysteresis loop of a freely rotating particle (measured relative to the field axis). First few cycles are marked in pink and the steady state is marked by the yellow dotted line and its loop area in light orange (H=70 kA/m, f = 1MHz). **b)** The amplitude (intensity of the color purple) and the zenith (red numbers) of the rotation trajectory of the anisotropy axis in the phase-space of the field parameters of the alternating magnetic field (green dot corresponds to data in Figure 1a).

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Index Terms — Hysteresis, Magnetic Nanoparticles, Computer Simulations.

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Micromagnetics of Chemical Barriers Inserted within Permalloy Cylindrical Nanowires: Towards the Control of Domain Wall Motion

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Cylindrical magnetic nanowires are a three-dimensional system in which magnetization may be manipulated by spin-polarized currents in order to controllably nucleate, move and pin magnetic domain walls (DWs). Such control makes them excellent candidates for three-dimensional storage devices such as in the well-known concept of Racetrack memories [1].

Due to their geometry, cylindrical nanowires can host a DW with curling magnetization not or weakly subjected to the Walker breakdown limitation [2], and thus that can reach velocities over 1 km/s. In order to achieve the desired control of DW motion, effective pinning sites need to be set along the wire's axis. Here, we propose a system based on cylindrical Permalloy ($Fe_{20}Ni_{80}$) nanowires with evenly-spaced chemical modulations: Fe-rich segments ($Fe_{80}Ni_{20}$) of length ranging from 20 to 100 nm and 1 μm separation.

We present an overview of their static micromagnetic configuration as well as their response to magnetic field and nano-second electric current pulses. This is a prerequisite to investigating and understanding the interplay of DWs with chemical modulations. Quantitative understanding is achieved combining magnetic imaging by means of X-ray Magnetic Circular Dichroism (XMCD) coupled to PhotoEmission Electron Microscopy (PEEM), Scanning Transmission X-ray Microscopy (STXM) or X-ray ptychography with <10 nm spatial resolution, and micromagnetic simulations with mumax3 and feeLLGood codes, as well analytical modelling. In addition, Transmission Electron Microscopy (TEM) combined with electron holography was used to extract valuable qualitative and quantitative information on the local magnetic behavior.

The XMCD images show a curling magnetic state at the chemical modulations that reduces the magnetic charges (Fig. 1 b)). The chirality of curling is random at rest but can be switched deterministically by means of the Oersted field of nanosecond current pulses. Moreover, domain wall pinning at the chemical modulations was observed experimentally.

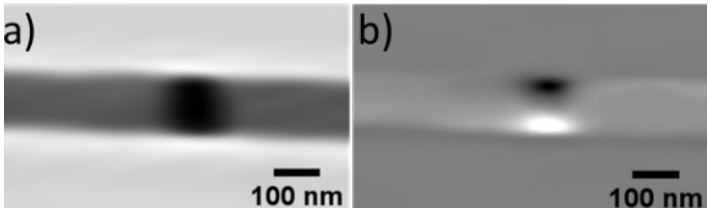

Figure 1 a) Reconstructed amplitude ptychographic XAS image at the Fe L3 edge of a Permalloy cylindrical nanowire of 140 nm of diameter with a chemical modulation ($Fe_{80}Ni_{20}$) of 100 nm in length (dark region). b) Reconstructed XMCD ptychographic image of a). The curling magnetization is evidenced by the dark and white bipolar contrasts.

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Nanolabel Optimization for the Development of a Magnetic Immunoserological Test for COVID-19

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The COVID-19 pandemic has shot and drastically changed our world lately. The severe consequences have exposed the need for new tools to reduce the impact of this and future emergencies. Lateral flow immunoassays (LFA), better known as "rapid tests", have been used to detect the infection. Now, when vaccination is the goal, they can be used to detect both immunoglobulin M (IgM) and immunoglobulin G (IgG) as the first body's immune response [1]. IgM is produced in the early stages of the infection whereas IgG takes longer but is more durable and could be the key to lasting immunity.

Magnetic Nanoparticles (NPs) have been lately proposed as labels to add quantification skills in LFAs. To be considered a *point-of-use* method, the magnetic LFAs must be associated with a magnetic reader that is fast and portable. We have developed a radio-frequency inductive sensor that takes advantage of the large initial permeability of the superparamagnetic NPs [3,4]. The first step to developing a magnetic LFA is, therefore, to optimize the nanolabels.

Magnetic characteristics are closely related to the chemical composition and crystalline structure of the materials. With this idea in mind, we have synthesised and analysed the performance of three different spinel ferrites (SFs), namely, Fe_3O_4, $MnFe_2O_4$ and $MnZnFe_2O_4$. All of them have been characterized in terms of particle size, crystallinity, and magnetic properties, such as initial permeability and saturation magnetization. This will prove which is the most suitable label yielding the highest quantitative signal in the inductive sensor.

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Studying the Degradation of Magnetosomes in Tumour Cells by Magnetometry and XANES Spectroscopy

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Magnetosomes are magnetic nanoparticles synthetized by magnetotactic bacteria (MTB), which are a group of bacteria that can align themselves along the earth's magnetic field. Magnetosomes can be made of magnetite (Fe_3O_4) or greigrite (Fe_3S_4) of high chemical purity, and have very uniform morphology and a narrow size distribution. These properties, together with their low toxicity and the bio-compatibility provided by their lipid envelope make them good candidates for many biomedical applications.

Some of the most recent applications of magnetosomes in research include: being used as heating agents in magnetic hyperthermia for cancer treatment [1], as drug carriers for targeted drug-delivery, and as contrast agents for magnetic resonance imaging (MRI). Researching and further developing these applications requires we understand how magnetosomes interact with cells and organisms. To increase our understanding of these interactions, our research group is employing human lung carcinoma cells, both in traditional two-dimensional cell cultures and in three-dimensional cell cultures (spheroids) [**Figure A**]. Spheroids are widely used tumour models, in which cells generate extracellular matrix and adhere to each other, creating adhesion and metabolic gradients.

Our research group has combined the use of these 3D spheroids and 2D cell cultures with X-ray absorption near edge structure (XANES; in CLAESS (ALBA) and BM23 (ESRF)) and magnetometry, to describe how magnetosomes are degraded in cancerous cells. Using these methods, we have observed that cancerous cells can degrade magnetosomes, by first oxidising magnetite to maghemite, and then storying the resulting Fe^{+} ions into ferritin [**Figures B** and **C**].

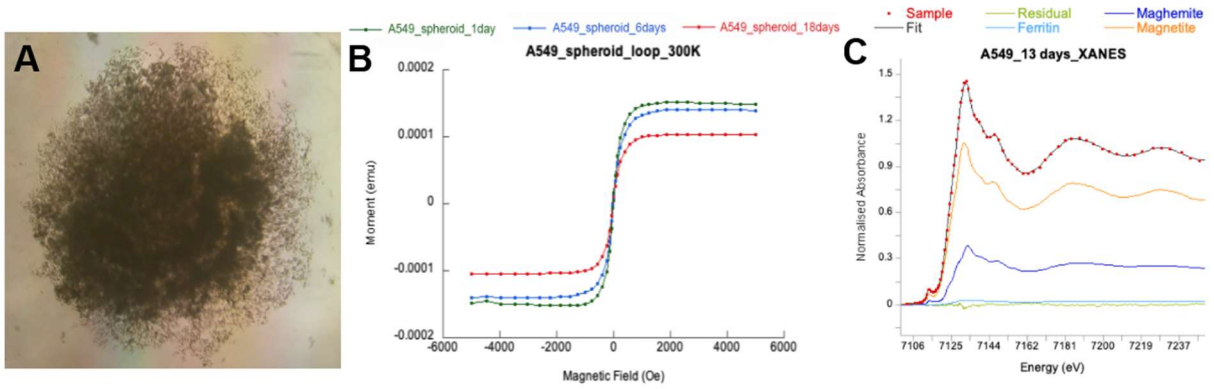

Figure A. Spheroid of human lung carcinoma cells (A549 cell line) with magnetosomes, at 6 days. **Figure B.** Magnetosome degradation measured by magnetometry (SQUID) in A549 spheroids after 1 day, 6 days, and 18 days of magnetosome internalisation. **Figure C.** Changes in magnetosome composition after 13 days of internalisation in A549 cells, as measured by Fe K-edge XANES spectroscopy, fitted to the linear combination of magnetite, maghemite and ferritin.

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Superconductivity Assisted Change of the Perpendicular Magnetic Anisotropy in V/MgO/Fe Junctions

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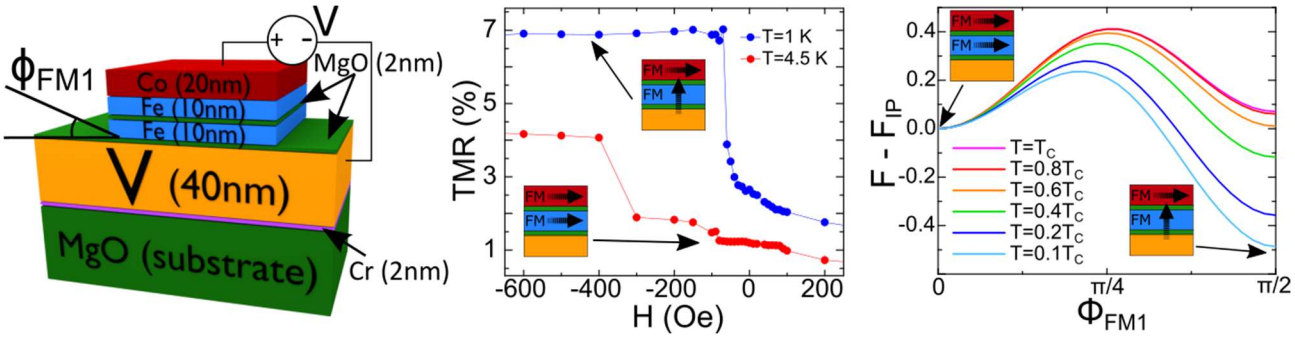
Controlling the perpendicular magnetic anisotropy (PMA) in thin films has received considerable attention in recent years due to its technological importance. PMA based devices usually involve heavy-metal (oxide)/ferromagnetic-metal bilayers, where, thanks to interfacial spin-orbit coupling (SOC), the in-plane (IP) stability of the magnetization is broken.

We have studied epitaxial V/MgO/Fe/MgO/Fe/Co junctions, where the soft Fe layer of the Fe/MgO/Fe/Co spin-valve part has competing in-plane and out-of-plane (OOP) magnetic anisotropies, and SOC is present at the V/MgO/Fe interface. In previous studies, we first observed a thousand-fold increase in tunneling anisotropic magnetoresistance below the critical temperature (T_C) of vanadium, supporting triplet Cooper pair formation [1]. Then we showed that under an in-plane rotation of an external magnetic field, new easy axes for the magnetization appear below T_C, directed in the above-T_C hard axes 45 degrees from the easy ones. We modelled our results in terms of the free energy of the system, which varies with the relative angle between the exchange field of the ferromagnet and the spin-orbit field by generating triplet Cooper pairs [2]. Now we demonstrate that the effective PMA is also enhanced below T_C. This produces a partial OOP magnetization reorientation without any applied field, and a reduction of the field required to induce a complete OOP transition. Our results suggest that the degree of effective PMA could be controlled by the junction lateral size in the presence of superconductivity and an applied electric field [3].

Our experimental findings, supported by theoretical modelling and numerical simulations of the ferromagnet-superconductor interaction, open pathways to active control of magnetic anisotropies in the emerging dissipation-free superconducting spin electronics.



Acknowledgements

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Index Terms — Magnetic Anisotropy, Superconductivity, Spin Orbit Interaction, Active Interfaces, Spintronics

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Excitation and Propagation of Edge Spin Waves in Ferromagnetic Triangles

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Spin waves, being usually reflected by domain walls, could also be channeled along them. Recent studies allowed observation of spin waves along domain walls in rectangular, circular [1] and triangular dots in the ground or metastable states. Triangular dots could also present edge pinned inhomogeneous magnetic states, depending on the direction of the external magnetic field. These edge domain walls yield the interesting, and potentially applicable to real devices property of broadband spin wave confinement to the edges of the structure [2,3], with capabilities to be redirected at angles exceeding 100 degrees. It has been previously shown how these waves could be generalized for arbitrary shapes and propose few devices (such as edge spin wave interferometers, controllers or splitters) where edge spin waves could be implemented [3].

Here we present simulation results obtained on the YIG based triangles where edge spin waves (ESW) were propagated over the corner in 2 micron sized triangles with a fixed thickness of 85 nm. The superior vertex angle, studied in the range of 40º-75º, has been optimized in order to obtain a higher transmission coefficient over the vertex of the edge spin waves. Our simulations showed resonance increase of the ESW transmission for the angles close to 50 degrees. A slight excess of the transmission above one could be due to positive interference with SWs propagating directly from the microwave field source to the opposite edge. A generated upper vertex domain wall's topology seems to be key in understanding the efficiency of the ESW propagation. We have also investigated the ESW transmission along the out of plane profile of the triangle and optimized the applied bias field to maximize the effectiveness of the exchange energy channels that behave as a propagation route for the spin wave.

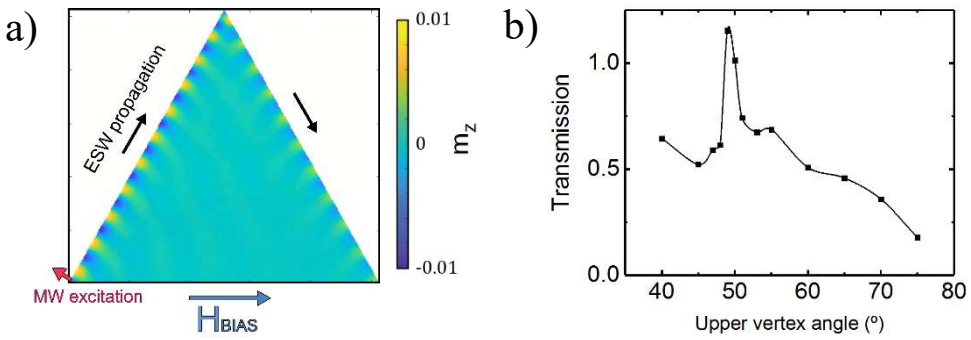

Figure. a) Snapshot of an edge spin wave propagated through both sides on a 2 micron side YIG triangle with a local microwave sinusoidal excitation perpendicular to the left side. b) Transmission coefficient of the ESW propagation through the upper vertex topology, showing a distinct increment for upper vertex angles in the 49º-50º range.

Acknowledgements

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Homogenization of Heating in Magnetic Hyperthermia through Exploitation of Magnetisation

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Achieving homogeneous tumour heating is one of the most long-standing challenges in magnetic hyperthermia for cancer therapy. Clinical studies must meet strict safety regulations that require knowledge and control over the physical properties of the chosen magnetic nanoparticles [1]. Whereas it is well-established that the heat released by magnetic nanostructures is influenced by interparticle interactions, as of today there is no method to analyze heat exchange at single-particle level in interacting systems at nonzero temperature. This gap needs to be bridged so to harness nanoparticle magnetization dynamics for the sake of biomedical applications.

Building on previous theoretical work [2], we present an equation to estimate the heat dissipation of individual, interacting particles at nonzero temperature that perform both field-induced and thermal switching. After validating this equation, we use the macrospin simulation tool Vinamax [3], to investigate a system of interacting particles with different anisotropies, as we showed in this contribution [4]. Our preliminary results indicate [Figure 1] that the generated heat becomes more homogeneously distributed at larger fields. We believe that this homogenization of the particle heating will help to achieve a more homogenized heating of tumors during hyperthermia treatments.

The use of the proposed equation would simplify the selection process of optimum nanoparticle distributions leading to optimal tumour heating. Its simplicity and flexibility also allow it to be integrated into multi-scale, multi-physics simulations to accurately assess the magnetic hyperthermia therapy without impacting the overall computational time.

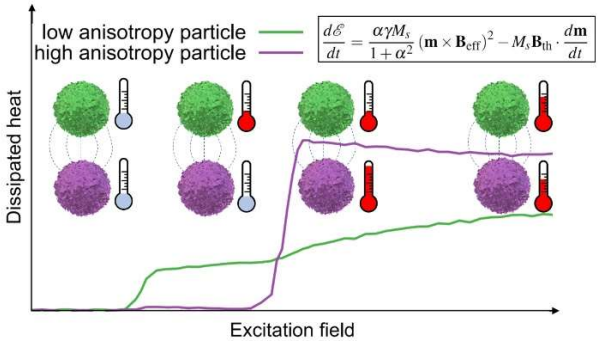

Figure 1. Heat generated in a system consisting of two interacting nanoparticles with different anisotropies. Both particles show switching behavior as soon as the excitation field amplitude overcomes their anisotropy barrier. The heat generation tends to become more uniform with increasing excitation fields.

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Index Terms — Micromagnetism

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Structural and Magnetic Characterization of Nanostructured NiO Prepared by Mechanical Milling

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Mechanical milling is a solid-state fracture technique that allows the synthesis of alloys in large quantities, in a simple way, which is also industrially scalable [1]. However, due to the fact that magnetism is govern by quantum effects, reducing the size of the alloy can cause changes in its magnetic behavior. Our objective is to investigate the relationship between milling time and the crystalline structure, microstructure, and magnetic properties of various NiO samples prepared with milling times between 1 h and 100 h. For this analysis, we employed techniques such as X-ray diffraction, transmission electron microscopy, and magnetic measurements.

Starting with a NiO powder, from the Sigma-Aldrich trademark, we prepared 6 samples with the following milling times: 0 h, 1 h, 3 h, 10 h, 50 h, and 100 h. We measured the diffraction patterns of all samples using XRD (with λCu in the 2θ range 10º -140º). Rietveld refinement of all diffraction patterns was carried out, obtaining a good fit to the rhombohedral model, with lattice parameters a=2.957 (0.002) Å and c=7.21 (0.01) Å. By analyzing the high-resolution spectra taken in the ESRF synchrotron (line ID22) λ = 0.3544 Å, we confirmed that rhombohedral structure. In addition, we observed an enhancement in the width of the diffraction peaks as the milling time increased, which is due to the joint effect of size reduction and strain, to a lesser extent.

The analysis of TEM images revealed that milling times of 50 h and 100 h lead to NiO NPs with mean diameters of 55 (19) nm and 45 (20) nm, respectively. Even though these results differ from those obtained by XRD [37 (2) nm and 29 (2) nm], they are within the same order of magnitude.

Hysteresis curves, measured with a vibrating sample magnetometer, confirmed the antiferromagnetic behavior of the samples. However, those obtained with milling times of 50 h and 100 h, also revealed the presence of a ferromagnetic contribution due to surface spin disorder [2]. Furthermore, from the measurements of the coercive field (at room temperature), we could determine that the NiO NPs exhibit a transition from the multidomain regime into the monodomain one within the hours of milling time.

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Nanosensors with Spin Waves

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We built an innovative sensor based on the interaction between nanostructures and gases using spin waves to detect the induced magnetic changes. The device is sensitive to low gas concentration of acetone, ammonia, carbon monoxide and benzene. When traces of these gases diluted in air pass through zinc ferrite nanoparticles, which are contained in a 2 mm diameter teflon tube, the magnetic properties of the nanostructures change. This change is detected by means of spin waves: due to the known dependence of their propagation on the external field [1], their frequency will shift as the nanoparticles' properties change. These excitations propagate along the surface of a 2 µm thick epitaxial film made of YIG (Yttrium Iron Garnet), a ferrimagnetic insulator with a quite narrow magnetic resonance line. The frequency of the spin waves is detected by means of an oscillator circuit connected to a frequency counter. Before manufacturing the device, the computer simulations and calculations described in [2] were replicated in order to optimize the design of the device.

The results show the possibility of developing new inexpensive, reusable, contactless magnetic sensors employing spin waves as mechanism of transduction. The device was exposed to the target gas for one minute, then purged with pure air for nine minutes. The sensitivity of the equipment is under 50 ppm of the reducing gases acetone, ammonia, carbon monoxide and benzene. Besides, the magnetic nanoparticles are reusable few minutes after each measurement, although the response decreases gradually (maybe longer purge times would prevent this phenomenon) until it gets stable when carbon monoxide or benzene are introduced. Considering that the low concentrations of the target gases, the outcome of this novel experiment is rather promising.

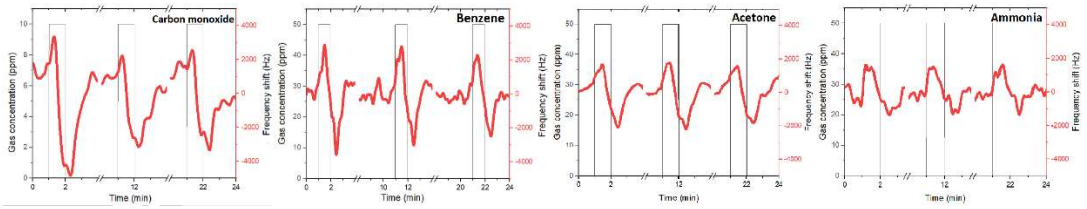

Fig 1: Response (Hz) of the sensor to the four target gases

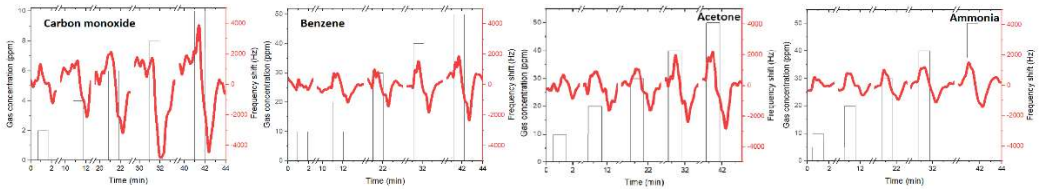

Fig 2: Response (Hz) of the sensor to different concentrations of the four target gases.

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Index Terms — gas sensor, sensing, nanoparticles, spin waves, magnons, YIG

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Magnetic Analysis: Fe-Co-Mn Alloy Produced by Spark Plasma Sintering

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Spark plasma sintering is a technique for the production of bulk specimens from powdered alloys. Processing conditions (as temperature and pressure) determines the final microstructure and, consequently, the mechanical and magnetic behavior [1]. In this work, we analyze the results obtained in a Fe-Co-Mn alloy.

From microstructural analysis carried out by means of X-ray diffraction, it is found that excessive temperature favors the formation of precipitates of a minority phase and that high temperatures favor the formation of intermetallic compounds and oxides. From the magnetic point of view, the higher magnetization was obtained at 1000ºC whereas the lower coercivity in the specimen heated at 750ºC. Thus, a compromise is needed to optimize the soft magnetic behaviour.

The results were compared with those obtained in powdered and sintered Fe-Co-Ni-B-Si and Fe high entropy alloys [2]. Spark plasma sintering process favours the increase of the magnetization, the decrease of the coercivity and the squareness ratio. Likewise, magnetic response of spark plasma sintered specimens was found to be very sensitive to the formation of undesired crystallographic phases during spark plasma sintering process. In conclusion, spark plasma sintering is an alternative (as a severe plastic deformation technique) for the development of magnetic alloys [3].

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Permeability Volume Distribution in Amorphous Magnetic Microwires: Experiment and Simulation

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The development of new digital technologies and robotic systems is one of the most important knowledge-intensive areas of modernization. Processes automation puts the problem of fast and accurate signal detection. Among the various types of sensors, a huge functionality is covered by the sensors based on magnetic materials. Giant Magnetoimpedance Effect (GMI) [1] allows the development of sensors with high sensitivity (~ pT/√Hz), low noise level (~ fT/√Hz), small size (>3 μm). Currently, GMI-based sensors using amorphous microwires are ones of the most sensitive magnetic sensors operating at room temperature [2].

Huge interest in amorphous magnetic microwires is caused by their magnetic and magnetoimpedance properties. In amorphous magnetic microwires strong magnetoelastic anisotropy and nontrivial volume distribution of magnetization are formed [3]. The response of amorphous microwires to a magnetic field largely depends on their micromagnetic structure, which determines the mechanisms of the magnetization reversal process. However, methods of its direct observation have strong size limitations [4] and cannot be applied to most of the samples. A complete description of the micromagnetic structure and the mechanisms of magnetization reversal processes in the microwires requires not only a comprehensive experimental study by indirect methods but also their numerical simulation, taking the obtained experimental data into account. Thus, modelling of magnetization reversal on a microlevel is necessary for the understanding of the main features and crucial details of such processes and further prediction of the properties of the amorphous materials.

In this work, the simulation of the microwires magnetization reversal by circular magnetic field was carried out to analyze the magnetization mechanisms and circular permeability distribution over the volume of the wire. Micromagnetic modelling was carried out using OOMMF package [5]. Magnetization evolution was obtained by solution of the Landau-Lifshitz-Gilbert equation. Magnetic field amplitude changes with radius as Bessel function (accounts skin-effect). Magnetization curves were obtained for equidistant points along the radius of the wire for the estimation of permeability. The results were compared with the experimental data. The details of the experiment are described in [6-7].

The analysis of the results of the experimental investigations of impedance showed nonuniform permeability distribution over the cross-section of the microwire. The comparison of the experimental and simulation results showed possible mechanisms of the distribution non-uniformity. The results obtained have shown that the magnetic permeability has features in the domain wall region. Non-uniform magnetization reversal process can cause the effective permeability (in reference to the external field created by current) oscillations.

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Incommensurate Magnetic Phases of the Multiferroic Compound $MnCr_2O_4$ Described with the Superspace Formalism

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Nowadays, chromium-based normal spinel oxides ACr2O4 are one of the most studied materials in the condensed matter community due to the interplay between its magnetic, electric and structural properties as well as to its potential application to different key industry sectors. In these compounds, several physical effects have been observed, which include magnetostriction, colossal magnetoresistance, multiferroic, spin frustration and more [1-4]. In particular, for MnCr2O4, the ground state magnetic structure is still controversial because the magnetic structures reported by different groups and investigated by independent techniques are inconsistent [1-7].

The magnetic structure of this compound was reinvestigated by magnetization, specific heat and neutron diffraction experiments at different temperatures. The results suggested that a new magnetic phase, not previously reported, is developed under 18 K when the sample is synthesized under a reductive atmosphere. The magnetic phases present in this sample were: long-range ferrimagnetic order below T_C = 45 K; incommensurate conical spin order with propagation vector $\vec{k}_{S1}$ = (0.62(1), 0.62(1), 0) below T_{S1} = 20 K; and incommensurate conical spin order with propagation vector $\vec{k}_{S2}$ = (0.660(3), 0.600(1), 0.200(1)) below T_{S2} = 18 K.

Using the superspace group formalism [8-10], the symmetry of the nuclear and magnetic structures is described. The presence of transverse conical magnetic structures in the lower-temperature phases implies the existence of multiferroicity. Using simple theoretical calculations, we derive the directions along which the electric polarization lies for each magnetic phase.

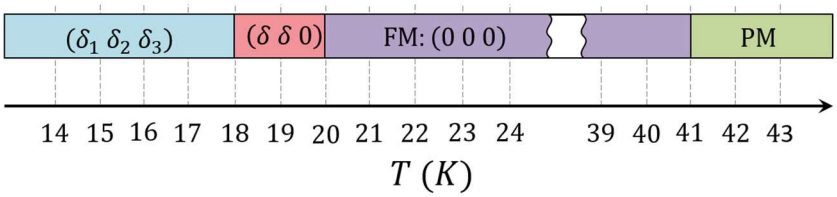

Fig. 1. Phases present in $MnCr_2O_4$ together with their phase transition temperatures. Green: paramagnetic order, purple: ferrimagnetic order, pink: conical order with $\vec{k}_{S1}$ = (0.62(1), 0.62(1), 0), blue: conical order with $\vec{k}_{S2}$ = (0.660(3), 0.600(1), 0.200(1)).

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Characterization of Ni-Nano Particles Inserted in Carbonaceous Materials with Controlled Porosity and Morphology

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Carbonaceous materials that include metallic nanoparticles (NPs) have attracted extensive interest during the last decades, especially those of metals like Ni and NiO in core/ shell morphologies. However, in order to improve NiO properties for those applications, a correlated analysis of its microstructure and magnetic properties, should be done.

In particular, Nickel oxide is widely studied due to its importance in technological applications (i.e., catalysis, batteries, ceramics, etc). To achieve this purpose, we have prepared five samples of 2-methylimidazole Nickel (NIOF) nanoparticles with carbonization temperatures between 400ºC and 600ºC; characterized their crystal structure and microstructure by X-Ray diffraction (XRD) and high-resolution transmission electron microscopy (HRTEM). Additionally, their magnetic properties were studied by SQUID magnetometer through ZFC-FC and M(H) curves.

The samples exhibit two crystallographic phases of Ni: face centered cubic-FCC and hexagonal compact phase-HCP. Additionally, at the lowest carbonization temperature Ni3C was also detected. XRD peaks become narrower and symmetrical as the carbonization temperature raises, suggesting that the Ni-NPs mean diameter increases. Inter planar distances were measured by analysing into detail HRTEM images. These studies corroborate XRD results and the existence of Ni3C phase on samples synthesized at the lowest carbonization temperature.

The analysis of M(H) curves recorded at room temperature, reveal that the saturation magnetization is low on samples that contain antiferromagnetic Ni3C or NiO phases. Besides, the saturation magnetization values (Ms) and mean blocking temperature values (TB) increases as the carbonization temperature rises because larger NPs are synthesized in those conditions.

From the magnetic analysis, we suggest that each NPs can be described as consisting of a metallic Ni core, surrounded by very thin shell of NiO.

Acknowledgements

Authors acknowledge scientific contribution of Julián Martin-Jimeno, Fabián Suarez-Garcia and J. Ignacio Paredes from Instituto Nacional del Carbon (INCAR); David Martínez-Blanco and Alaa Adawy from Scientific-Technical Services (SCTs); Jesús Angel Blanco from Dept. of physics; funding through research projects: FC-GRUPIN-IDI/2018/000185 and RTI2018-094683-B-C52.

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Influence of Design Parameters of Core@Shell Magnetic Nanoparticles in Magnetic Hyperthermia

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Fe_3O_4 magnetic nanoparticles (MNPs) are one of the most widely used MNPs due to their biocompatibility, their magnetic response and the availability of facile wet chemistry procedures that allow to produce size controlled particles with desired superparamagnetic behavior [1-3]. This makes Fe_3O_4 nanoparticles a selected candidate in numerous applications. Magnetic hyperthermia produced with Fe_3O_4 MNPs has been optimized in the last years, to produce an innovative technology (MAGFORCE) used for clinical applications in brain tumor treatments. It is based on the heat released by MNPs, when they are exposed to an alternating magnetic field, absorbing its magnetic energy, transforming it by relaxation processes (Néel and Brown) into thermal energy, thus acting as nanometric-scale heat sources. However, magnetic interactions (dipole interactions, exchange interactions, etc.), the composition and properties of the coating materials and the solvent viscosity can affect the magnetic hyperthermia performance of MNPs, that must be therefore optimized. For this reason, the aim of this work is the study of the magnetic properties of Fe_3O_4 - based MNPs (Fig. 1.a, TEM image of Fe_3O_4 MNPs) and the effect of their design parameters on magnetic hyperthermia performance.

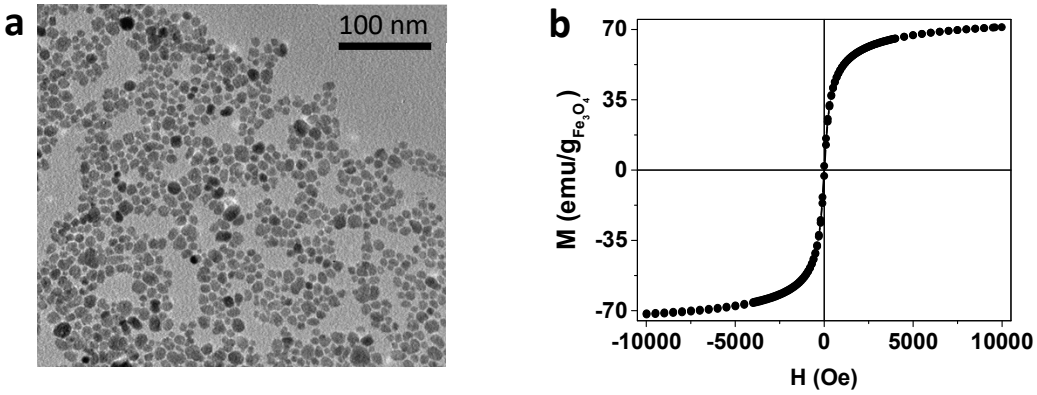

Figure 1. **(a)** Transmission electron microscopy (TEM) micrograph of Fe_3O_4 MNPs dispersed in water.

(b) Hysteresis loop of Fe_3O_4 MNPs.

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Low Temperature Magnetic Force Microsocopy Characterization of Adjustable 3D Ferrimagnetic Multilayers Based on NdCo+GdCo Trilayers

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Multilayered systems allow us to tune the desired magnetic behavior of the entire structure by precisely adjusting material properties, thicknesses, and magnetic interactions such as exchange and magnetostatics for the involved materials. This capability is extremely useful to build advanced spintronic devices or magnetic recording media. Ferrimagnetic materials such as Gd-Co alloys exhibit adjustable magnetization, offering the possibility of controlling features such as spin-wave modes, skyrmion nucleation or fast domain wall motion [1,2]. In addition, temperature dependence of all these properties increases the interest of this kind of systems.

A GdCo/NdCo/GdCo trilayered system has been designed to support an exchange spring at the top layer as ferrimagnetic GdCo alloys present a soft magnetic behavior with weak PMA [3] [Figure 1], so the middle NdCo layer with its high anisotropy (one order of magnitude larger than GdCo layer) can create a pattern of stripe domains with alternating up-down magnetization orientation, that can be used to control the configuration in the neighbouring GdCo layers via interfacial exchange and magnetostatic interactions.

Low temperature MFM under variable field shows the results of the anisotropy, exchange and magnetostatic interactions across the entire GdCo/NdCo/GdCo trilayer: Stripe pattern reconfiguration along the entire hysteresis loop (mainly induced by the NdCo mid-layer) and the collapse of the top PMA stripe pattern above B_z=800mT.

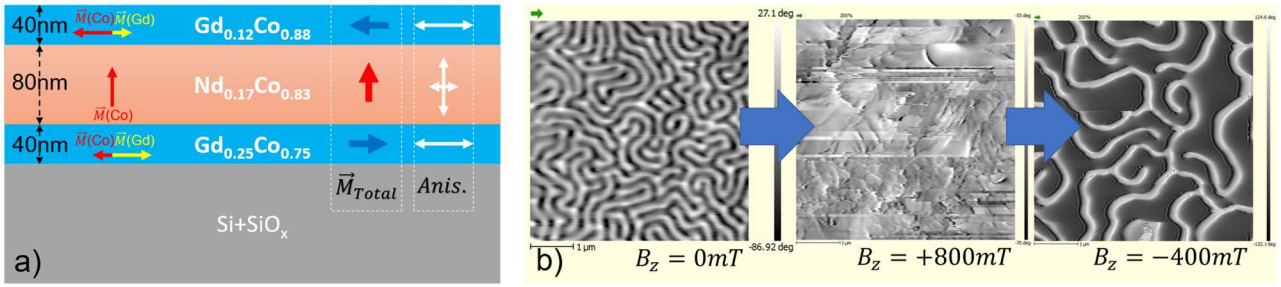

Figure 1. a) Exchange coupled GdCo/NdCo/GdCo trilayers b) MFM characterization at 4K and B_z=0, +0.8T and -0.4T

Acknowledgements

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Index Terms — magnetic force microscopy, ferrimagnetism, low temperature, perpendicular magnetic anisotropy, exchange springs

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Spin-Charge Interconversion in 111-Oriented Epitaxial Pt Thin Films

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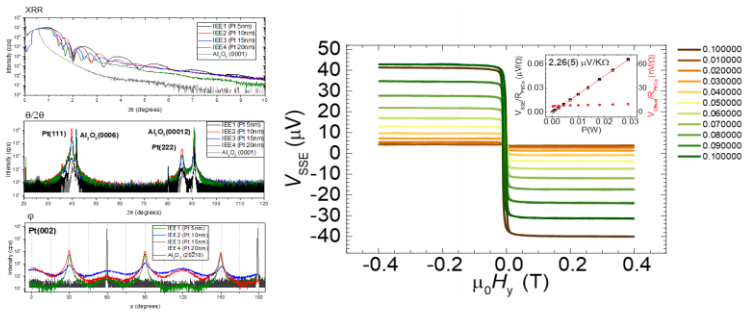
Current advances in spintronics mainly rely on spin-charge current interconversion. The enhancement of the efficiency of this process is one of the key points of study in the community since it will allow for the development of a new generation of efficient devices, from MRAM[1] to logic, neuromorphic computing[2] or energy harvesting[3]. Different approaches have been used to obtain optimal spin-charge interconversion such as increasing the spin Hall angle of a material with high spin-orbit coupling[4], using the Rashba-Edelstein effect[5], interfacial effects[6] or taking advantage of topological materials.

There is currently a disagreement in the literature regarding the role of epitaxial platinum in spin Hall phenomena. While some recent studies report an isotropic behaviour of the spin-Hall effect[7], others report a different value of the spin conversion with the crystalline direction in Pt systems[8]. In this work, we will discuss the spin conversion for different crystallographic directions in 111 oriented epitaxial Pt/Co bilayers with varying Pt thickness. We have grown by means of DC sputtering at high temperature a set of samples with the stack Al2O3(0001)//Pt(111)/Co/AlO_x with varying Pt thickness obtaining in all of them high crystalline quality as observed by X-ray diffraction. We also observe an in-plane periodicity of 60º, as expected for a hexagonal lattice. In order to characterize the spin conversion at different crystallographic directions, we use three different techniques: spin-torque and spin pumping ferromagnetic resonance as well as spin Seebeck effect measurements. In all the cases we find a tiny dependence of the relevant spin conversion parameters with the crystallographic direction.



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Index Terms — Spintronics, Thin films, Nanomagnetism, .Spin Hall, MRAMs

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Spin Current Generation From Incoherent Magnon Excitation in the Multifunctional Ferrimagnet $Ga_{0.6}Fe_{1.4}O_3$

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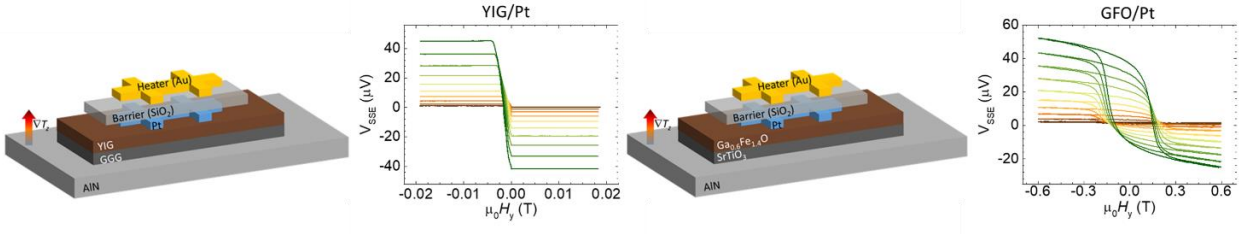
The search for multifunctional materials is currently a hot topic in spintronics. Currently, functional devices are typically made of a bilayer composed of a material with large spin-orbit coupling (NM) and a ferromagnet (FM). These types of devices allow functionalities like the manipulation of the FM magnetization by the spin Hall effect (SHE)[1] in the NM or energy harvesting employing its inverse counterpart the inverse spin Hall effect[2]. Insulating ferrimagnets are preferred for this purpose to pave the way towards low dissipation spintronics devices[3]. Additional functionalities like the possibility of the electric field control of the magnetic properties of such systems could be given to these heterostructures through the introduction of multifunctional ferromagnets opening the possibility of designing more efficient and versatile devices[4].

In this work, we have studied the thermo-spin current generation in bilayers composed of Pt and the multifunctional magnetoelectric $Ga_{0.6}Fe_{1.4}O_3$ (GFO)[5]. We compare the performance of the system with the widely used yttrium iron garnet (YIG) obtaining a similar value of the spin Seebeck effect (SSE), likewise to what was observed previously in spin Hall magnetoresistance[6]. In addition, by fabrication of thermo-spin devices with controlled dimensions, we can accurately quantify the relevant parameters of the thermal effects, obtaining more precise and comparable values for the spin Seebeck coefficient.

These results pave the way for the use of the magnetoelectric multiferroic GFO to control the spin current production of NM/FM heterostructures by an electric field.



Acknowledgements

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Index Terms — Spintronics and magnetic technologies, Thin films, Multiferroicity, Spin Caloritronics, Nanomagnetism

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From Magnetically Soft to Hard FeNi Nanowires: In the Search of the Cosmological $L1_0$-FeNi Phase

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Tetrataenite, chemically ordered $L1_0$-FeNi naturally formed only in some meteorites over millions of years in cosmos, is a promising candidate for the substitution of the strongest rare-earth permanent magnets existing nowadays, as it could reach a $(BH)_{max}$ of 40 MGOe [1-3]. The synthesis of experimental Fe-Ni model systems (e.g. thin films, nanostructures…) may provide invaluable information towards the artificial synthesis of the $L1_0$-FeNi phase in feasible timescales. Herein, we present the study of arrays of FeNi nanowires (NWs) grown by electrodeposition under variable conditions for tuning the Fe:Ni ratio and the magnetic properties.

The 40 nm-diameter NWs were synthesized by potentiostatic electrodeposition into anodized aluminum oxide (AAO) templates using different aqueous electrolytes and electrodeposition potentials (Fig. 1(a)). The geometry, composition, crystallographic structure and magnetic properties of the arrays of FeNi NWs were characterized by SEM, EDX, XRD and VSM, respectively. EDX chemical composition analysis of the samples showed anomalous co-deposition [4], where Fe deposits in ratios higher than its electrolyte molar fraction, varying with both the applied potential and the electrolyte composition. XRD measurements show a change from *bcc* crystallographic structure for high Fe content to *fcc* structure at mid and low Fe content (Fig. 1(b)). A careful control of the stoichiometry of the NWs makes possible achieving a range of magnetic hardness, reaching values of coercivity from 0.2 to 1 kOe by increasing the Ni content (the highest value achieved for electrodeposited NWs corresponding to the non-anomalous region of the $Fe_{23}Ni_{77}$ electrolyte) (Fig. 1(c)).

This study shows the possibility of tuning dramatically the magnetic properties of FeNi NWs by varying in a simple manner (choice of potential and electrolyte) the Fe:Ni ratio and crystallographic phases in the system. This possibility will be explored as a first step to enable the formation of the $L1_0$-FeNi ordered phase.

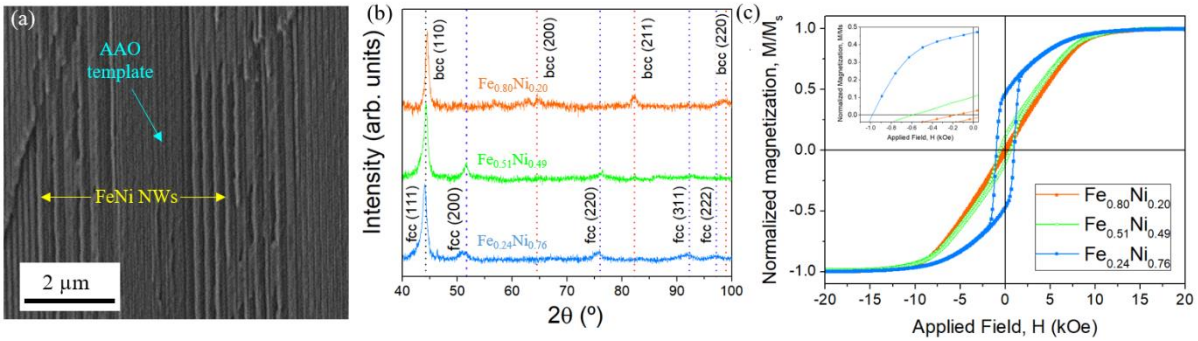

Fig. 1. (a) SEM image showing an array of FeNi NWs in AAO template; (b) and (c) XRD patterns and room temperature hysteresis loops for arrays of NWs with composition $Fe_{0.80}Ni_{0.20}$, $Fe_{0.51}Ni_{0.49}$ and $Fe_{0.24}Ni_{0.76}$.

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Index Terms — nanowire arrays, FeNi, tetrataenite, anomalous co-deposition, magnetization reversal

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Controlling the Self-Assembly of Multicore Iron Oxide Nanoparticles to Enhance Magnetic Properties for Biomedical and Environmental Applications

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Iron oxide magnetic nanoparticles with flower-like morphologies (nanoflowers) are promising materials for magnetically induced catalysis and hyperthermia therapy due to their outstanding heating efficiencies [1,2]. Even though, their structure and magnetic state have been previously studied, the formation mechanism of these multicore nanostructures is still poorly understood. In this work, we study the formation mechanism of iron oxide nanoparticles through the well-known polyol process in the presence of an amino co-solvent. These nanostructures are formed through a multistep process in which first, the polyol solvent together with the amine and iron chlorides (II and III) form a green-rust like complex that modulates the nucleation rate and growth of magnetite nanocrystals. By increasing the amount of amine, the stability of the green-rust increases inducing a crossover between a classical to a non-classical formation mechanism.

As it can be seen in Figure 1, the non-classical pathway with an amount of amine between 25 and 50 %, leads to the formation of multicore structures that will eventually sinter to form single core nanoparticles. The intermediate nanoflowers (NF-1), unlike the fully grown and formed nanoflowers (NF-2), displays some misalignment between the neighbouring cores in the structure. To understand the effect of this alignment and magnetic coupling between cores, their heating efficiencies were compared to the ones of single core nanoparticles (SC-1 and SC-2). Specific absorption rate (SAR) values were estimated considering an alternating magnetic field of 24 kA/m and 200 kHz frequency (Figure 1). In general, the nanoflowers' magnetic collective behaviour and the better alignments between cores enhance SAR values making this material a promising alternative for environmental and biomedical applications [3].

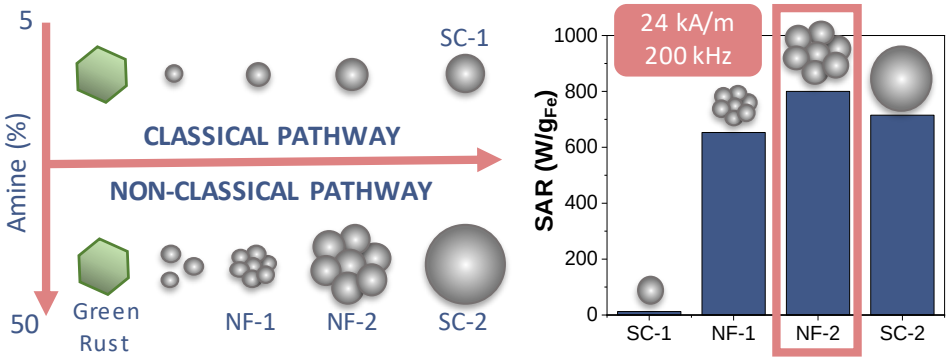

Figure 1. SAR values of single core (SC) and nanoflowers-like (NF) nanocrystals obtained by classical and non-classical pathways. The amount of amine controls the formation mechanism.

Acknowledgements

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Index Terms — iron oxide nanocrystals, magnetic nanoparticles, formation mechanism, magnetic hyperthermia

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Synthesis and Characterization of Magnetocaloric Ni-Co-Mn-Ti Heusler Alloys

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Energy efficient materials are amongst the priority topics in scientific research today. The data from U.S. Energy Information Administration (EIA) [1] signifies the fact that Spain which is the sixth-largest energy consumer in Europe consumes much of its electricity generated from non-renewable energy sources. Temperature control systems, with today's world facing drastic climate changes, account for an important and relevant source of coping with extreme weather conditions and imply significant energy consumption.

Magnetocaloric (MC) materials, which experience a large temperature variation when subjected to magnetic fields in adiabatic conditions [2], are increasingly getting scientific attention due to their application in solid-state magnetic refrigeration devices. These devices show larger energy efficiencies in comparison to the conventional gas compression-expansion system (~50% enhancement). Among the materials which show large magnetocaloric effect are the first-order-phase-transition (FOPT) Ni-Mn-X type Heusler alloys. The addition of an easily available transition metal like Ti at X-site not only shows a magneto-structural phase transition for the FOPT Heusler alloy system but also helps in stabilization of the austenitic phase. In this work, we synthesized a Heusler alloy with a nominal composition $Ni_{36}Co_{14}Mn_{35}Ti_{15}$ by arc melting. Due to evaporation losses of Mn during the melting process, an excess 6% Mn was added. A fraction of the prepared bulk sample was used for suction casting. Both the arc melted (Sample 1) and suction casted samples (Sample 2 and 3) were annealed at 1000°C for 4 days (96h). In the suction casting process, a high arc power was used for sample 2 whereas a lower arc power was used for sample 3. The results indicate that both the suction casted and arc melted samples exhibited an increase in magnetization upon heating which corresponded to the martensitic transition, followed by a decrease in magnetization due to the Curie transition of austenitic phase. With cooling, the martensitic transformation was shifted to lower temperature which account for the characteristic hysteretic behavior for this FOPT Heusler alloy. It was established that arc melted sample (sample 1) showed a higher magnetocaloric response in comparison to the suction cast samples (sample 2 and 3). Also, maintaining a low arc power during suction casting (sample 3) enhanced the magnetocaloric response of the Heusler alloy.

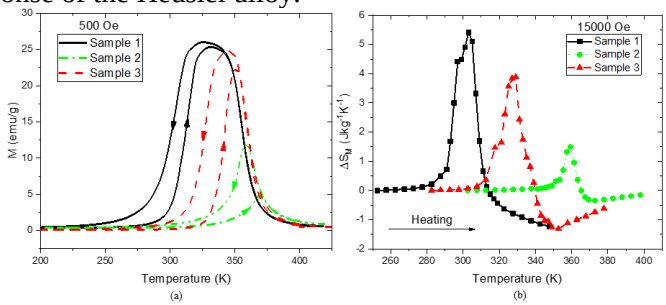

Figure 1(a): Temperature dependence of magnetization and (b) Isothermal entropy change (DSiso)

Acknowledgements

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Exploring the Ratchet Effect in Chemically Modulated Cylindrical Nanowires

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Cylindrical nanowires are promising nanostructures for the development of a new generation of 3D recording devices like race-track memories [1], systems designed to allow a higher data storage, a faster access to data and lower energy consumption compared to the 2D hard disks. Their application in devices rely on efficiently controlling the movement of magnetic domain walls (DW) for example by means of electric currents. In recent studies, we have demonstrated that local changes in composition along the axis of permalloy (Py) nanowires can pin the DW and this DW can be move in a reliable way under the application of magnetic field [2]. Following the same concept, in this work we propose a gradual change in Fe/Ni ratio along the NW's length to create a ratchet energy landscape for the asymmetric domain wall motion depending on the direction of the movement.

Nanowires were synthesized using template assisted electrodeposition. Composition was continuously changed along the nanowires between $Fe_{80}Ni_{20}$ and $Fe_{20}Ni_{80}$. The magnetic characterization of single nanowires was carried out using X-ray Photo Emission Electron Microscopy (XPEEM) at ALBA synchrotron. With this microscope we correlate the chemical structure of single nanowires with their magnetic configuration. In addition, by applying pulses of magnetic field along the nanowire axis we study the magnetic state depending on the direction of the applied magnetic field. First Ordered Reversal Curves (FORC) were also measured in arrays of nanowires. Figure 1 shows the FORC diagrams for nanowires with homogeneous composition of $Fe_{20}Ni_{80}$ (a) and for chemically modulated ones (b). While the diagram of Py NWs is highly symmetric with respect to the interaction field (Hu), in the case of modulated nanowires, an asymmetry arises evidencing the changes of the interaction fields within the array (highlighted by a dashed red square).

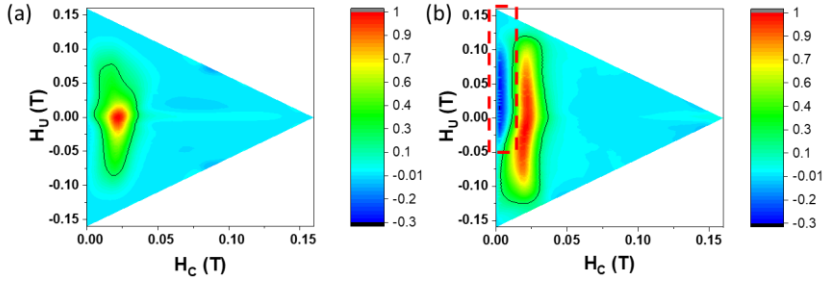

Figure 1. FORC diagrams. (a) Array of $Fe_{20}Ni_{80}$ nanowires and (b) array of chemically modulated Fe-Ni nanowires.

Acknowledgements

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Hydrothermal Synthesis of Iron Oxide Nanoparticles for Biomedical Applications

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Iron oxides are the most common magnetic nanoparticles for thermal therapy in biological systems via magnetic hyperthermia or photothermia. These nanoparticles are suitable for applications because of the high biocompatibility and colloidal stability that can be increased by coating the nanoparticles with inorganic molecules (dextran, APS, citric acid...) [1] [2] [3]. The magnetic properties of these nanoparticles depend on the iron oxidation states and on the particle sizes.

In this work, a one-step method is presented to synthesize either magnetite (Fe_3O_4) or hematite (α-Fe_2O_3) with a simultaneous control of both, the oxidation state and the nanoparticle size. The hydrothermal synthesis of Fe_3O_4 and α-Fe_2O_3 is performed under a moderate temperature and high pressure using a stainless-steel autoclave. It is possible to obtain any of the materials just changing the iron salt precursor and the time in the autoclave. The samples obtained have been characterized by XRD, HRTEM and SQUID magnetometry. The resulting colloids are stable with a pH nearly neutral (between 7 and 8). Results on fluid magnetic hyperthermia and photothermia in the second biological window are also shown.

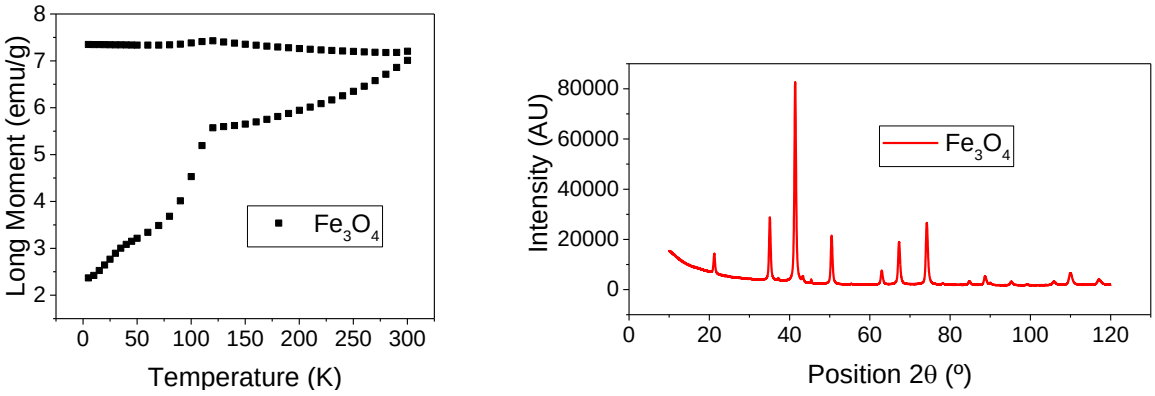

Figure 1. a) ZFC-FC curves of an iron oxide sample. b) Corresponding XRD pattern.

Acknowledgements

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Magnetic Hyperthermia of Magnetotactic Bacteria Doped with Terbium and Gadolinium

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Magnetotactic bacteria (MTB) are self-propelled aquatic microorganisms widely studied as microrobots because of their qualities [1-3]. MTB have the ability to biomineralize magnetosomes, magnetic nanoparticles which are covered by a lipid bilayer membrane, which allows them orientate and navigate using their flagellum along the geomagnetic field lines and to be guided by external magnetic fields [1]. The properties and characteristics of the MTB make them unique for several biomedical applications, such as magnetic hyperthermia, drug delivery or MRI imaging [4].

In this work, we have analyzed the MTB performance as magnetic hyperthermia agents for cancer treatments. MTBs display an optimal chain configuration, thanks to which the hysteresis losses are maximized. This leads to a outstanding heating efficiency, as has been reported in [4,5]. Furthermore, given that MTB can be doped with different elements to tune their magnetic properties [6,7], we have successfully cultured and doped MSR-1 with Tb^{3+} and Gd^{3+}, and studied their magnetic hyperthermia performance.

We have evaluated their heating efficiency performance by means of the well-known specific absorption rate (SAR). The SAR values were directly calculated using the area of the AC hysteresis loops. To do that, we use a homemade AC magnetometer where we measure the hysteresis loops of our three samples with an amplitude of alternating magnetic fields between 0 to 90 mT at a frequency of 133 kHz.

The evolution of the SAR values vs. the applied field (H) is depicted in Fig. 1. There, it can be seen that the SAR is almost neglegible below 20 mT in the three samples. Then, between 20 and 40 mT, the SAR increases rapidily until it achieves saturation. This tendency is in good agreement with the one reported in previous studies for undoped MTBs [4,5]. The saturated SAR values are of 9.2, 7.8 and 6.5 $Wg^{-1}kHz^{-1}$ for undoped, Tb and Gd doped bacteria. These values are high compared to the literature [8].

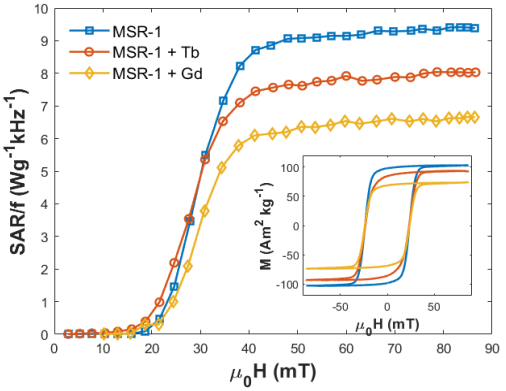

Fig 1: SAR normalized by the frequency of 133 kHz corresponding to MSR-1 undoped, and culture with two rare earths, terbium and gadolinium. **Inset**: hysteresis loops measured by AC magnetometer under a magnetic field amplitude of 90 mT.

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Index Terms — magnetotactic bacteria, magnetic hyperthermia, specific absorption rate (SAR), *Magnetospirillum gryphiswaldense*, rare earths.

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Growth Stabilization and Magnetic Response to Bending Strain in Epitaxial Ferrite Thin Films on Mica

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We present our study on the growth and characterization of functional iron oxide thin films on flexible mica substrates to investigate the influence of strain on magnetic properties. Despite their notably different crystallographic structure, we were able to stabilize spinel and metastable epsilon iron oxide, with exceptionally high quality. We prepared thin films of the complex ε-Fe_2O_3 (eFO) and a series of common spinel ferrites (XFe_2O_4 [X = Fe,Ni,Co]) as test system due to their distinct intrinsic magnetocrystalline anisotropy [1]. We will show the optimization of the growth parameters and buffer layer systems that enabled us to prepare these films. In addition, we show a precise microstructural analysis, via X-ray diffraction combining standard omega-2theta and reflectivity measurements, as well as pole figure for the identification of the specific crystal structure and epitaxial relationships. We determined that the spinel phase grows with (LLL) texture and twinning in magnetite and $CoFe_2O_4$ is strongly reduced as only one domain could be identified. On the other hand, eFO shows the formation of 3 distinct in-plane domains, with out-of-plane (00L) texture.

With these magnetic films epitaxially grown on mica one can follow a simple approach, by bending the substrate, to probe the effect of lattice deformation on the magnetic anisotropy of the films. Here, we investigate the effect of tensile and compressive bending strain on the magnetic properties at room temperature and below. Furthermore, we investigate the low temperature transitions of magnetite and epsilon iron oxide with measurements of M(T) and M(H) at different temperatures. Interestingly, magnetite Fe_3O_4 thin films show a clear dependence on different bending strains displaying changes in the coercive field (see figure 1a), remnant/saturation magnetization and Verwey transition. In contrast the $NiFe_2O_4$, $CoFe_2O_4$ and ε-Fe_2O_3 thin film only show weak variations of the magnetic properties (see figure 1b) with strain although reported otherwise in literature [2,3]. We discuss these reported results with respect to our samples.

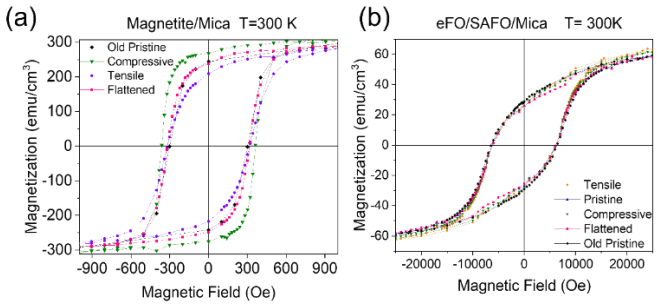

Figure 1: Magnetization response for different bending states of the magnetite (a) and epsilon iron oxide (b) thin films at room temperature.

Acknowledgements:

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3D Skyrmionic Configurations in Soft Magnetic Nanodots With no Dzyaloshinskii-Moriya Interactions

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Magnetic skyrmions are widely attracting researchers due to fascinating physics and novel applications related to their non-trivial topology.1 Néel skyrmions have been extensively investigated in magnetic systems with Dzyaloshinkii-Moriya interaction (DMI) and Perpendicular Magnetic Anisotropy (PMA). However, so far, at least PMA is considered to be a necessary ingredient for skyrmion stabilization. In this work, we have used micromagnetic simulations to show that 3D quasi-skyrmions, spin textures with topological charge close to 1, can be stabilised in soft (permalloy) magnetic nanodots (planar disks and hemispheres) with no DMI.2 We have found that the range of geometrical parameters were the skyrmions are stabilized is wider in magnetic hemispheres than in planar circular nanodots. We argue that the key factors responsible for the stabilization of DMI-free skyrmions are the magnetisation confinement and surface curvature. Besides, the curvature introduces chirality to the system, as the core magnetization direction and the radial magnetization component are coupled.3 We have calculated the state diagram for quasi-skyrmions as well as the 2D topological charges and gyrovector values, as a function of the geometrical parameters. Our results open the door for a new research line related to the nucleation and stabilization of magnetic skyrmions in a broad class of nanostructured soft magnetic materials.

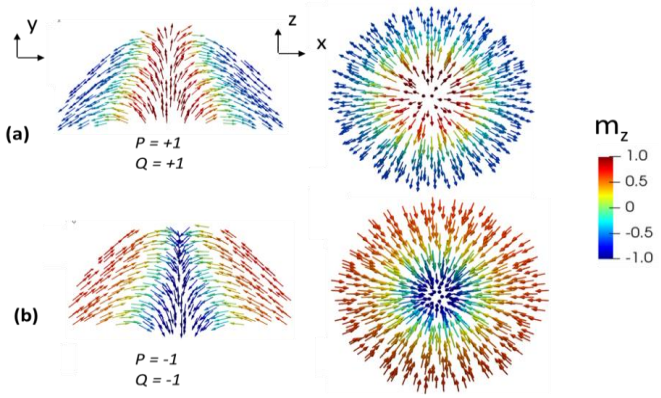

Figure 1. (a-b) Chiral quasi-skyrmion magnetization configurations in permalloy caps. P and Q stand for the polarity and the chirality of the skyrmion respectively.

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Study of Dipolar Collective Properties in Binary Random Assemblies of Magnetic Oxide Nanoparticles

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Binary random assemblies (BRAs) of bare oxide nanoparticles (NPs) are the basis of an ever-increasing catalogue of applications. Collective behavior in magnetic nanoparticles assemblies can be useful for some applications like hyperthermia [1], or detrimental for others like magnetoresistance sensing [2]. Therefore, understanding the behavior and properties of these systems is crucial for upcoming applications.

The studied BRAs have been prepared mixing in different proportions low/high magnetic anisotropy particles: pure maghemite (low-anisotropy) and Co-doped maghemite (high-anisotropy) NPs with the same size (6.8 nm in diameter) and large difference in anisotropy energy. The results show that dipolar interactions are strong enough to fully couple the two types of NPs at low fields, yielding a single collective temperature. Surprisingly, this temperature increases with the average local anisotropy (increasing proportion/concentration of Co-doped particles) across the series despite the decreasing dipolar interactions. Moreover, a strong memory effect in the zero-field-cooled magnetization – a fingerprint of collective (*superspin glass*) relaxation of the magnetization – is observed for the assemblies of pure maghemite NPs and Co-doped maghemite NPs (end members of the series) but is barely detectable in the mixed BRAs. In contrast, the hysteresis loops measured at low temperature (5 K) display a two-phase character, indicating weak coupling which affects the coercive and exchange bias fields of the mixtures.

This study brings to light the important role of the anisotropy contrast of the mixed particles which gives rise to a complex scenario, as well as how different properties will appear collective of individual-like depending on extrinsic conditions (field and temperature) [3].

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Index Terms — magnetic nanoparticles assemblies, collective behavior, superspin glasses

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Antenna Resonance of a Magnetic Microwire Applied to Anti-Theft Technology

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The investigated technology is based on the patent "Label, system and method for detecting objects at large distances" [1]. This technology combines the antenna behaviour exhibited by a magnetic microwire under the incidence of an electromagnetic wave[2], with the giant magnetoimpedance effect characteristic of nearly zero magnetostrictive microwires[3].

When an electromagnetic wave of wavelength $\lambda=2L/(2n+1)$, with n=0,1,2,…, impinges on a conductor wire of length L a maximum electrical current is induced in the wire (antenna resonance), which re-radiates the electromagnetic wave. Using a pair of antennas, the transmission coefficient, S_{21}, of the incident wave through the microwire can be measured by means of a vector network analyser (VNA) both on frequency and time domains. The application of a biasing AC magnetic field modifies continuously the wire impedance due to the magnetoimpedance effect. This originates a modulation of S_{21}, ΔS_{21}, with the specific frequency of the bias field, permitting to detect the labelled object.

Transference of this technology from the lab to a commercial prototype leads us to several challenges, including the blocking effect of the EM waves produced by the human body as well as the labelled objects, the necessity to be able to detect the microwire independently on its orientation and the detuning of the wire when is attached to different objects.

Regarding the blocking effect, joule annealing of the samples has revealed a better performance of the wire. On the other hand, different characteristics of the transmitting and receiving antennas as well as the geometry of the magnetic label have been also studied in order to improve the detection of the labelled object independently on its orientation. The results suggest that the best performance of the detector would correspond to the combined use of circularly polarised antennas with a label composed of two perpendicular microwires. However, a redesigning of the magnetic field is required in order to be able to detect a single wire independently on its orientation.

Acknowledgements

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Index Terms — anti-theft technology, magnetic microwire, giant magnetoimpedance, magnetic label

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Electric Current Effects in Sensors Based on Anisotropic Magnetoresistance

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Magnetic sensors based on the anisotropic magnetoresistance effect (AMR) are of great interest nowadays due to their numerous applications. One possible application is the detection of magnetic nanoparticles [1], since these sensors present a high sensitivity to slight magnetic field variations. However, one of the challenges posed by magnetoresistance-based sensors is the difficulty to obtain accurate numerical results when predicting their magnetic response.

As a consequence, in order to obtain the most realistic results possible, it is necessary to resort to multiscale simulations [2] in order to fully describe the effect of the magnetization of the material on the current that flows through it. The method that we propose uses the following methodology: i) Calculation, by micromagnetic simulations, of the magnetization configuration in the sensor for different values of an external magnetic field, which allows us to obtain information of the magnetization at any point in space, and ii) Solving a classical electrodynamic problem of current transport based on the magnetic state obtained in the previous point, in order to calculate the electrical resistance of the material. The results from each study (micromagnetic and current transport) condition the other one, which constitutes a coupled, multiscale problem that is solved in an auto-consistent way.

In this study, we have observed how the electric current passing through an AMR sensor is not uniform due to the resistivity dependence of the magnetization state, a phenomenon not usually considered in classical approaches. As a result, the field generated by the electric current flowing through the sensor can generate asymmetries in the magnetoresistance (ΔR vs H) curve. This translates into operating regions with increased sensitivity, as Figure 1 shows. The described effect is heavily influenced by the sensor geometry, especially near the contacts, where the highest current accumulation takes place. Operating at an optimum bias field, we increase sensor sensitivity by about 30% in a test sample consisting of a 10 nm thick Permalloy thin film with an elliptical shape (320 × 160 nm).

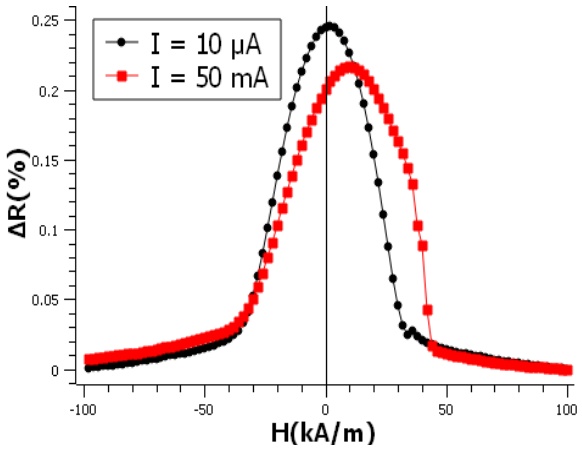

Figure 1. AMR curve without (black) and with (red) current effects being taken into account. A symmetry break has been generated in the positive field region of the red curve, which results in a steeper slope (higher sensor sensitivity).

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Index Terms —Anisotropic Magnetoresistance Sensors, Multiscale Simulations, Oersted Field

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High Anomalous Nernst Effect on Magnetic Multilayers With Perpendicular Magnetic Anisotropy

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Anomalous Nernst Effect (ANE) has attracted interest during the last years due to its potential for energy harvesting. Nernst effect is a thermomagnetic phenomenon originated by the motion of charge carriers when a magnetic field is applied perpendicular to a thermal gradient. The magnetic field bends the path of the charge carriers travelling across the thermal gradient due to Seebeck effect, which cause an electric field in the perpendicular direction. Therefore, to optimize the ANE is convenient to have a preferential magnetization direction perpendicular to the thermal gradient. This is the case of the devices shown in this work, where magnetic multilayers with high Perpendicular Magnetic Anisotropy (PMA) are exposed to in-plane thermal gradient. We have evaluated the ANE effect of Co/Pt sputtered multilayers, which show high PMA [1]. Microscale devices have been used to study the dependence of the Nernst effect with the magnetization. Moreover, Magnetic Force Microscope (MFM) images of the PMA stripe have been obtained during the Nernst voltage measurements while applying the thermal gradient. Comparing different multilayer configurations, we found a maximum ANE coefficient of ~0.9μV/K for [Co0.6/Pt1.8]10. This value is in the same order of magnitude of the maximum ever observed in other materials [2,3], but with the advantage of having a material with remanent perpendicular magnetization.

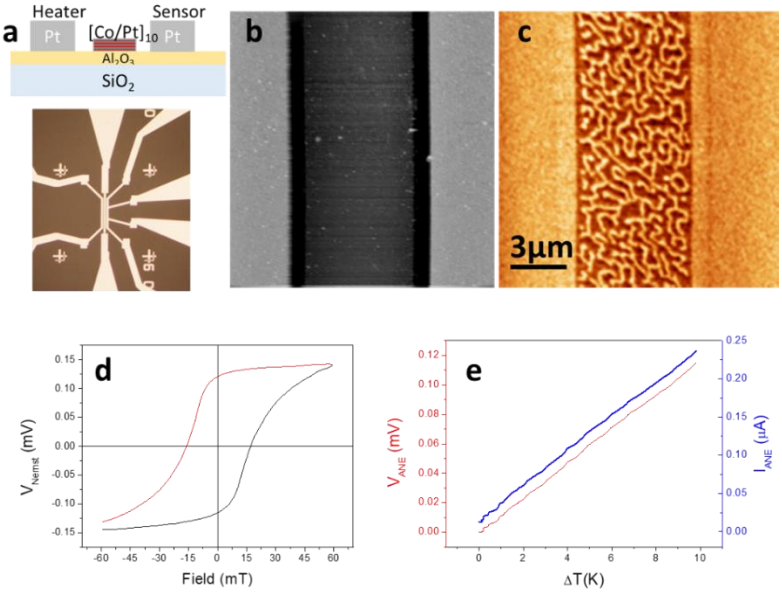

Figure 1: a) Scheme and optical microscope image of the device. b) AFM topography and c) magnetic signal measured by MFM of the device. d) Hysteresis loop of the Nernst voltage as a function of the magnetic field. e) Voltage and current obtained from the device as a function of the thermal gradient.

Acknowledgements

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Enhancing the Magnetocaloric Response of High-Entropy Metallic-Glass by Microstructural Control

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As a new alloy design concept, high-entropy alloys (HEAs) have attracted more and more attention. For overcoming properties limitations, HEAs have evolved from first generation, with quinary equiatomic single-phase, to second-generation with multi-phase and non-equiatomic compositions. From the magnetocaloric (MCE) point of view, rare-earth (RE) containing high-entropy metallic-glasses (HE-MG) are of current interest [1]. However, the equiatomic HE-MG has a limitation of temperature (which typically concentrate around < 60 K). It is reported that the second-generation magnetocaloric HEA can effectively overcome the limitations of MCE in HEA. For example, non-equiatomic FeMnNiGeSi HEA exhibits significantly larger MCE properties with respect to other RE free HEAs, originating from a first-order magnetostrctural phase transition [2,3]. The low temperature limitation of HE-MG has been overcome by non-equiatomic $(Gd_{36}Tb_{20}Co_{20}Al_{24})_{97}Fe_3$ HE-MG microwires, which show the Curie temperatures up to 108 K. In addition, $(Gd_{36}Tb_{20}Co_{20}Al_{24})_{97}Fe_3$ microwires exhibit the presence of minor content nanocrystals, which broaden the Curie temperature distribution [4]. In this work, microstructural control conducted by current annealing is used to further enhance magnetocaloric responses of $(Gd_{36}Tb_{20}Co_{20}Al_{24})_{97}Fe_3$ microwires. The fraction of nanocrystals increases with increasing current density. Within a certain current range, the annealed microwires exhibit similar magnetic entropy changes and increased cooling efficiency when compared to the as-cast microwires. The enhanced MCE properties are attributed to the broadened working temperature span due to the composition difference between phases. For an analysis of the transition, the multi-phase character leads to challenges in rescaling the magnetocaloric curves, which are overcome by using two reference temperatures. Among the amorphous RE containing HEAs, our work increases the working temperature beyond the typical <60 K limit while maintaining comparably large MCE properties. This demonstrates that microstructural control is a feasible way, in addition to appropriate compositional tuning, to enhance the magnetocaloric effect of HEAs [5].

Acknowledgements

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Analysis of the Effects of Chemical Composition and Manufacturing Conditions of Soft Nanocrystalline Magnetic Alloys and Composites

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In recent years, the study of soft nanocrystalline alloys has been on the rise. The main reason for these interests lays with the wide range of applicability of these alloys due to their specific properties. Said properties include shape magnetic memory effect, magnetocaloric effect and high magnetoresistance [1]. However, magnetic alloys do not always share all the previously listed properties. General applications of these alloys include their implementation in actuators, sensors and transformer cores [2,3]. The main applicability of the said alloys depends mainly on the formation of nanocrystalline structures within the alloy. Due to this dependency, chemical compositions and manufacturing conditions must be optimized to ensure the presence of nanocrystalline structures within the soft magnetic alloy.

The present study analysed a total of nine different alloys that can be classified as either Fe-based or Ni-Mn-based alloys. Fe-based alloys are manufactured by mechanical alloying while Ni-Mn-based alloys are manufactured by melt spinning or the Taylor-Ulitovsky method. Also, composites are produced from an epoxy resin or glass coating as the matrix and the soft nanocrystalline alloys as the reinforcement (developed from metallic powders, ribbons or microwires). The analyses performed on the samples include a microstructural analysis by X-Ray Diffraction (XRD), a thermomechanical analysis by Differential Scanning Calorimetry (DSC) and Dynamic Thermomechanical Analysis (DTMA) and functional analysis in the form of the thermomagnetic response by Vibrating Sample Magnetometry (VSM) of the samples.

The results clearly show the dependence of both chemical composition and manufacturing conditions on the properties of the analysed alloys. The thermal stability of the alloy and the corresponding crystal growth peak temperature have been observed to be affected by chemical composition and manufacturing conditions. Structural analysis confirmed the presence of nanocrystalline structures while the magnetic analysis confirmed soft magnetic behaviour. Finally, thermomechanical analysis of the composites detected a variation of mechanical properties associated to an energy dissipation process at the matrix-reinforcement interphase [2,4].

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Understanding the Initial Growth Stages in NdFeB Films: Epitaxial Films Prepared by Molecular Beam Epitaxy with Varying Underlayer

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Rare-earth transition metals thin films have attracted a lot of attention due to their high magnetic anisotropy that makes them excellent candidates for several applications including high density magnetic recording [1-2], microelectromechanical systems and actuators [3] and novel spintronic devices [4]. Our study focuses on the understanding of the mechanisms involved in the formation of the $Nd_2Fe_{14}B$ phase in thin films and the influence of the buffer layer material on the structural and magnetic properties in an extremely low thickness range of 5-10 nm. This range will be likely below that required to fully develop the hard magnetic properties in NdFeB films, but it is extremely important to understand and optimize the initial growth stages in NdFeB when aiming at its integration in novel miniaturized devices (e.g. microdevices for *in vivo* microsurgery applications, as aimed in the framework of this project [5]).

NdFeB films (5-10 nm) have been grown by co-deposition of each element by Molecular Beam Epitaxy (MBE). Different buffer layers (Vanadium, Iron and Iridium) on MgO (001) have been explored in order to induce different lattice strains on the NdFeB lattice and influence the magnetic response of the system. Epitaxiallity of the samples has been corroborated by X-Ray Diffraction (XRD) and *in situ* Low Energy Electron Diffraction (LEED) measurements (Fig. 1a,b,c,e). Magnetic characterization (Fig. 1d) has been carried out by Vibrating Sample Magnetometer (VSM) demonstrating the possibility of inducing a strong magnetic anisotropy in good accordance with the epitaxiallity of the films. A thorough stoichiometric and electronic characterization has been carried out by both X-ray and Ultra-Violet Photoelectron Spectroscopy (XRD and UPS, respectively) also reporting values of the work function of the system (Fig. 1e)).

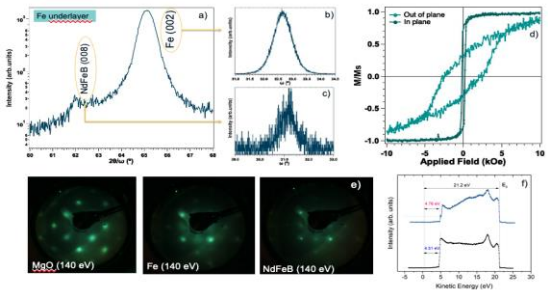

Figure 1: a) XRD pattern of a NdFeB thin film with an Fe underlayer, b) rocking curve measurement of Fe (002), c) rocking curve of NdFeB (008), d) room temperature hysteresis loop, e) LEED pattern of MgO substrate, Fe buffer layer and NdFeB film, f) work function measurements of Fe buffer (bottom) and NdFeB film (top).

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Index terms – NdFeB, thin films, molecular beam epitaxy

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Synthesis and Characterization of Fe3O4@MgO@CoFe2O4 Core/Shell/Shell Magnetic Nanoparticles

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The Core/shell (CS) architecture make possible to combine in the same nanoparticle (NP) different materials, increasing the degrees of freedom to design and manufacture new systems. By reducing the size to the nanoscale, its magnetic and structural order is modified with respect to the bulk material [1]. Surface and interface effects dominate the physicochemical properties of NPs since the proportion of surface ions increases with respect to the total number. In addition, new properties are observed in CS bimagnetic materials due the exchange interaction at the interface [2], as exchange-bias (HEB) [3] or exchange-spring [4], which are evidenced in the displacement of hysteresis cycles, an increase in the coercive field and the thermal stability of the magnetic moment, among others.

Recent studies in CS NPs shown that, by systematically varying the shell composition, is possible to fine-tune the magnetic and electrical transport proprieties of these systems [5-6]. In this frame, the design and fabrication of more complex and higher quality NPs is a key factor to develop new multifunctional nanoparticles for advanced applications [1].

In this work we present that high quality core / shell / shell (CSS) NPs can be grown by adapting the seed-mediated growth method proposed by Sun et al [7].

Fe3O4@MgO@CoFe2O4 CSS monodispersed NPs were synthesized by thermal decomposition of organometallic precursors in the presence of surfactants in a three-step process. Their structure and morphology were characterized by different techniques of transmission electron microscopy (TEM) and powder X ray diffraction. By analyzing TEM images, we obtain a monodisperse size distribution whit mean size of (29±6) nm. CSS structure can be confirmed by observing high angular annular dark field scanning transmission electron microscopy (HAADF STEM) images, that shown a dark annular contrast due to the presence of MgO in the inner shell, and from the elemental mapping performed by electron energy lost spectroscopy (EELS) the stoichiometry is corroborated. The magnetic properties were studied from magnetization measurements as a function of the applied field (MvsH), using field cooling(FC) and zero field cooling(ZFC) protocols, and temperature (MvsT), in a range of ±2.5T and 5K-380K. In the FC MvsH curves the presence of an HEB field was observed below 125K. The results are analyzed in term of the magnetic coupling between the soft Fe3O4 and hard CoFe2O4 magnetic phases, and the role of the nonmagnetic MgO separator is discussed

Acknowledgements

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Oersted-Field and Current-Induced Dynamics of Bloch Point in Cylindrical Ni Nanowires

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As three-dimensional nanomagnetism evolves, novel non-trivial magnetic textures emerge as appealing information carriers for recording and spintronics based on curved nanosystems and particularly Cylindrical Nanowires (NWs) [1,2]. One of the most fascinating candidates that is likely to reach the high velocities required for fast recording technologies is the Bloch Point (BP) domain wall (DW). Recently, theoretical evidence indicated that BPs in NWs could reach high velocities close to 2 km/s in the magnonic regime [2]. While the observation of the BP DW in cylindrical NWs is no longer recent [2], scarce numerical studies that combine both current and Oersted field have been published in NWs [4], despite first attempts to measure DW velocities are in progress [5].

In this work we evaluate the dynamics of the BP DW under both current directions in a Ni NW with 100 nm in diameter. We investigate two cases: i) pre-nucleated BP Wall, and ii) the BP DW originated from the transformation of a Vortex-Antivortex DW. The effects of both spin-polarized current and Oersted field are considered. We discuss in detail the role of the chirality of the BP in relation to the Oersted field, also reported previously in precursors of BPs [4]. We show that while the pre-nucleated DW with the same chirality as that of the Oersted field propagates always against the current direction, the BP originated either from the transformation of the BP with the opposite chirality or from the vortex-antivortex DW can either stop the propagation or propagate parallel to the current. We attribute this effect to the role played by the inertia of the BP in its dynamics. Finally, we provide values of the velocities achieved by the BP in the NW as a function of applied current in Figure 1.

We conclude that BPs with vanishing momentum propagate opposite to the current with velocities that may be suppressed by the Oersted field. Importantly for spintronic applications, both momentum and inertial mass play a major role in the dynamics of BPs that has not been envisaged up to know.

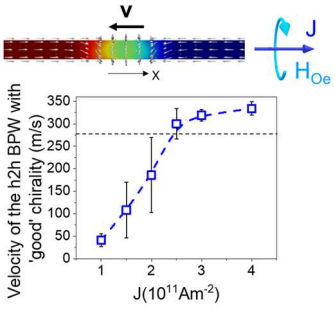

Figure 1. The average velocity of a head-to-head BPW driven by a spin-polarized current in a Ni nanowire far from the ends of the nanowire as a function of the current density.

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Differential Refractometry for Detection of Magnetic Nanoparticles

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Magnetic lateral flow immunoassay (MLFIA) is a technique for bio-analysis [1] that significantly reduces the cost and measurement time compared to other traditional methods. This type of immunoassay uses magnetic nanoparticles (MNP) as identifier to detect biomolecules of interest [2]. The uses of the MLFIA are in constant expansion and a wide range of tests have been develop [3]. This technique is used in medical diagnosis, food analysis and environmental monitoring. The usage of MLFIA could be deployed in developing countries providing diagnosis tools not currently available.

At the moment, the measurement of the MLFIA requires expensive and specialized equipment that limits the implementation of this technology. In preliminary studies a low-cost electronics systems based on source coupled oscillators (SCO) that operates at the self-resonant frequency (SRF) of the sensing inductor [4] have been defined and tested. These prototypes have shown a great sensitivity at a low cost, however, the measurement setup inherited from previous studies inject noise in the signal that reduces the final sensitivity.

To improve the measurement resolution a new measurement paradigm is proposed. The inductive detectors used are susceptible to a wide range of noise sources including temperature variations, mechanical deformations, humidity, etc. To reduce the noise present in the measurements we propose the usage of an array of sensing inductors as shown in figure 1 a). Subtracting the decoupled SRF of two sensing inductors, one measuring the sample and other used as reference, we obtain a signal that is correlated to the mass of MNP and discards a wide range of noise sources. Using this differential refractometry setup the stability of the signal is improved in terms of standard deviation as shown in the histogram in figure 1 b).

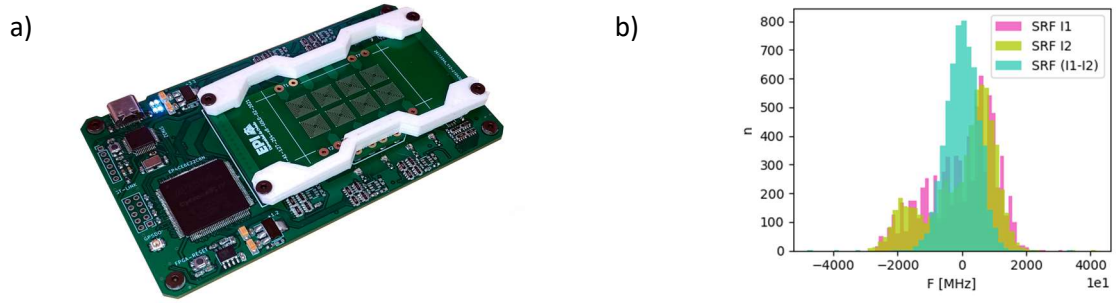

Fig. 1. a) Differential refracometer tested. b) Histogram of the measured SFR and differential setup.

This system architecture is more suitable for the projected uses. It reduces the influence of ambient noise that is a problematic aspect of a portable device, with a minimal increase in cost.

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Magnetization Reversal in Rhombohedral Ni Ranotubes

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One-dimensional (1D) structures such as nanowires or nanotubes are nowadays a vast field of research. Several studies based on ferromagnetic nanowires and nanotubes, among other magnetic nanomaterials, have been carried out during last years to understand the main mechanisms that govern their magnetisation reversal process according to the geometry, material composition and size, geometry or spatial arrangement of these nanostructures [1, 2]. In this study, the magnetisation reversal mechanism for nickel nanotubes having a rhombic geometry has been investigated from both, theoretical and experimental points of view [3-6]. The micromagnetic simulations were performed by means of the mumax3 programme employing typical values for the magnetic parameters of the polycrystalline Ni [7], where the size of rhombic nanotubes is around 5000 nm in length, having 590 nm of major diagonal and 360 nm along the minor diagonal, while the wall thickness ranges from 10 nm up to 150 nm. The peculiar geometry exhibited by these rhombohedral Ni nanotubes induces clear differences in the magnetization reversal processes due to their different shape when compared respect to the more usual cylindrical ones. This peculiar geometry further limits the magnetic domain reversal due to sharp edge angles at the nanotube corners, which can lead to the appearance of magnetic singularities near the nanotube vertex that induce the nucleation of vortex domain walls. The nucleation and domain wall propagation appearing at the vertex of rhombic Ni nanotubes seem to be vortex-shaped, while vortex-antivortex structure is also occurring through the emergence of a C-state or an S-state. Therefore, the reversal mechanism is limited by the geometry of the nanotube and is anchored until the external applied field is strong enough to reverse the magnetization via a less favourable pathway. The main mechanisms that govern the magnetization reversal in these rhombic Ni nanotubes are discussed in the framework of the micromagnetic simulations and compared with experimental measurements, achieving a good agreement between the obtained results. The future of such peculiar nanotube geometries with varying their composition and size properties could lead to interesting novel magnetic phenomena related to their magnetic domain walls movement and magnetic pinning, in the fields of electronics or computing, as well as in biomedicine or catalysis.

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Magnetic Relaxation in Ɛ-Fe_2O_3 Nanoparticles

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Ɛ-Fe_2O_3 has a strong uniaxial magnetic anisotropy[1], a sizeable magnetization well above the room temperature[2] and magnetic resonances in the millimeter wave range[3]. On these grounds, it is an appealing material for IT applications as a recording medium and functional material for non-reciprocal devices. For these applications, the retention of the magnetic state is essential. Since this iron oxide polymorph is typically stabilized in the form of nanoparticles or thin epitaxial films, the relaxation of magnetization needs to be assessed. We have prepared Ɛ-Fe_2O_3 nanoparticles of different sizes (to nm) using different soft chemistry techniques to characterize its relaxation properties. Here we present time dependent magnetic measurements to study the influence of particle size in the magnetic relaxation of this system.

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Coupled Micromagnetic Simulations with NEGF-based Coherent Transport in Magnetic Tunnel Junctions

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Spin-transfer torque driven magnetization dynamics in magnetic tunnel junctions [1,2] allow for modern spintronic devices like the non-volatile and thus energy-efficient magnetoresistive random-access memory (MRAM) [3]. While coupling the Landau-Lifshitz-Gilbert (LLG) equation with the spin-drift-diffusion model allows for micromagnetic simulation of the magnetization dynamics in most GMR-based devices [4], the situation is more complicated in structures that exhibit coherent transport properties like magnetic tunnel junctions. This is due to the comparably high computational cost of solving the Schrödinger equation on the device region.

In our work, we present an efficient solution strategy for the LLG with spin-transfer torque in magnetic tunnel junctions that takes advantage of the constant nature of the fieldlike and dampinglike torque coefficients for fixed voltages with respect to the angle between the two magnetization directions. We then compare the results to the well-known torque model of Slonczewski [5].

In accordance with previous experimental [6] and theoretical work [7], we find the dampinglike torque component to have a quadratic voltage dependence. Our coupled simulations depicted in Fig. 1 show that this behaviour results in a non-monotone critical switching time for the antiparallel to parallel magnetization reversal direction i.e. for positive bias voltage.

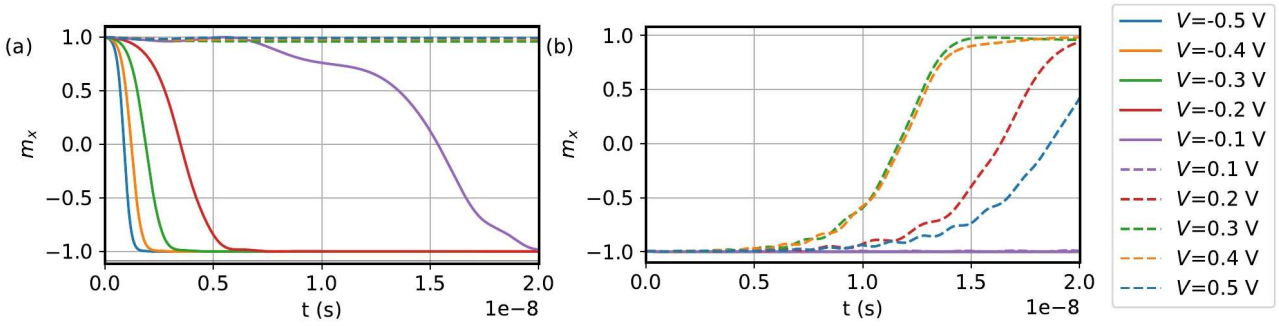

Fig. 1: Magnetization dynamics in an asymmetric magnetic tunnel junction. Subfigure (a) shows the parallel to antiparallel magnetization reversal for negative voltages, (b) shows the antiparallel to parallel switching direction for positive voltages.

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