4th Young Researchers in Magnetism

19th November 2020

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

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4th Young Researchers in Magnetism

The annual meeting of the Spanish Magnetism Club and the Spanish Chapter of the IEEE Magnetics Society will be held ONLINE.
The 4th Young Researchers in Magnetism, the traditional special session devoted to young researchers will take place during this meeting, the 19th November. This year, it is being organized for and by the young researchers.

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4th Young Researchers in Magnetism

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4th Young Researchers in Magnetism

PROGRAMME

SESSION 1 (10:00 - 13:15H)

CHAIR: IRENE MORALES, Complutense University of Madrid (UCM), Spain

10:00 Welcome Address

10:15 **S101** - Control of vortex structures in cylindrical magnetic nanowires with spin-polarized current and field. **José A. Fernández-Roldán**

10:30 **S102** - Enhanced Curie temperature and refrigerant capacity in melt-extracted Fe-doped GdTbCoAl high entropy metallic glass microwires. **Hangboce Yin**

10:45 **S103** - Exploiting nanomagnetism for bio-markers detection in biological fluids. **Elena Sanz-de Diego**

11:00 **S104** - Microfluidic platform fabrication for the optical analysis and magnetic detection of magnetotactic bacteria. **Nerea Lete**

11:15 **S105** - Study of stripe domains on ferromagnetic MnBi hexagonal micro-islands. **Melek Villanueva**

11:30 **S106** - Boosting environmental remediation processes with engineered superparamagnetic nanoreactors. **Álvaro Gallo-Cordova**

11:45 **S107** - Shape-related effects on single ferromagnetic nanoparticles: A micromagnetic approach. **Rafael Delgado-García**

12:00 **S108** - Effect of thermal treatments and pressure on the structural and magnetic transitions in nickel-rich NiFeGa ribbons. **Alejandro F. Manchón-Gordón**

12:15 **S109** - Superconductivity-induced change in magnetic anisotropy in epitaxial ferromagnet-superconductor hybrids with spin-orbit interaction. **César González-Ruano**

12:30 **S110** - Influence of the spatial distribution of Iron Oxide Nanocrystals into Phospholipidic Capsules on their Magnetic Losses. **Diego Gómez**

12:45 **S111** - Contribution to the comprehension of the effect of praseodymium substitution on magnetic behaviour of nanostructured Fe65Co35. **Nacira Djellal**

13:00 **S112** - Non-equilibrium path for the light-induced nucleation of skyrmion lattices. **Pablo Olleros-Rodríguez**

COFFEE-POSTER BREAK (15:00 - 16:00H)

CHAIR: ALBERTO ANADÓN BARCELONA, Institute Jean Lamour, Nancy, France

P01 - Spin Orbit driven effects and thermal activation of ferromagnet intercalated graphene-heavy metal interfaces. **Adrián Gudín**
P02 - Evaluating the heating efficiency of iron oxide nanoparticles for photothermal therapies. **Daniel Arranz**
P03 - Improved averaging of hysteresis loops from micromagnetic simulations of non-interacting uniaxial nanoparticles. **Rafael Delgado**
P04 - Rare earth-free MnAlC permanent magnets produced by hot-pressing from ε-phase gas-atomized and milled powder. **Carla Muñoz**
P05 - Spin waves in cylindrical nanowires in the vortex state. **Diego Caso**
P06 - Modelling of magneto-thermoelectric response from a domain wall. **Elías Saugar**
P07 - Mild electro-mechanical processing of water-quenched amorphous microwires for property improvements. **Alexander Valeriano Inchausti**
P08 - Tuning microwave absorption property of few-layered graphene/ magnetic microwires composite materials for electromagnetic interference shielding. **Álvaro Peña**
P09 - Controlling the magnetic bubbles configuration in CoPt multilayers. **Jorge Marqués Marchán**
P10 - Superferromagnetic behavior on ordered superlattices of uniaxial nanoparticles: A micromagnetic approach. **Rafael Delgado**
P11 - Magnetic nanoparticles: synthesis, characterization and applications. **Virginia Vadillo**
P12 - Controlling interfacial phenomena in hybrid V2O3/Co bilayers. **José Manuel Diez**

SESSION 2 (16:00 - 19:H)

CHAIR: EIDER BERGANZA, Karlsruhe Institute of Technology, Germany

16:00 **S201** - Exploring Ferromagnetism of Individual 3D Cobalt Nanotubes Grown by Focused Electron Beam Induced Deposition. **Javier Pablo-Navarro**

16:15 **S202** - Scale-up of nanowire synthesis for the application in composite bonded magnets. **Claudia Fernández-González**

16:30 **S203** - Correlation between particle size and deformation and subsequent effects on magneto-structural properties. **Deepali Khanna**

16:45 **S204** - Element-Specific hysteresis loops on intracellular magnetosomes synthesized by magnetotactic bacteria *Magnetovibrio blakemorei*. **Lourdes Marcano**

17:00 **S205** - Development of novel MnAlC-based permanent magnet composite materials by solution casting to obtain flexible filaments for 3D-printing. **Daniel Casaleiz**

17:15 **S206** - Low-cost electronic system for detection and quantification of magnetic nanoparticles based on source coupled oscillators. **José Luis Marqués**

17:30 **S207** - Coexistence of dual spin dynamics in GdCu Superantiferromagnetic Nanoparticles. **Elizabeth M. Jefremovas**

17:45 **S208** - Magnetic detection of neural activity in spinal cord slices. **Arturo Vera**

18:00 **S209** - Deconvoluting overlapped phase transitions in biphasic magnetocaloric composites by the scaling laws of the magnetocaloric effect. **Álvaro Díaz García**

18:15 **S210** - Water assisted sol-gel synthesis of Ba(1-x)Bi(x)Ti(1-y)Co(y)O3: Growth, structure and multiferroic properties. **Jallouli Necib**

18:30 **S211** - Nanoscale manipulation of magnetic domains by interfacial strain-induced proximity. Javier Rodríguez

18:45 Awards & Closing

4th Young Researchers in Magnetism

BOOK OF ABSTRACTS

S101

Control of Vortex Structures in Cylindrical Magnetic Nanowires with Spin-polarized Current and Field

J. A. Fernandez-Roldan[1,2,*], R. P. del Real[1], C. Bran[1], M. Vazquez[1], O. Chubykalo-Fesenko[1]

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Cylindrical magnetic nanowires are candidates for the building blocks of 3D information technologies such as shift registers, magnetic recording, spintronics, logic gates, and sensing devices [1-4]. Spin-polarized current is an energy-efficient way to excite magnetization dynamics in planar nanostructures, while, in cylindrical nanowires, this research is doing its first steps [5]. We investigate by micromagnetic simulations the magnetization dynamics in a Permalloy cylindrical nanowire (100 nm diameter and 1 μm length) under the simultaneous application of electric current and magnetic field. The magnetization reversal process starts with the creation of open vortex structures with different rotation senses at the ends of the nanowire. We conclude that the electric current by itself enlarges or reduces the length of these vortex structures according to the rotational sense of the associated Oersted field. Large enough current densities produce a vortex structure that covers the whole nanowire surface. At the same time, the magnetization in the very core of the nanowire remains the same, i.e. no complete magnetization reversal is possible in the absence of an external magnetic field. The simultaneous action of the applied electric current and magnetic field allows the complete control of the vortex structures in terms of setting the polarity and vorticity. In Figure 1 we present the resulting diagram of magnetic states obtained after the application of field and electric current. The state diagram shows the values required for the vorticity and axial magnetization switching and will become very useful for future experiments on current-induced domain wall dynamics in cylindrical magnetic nanowires.

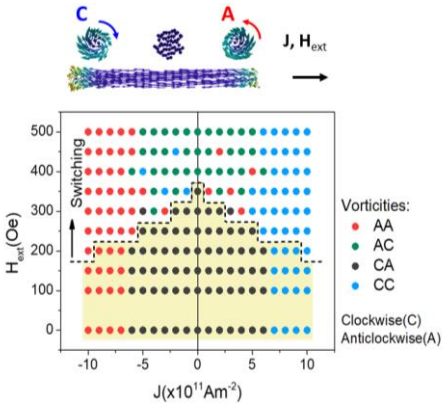

Figure 1. Diagram of magnetization vortex states obtained after the simultaneous application of magnetic field, H_{ext}, and electric current density, J. The vorticity of the vortex (or curling) structures at the ends of the nanowire in the final magnetization state is indicated for different J and H_{ext} fields. C and A stand for Clockwise and Anticlockwise vorticity as indicated in the upper sketch. The threshold for the axial component switching field is indicated by the dashed line. No magnetization switching occurs below this line (yellow-shaded region).

Acknowledgements

The authors are thankful for the support from Spanish Ministry of Economy and Competitiveness (MINECO) under Project MAT2016-76824-C3-1-R and from the Regional Government of Madrid under Project S2018/NMT-4321 NANOMAGCOST-CM.

References

[1] S. Parkin and S.-H. Yang, *Nature Nanotechnology* **10** (2015) 195.
[2] F. Nasirpouri *et al*., *Scientific Reports* **9** (2019) 9010.
[3] S. Ruiz-Gómez *et al*., *Scientific Reports*, **8** (2018) 16695.
[4] J. Garcia *et al*., *Journal of Magnetism and Magnetic Materials* **383** (2015) 88.

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S102

Enhanced Curie Temperature and Refrigerant Capacity in Melt-extracted Fe-doped GdTbCoAl High Entropy Metallic Glass Microwires

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We report the effect of Fe-doping on the structure, magnetic and magnetocaloric properties of $(Gd_{36}Tb_{20}Co_{20}Al_{24})_{100-x}Fe_x$ (x = 0, 1, 2 and 3 at.%) high entropy metallic glass microwires. Experimental results indicate that the microwires prepared by the rotated-dipping process are uniform and continuous. The thermal stability and glass forming ability of the microwires decrease with increasing Fe content. The deterioration of glass forming ability of the microwires is due to the relatively large change of the mixing enthalpy and the mixing entropy, caused by Fe-doping. Fully amorphous structure of the alloys with x=0 and x=1, and dual phase amorphous and nanocrystalline structure for the alloys with x=2 and x=3 are confirmed by transmission electron microscopy observations. The large difference among the mixing enthalpies of different atomic pairs in Fe-doped GdTbCoAl microwires lead to the formation of crystalline phase in the supercooled liquid. The growth of crystalline phase is hindered due to the relatively large atomic size difference, mixing enthalpy, the covalent bonding character of Fe-Al and Co-Al atomic pairs and increased melt viscosity of Fe-doped GdTbCoAl microwires. The nanocrystalline phase which exists in the liquid matrix is retained and frozen in Fe-doped GdTbCoAl microwires. The phase separation and the composition difference between nanocrystalline and amorphous phase are enhanced by increased Fe-doping.

The Curie temperature of the high entropy metallic glass microwires increases with increasing Fe content, ranging from 81 K for the Fe-free alloy to 108 K for the alloy with x=3, which can be ascribed to the strong exchange interactions of rare-earth-Fe and Fe-Fe pairs. The second-order paramagnetic-ferromagnetic transition of all microwires is confirmed by Arrott plots and universal scaling. The peak values of magnetic entropy change decrease, whereas the refrigerant capacity decreases firstly and then increases to a value higher than that for Fe-free alloy, with increasing Fe content. The increase of refrigerant capacity is attributed to the broadened working temperature range, which is ascribed to wide Curie temperature distribution induced by the composition differences among nanocrystalline, interphase region and amorphous phase.

Among the studied alloys, $(Gd_{36}Tb_{20}Co_{20}Al_{24})_{97}Fe_3$ microwire holds the greatest potential multifunctional applications in magnetocaloric-effect-based refrigeration over a relatively broadened working temperature range.

Acknowledgements

The authors would like to acknowledge the financial support from the National Natural Science Foundation of China under Grant Nos. 51871076, 51671070, 51801044, and the 66th China Postdoctoral Science Foundation under Grant No. 2019M661275.

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S103

Exploiting Nanomagnetism for Bio-markers Detection in Biological Fluids

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Biological markers are measurable indicators of biological and/or physiological conditions. The precise identification of bio-markers and their assignment to specific diseases or cancer stages have boosted the research activity for the sake of predicting clinical outcomes. Immuno-assays methods have been the most employed techniques for specifically detecting biomarkers in patient samples. This detection technology presents relevant lacks that can benefit of the progress in nanoscience and nanotechnology. Among others, magnetic nanoparticles (MNPs) have been widely studied for different diagnosis, therapeutic, and sensing applications. For the latest, the potential of MNPs as magnetic transducer for detection methods relies on how the magnetic properties of F-MNPs vary after their interaction with biomarkers. Moreover, the detection display is achieved by different magnetic techniques, such as AC susceptometry, magnetometry, or giant magneto-resistance.

Here, we present a novel, quick, and versatile methodology for magnetic detection of biomarkers dispersed in biological fluids (i.e. buffer saline, urine, blood,...), which is based on the variation of the AC hysteresis loops of F-MNPs after interacting with an analyte (see figure). Such detectable variations can be measured after short F-MNP-analyte incubation times (< 15 min), and are associated with the increase of the hydrodynamic volume and/or biomarker specific adsorption. AC magnetometry measurements display the interactions and takes few seconds (< 5s) for being acquired. The most original aspect of our novel approach is the fact that the sensitivity can be modulated down to 1 nM by several parameters (see figure below). Here, we show the proof of concept of this novel and versatile magnetic methodology, whose potential relies on exploiting advantages offered by nanomagnetism to enhance the detection sensitivity, which so far achieves in 1 nM. As shown in the Figure, different parameters influencing the variation of AC hysteresis loops of F-MNPs after specific interactions have been assessed for setting the optimal conditions for detection of biomarkers dispersed in fluids.

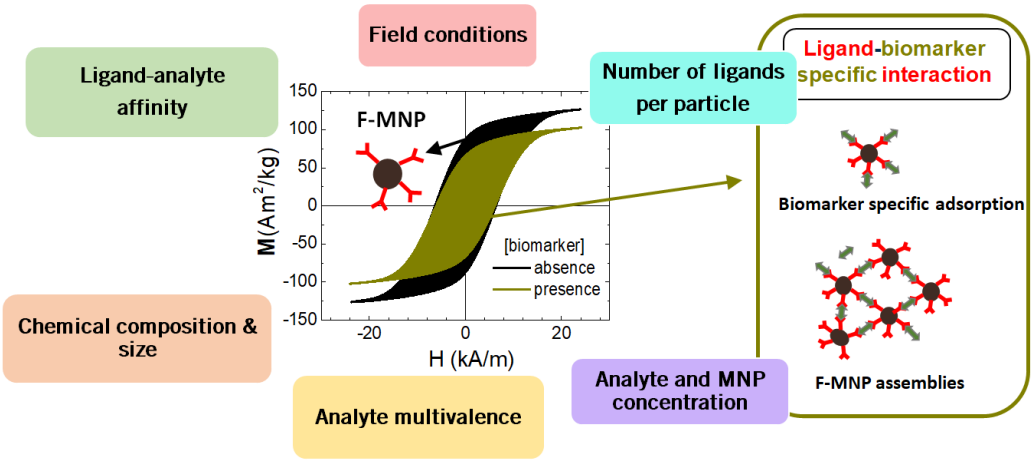

Figure 1. General scheme of the proposed detection method with parameters that modulate its sensitivity.

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S104

Microfluidic Platform Fabrication for the Optical Analysis and Magnetic Detection of Magnetotactic Bacteria

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Magnetotactic bacteria are aquatic microorganisms that swim following the Earth's magnetic field lines using an internal chain of magnetic nanoparticles called magnetosomes, which actuates as a compass needle. Therefore, magnetotactic bacteria be externally manipulated, guided and detected, and they could be used for detection and treatment of cancer through MRI, magnetic hyperthermia or drug delivery [1]. To implement and optimize these applications, it is interesting to study their swimming mechanisms and response to external magnetic fields. This can be done either by direct observation in an optical microscope, or indirectly by magnetic sensing through the detection of the stray field that the magnetosome chain creates. In this work we report the development of microfluidic platforms that allow both types of monitoring. The device should meet certain requirements: a transparent substrate thin enough so that the microscope (of inverted type) can focus in the desired area; low profile microchannels (small depth) to avoid the bacteria swimming out of focus; a proper alignment between the microchannel and the elements that form the sensor; and an adequate bonding between the substrate and sealing element to avoid fluid leakage.

We explore two approaches for the integration of the magnetic sensors into the microfluidic channels while also meeting the requirements stated above. In both cases, we first pattern the Permalloy magnetic sensors and contact pads onto the 0.13 mm thick glass substrate using standard photolithography processes. For the first method, we use SU-8 as a mold to fabricate the channel in PDMS by replica molding, and then bind the patterned PDMS to the substrate where the sensors have been defined. For the second approach, we build the channel directly on top of the substrate using SU-8 and seal it with a flat PDMS slab. The second method presents two advantages: the magnetic sensors can be more accurately aligned with the channel during the fabrication process and fluid insertion is improved thanks to the better wettability of SU-8 compared to PDMS [2]. Finally, it is to be noted that PDMS is bonded in both cases by surface activation by oxygen plasma, but this step requires a coating of 55 nm SiO_2, deposited by RF magnetron sputtering, on top of all non-glass materials (sensor metals and SU-8).

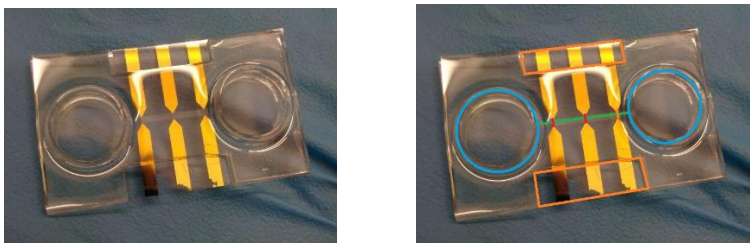

Fig. 1. Photography of a microfluidic platform fabricated using SU-8 channels (second method). The figure shows the two holes for the attachment of the fluid reservoirs (blue), the microfluidic channel (green), the pairs of electrical contacts (gold) connecting the sensor stripes (red) and the opening in the PDMS (orange) for external measurements.

Index Terms — Magnetotactic bacteria, microfluidic channel, magnetic sensor, plasma bonding.

Acknowledgements

The Spanish government supports this work under grant MAT2017-83631-C3 and N. Lete acknowledges grant PRE-2018-1-0252 from the Basque government.

References

[1] D. Gandia, L. Gandarias, I. Rodrigo *et al.*, *Small* **15** (2019) 1902626.
[2] Z. Zhu, P. Chen, K. Liu, C. Escobedo, *Micromachines* **7** (2016) 230.

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S105

Study of Stripe Domains on Ferromagnetic MnBi Hexagonal Micro-islands

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Permanent micro-magnets are widely used in many devices such as MEMS and diverse biological applications. However, their fabrication typically includes several complex processing steps. MnBi possesses excellent permanent magnet properties including a high Curie temperature of 711 K, a high magnetocrystalline anisotropy of 1.6 MJ/m^3 at room temperature, a relatively high $(BH)_{max}$ of around 20 MGOe and, remarkably, an unusual positive temperature coefficient of the coercivity [1]. These features make MnBi an attractive rare earth-free permanent magnet alternative for high temperature applications.

In this study, we have fabricated well-defined hexagonal MnBi micro-islands by a single-step method and with no need for any post-processing (e.g. lithography) [2]. Moreover, we have managed to prepare these hexagonal micro-islands with a strong perpendicular anisotropy, governed by the growth conditions, without applying any external magnetic field. A crater-like shape of the hexagonal islands has allowed us to study the periodicity *D* of magnetic stripe domains (inset Fig. 1) as a function of thickness, finding a D = 1.18 * sqrt (T) dependence (Fig. 1) in good agreement with theoretical predictions [3]. We will show the possibility of tuning the magnetic anisotropy of MnBi nanostructured films (from out-of-plane to in-plane) by simply varying the deposition temperature [2]. High coercivities of 13 and 14 kOe at 400 K have been obtained for out-of-plane and in-plane MnBi samples, respectively. Micromagnetic simulations show a correlation between the origin of the high anisotropy of the samples and their crater-like shape.

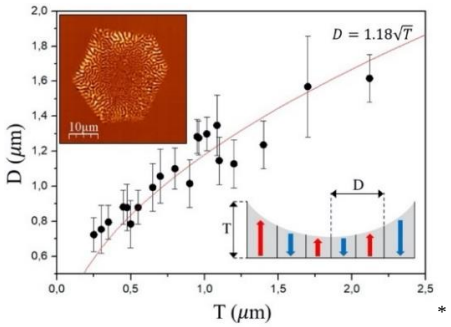

Figure 1. Dependence of domain width, D, on the thickness, T, of the micro-islands from MFM images (inset) measured at remanence after sample demagnetization. The D = 1.18 * sqrt (T) law is obtained by fitting the data points (red line).

Index Terms — Thin films, Nanostructures, Magnetic domains, Magnetic anisotropy, MnBi.

Acknowledgements

IMDEA acknowledges financial support from the EU M-ERA.NET Network and MINECO through "NEXMAG" (Project Success Case at H2020 M-era.Net, Ref. PCIN-2015-126) and "3D-MAGNETOH "(Ref. MAT2017-89960-R); and from CM through "NANOMAGCOST" (Ref. P2018/NMT-4321).

References

[1] K. Patel *et al.*, *Nanoscale* **10** (2018) 11701.
[2] M. Villanueva *et al.*, *J. Alloys Compd.* **852** (2021) 156731.
[3] C. Kittel, *Phys. Rev.* **70** (1946) 11–12.

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S106

Boosting Environmental Remediation Processes with Engineered Superparamagnetic Nanoreactors

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The rapid industrialization has generated crucial challenges dealing with environmental pollution. There is a huge generation of industrial solid wastes that ends up in solid landfills and eventually in different waterbodies in the form of leachates, the same with polluted effluents from a large list of industrial activities. The great diversity of compounds in solid landfill leachates and the mixture of hazardous dyes in textiles wastewaters restrict the efficiency of the most common treatment techniques. Engineered inorganic nanoparticles like metal oxides stand out as an important class of nanomaterials with promising potential for full scale environmental remediation [1]. Iron oxide nanoparticles present unique properties for the development of magnetic separation and degradation strategies that attenuate the dramatic effect of these contaminants [2]. Furthermore, the ability of self-heating under the influence of an alternating magnetic field (AMF) represents a remarkably advantage to reach greater production yields in shorter residence times [3].

The present study describes the performance of three different shaped 40-50 nm iron oxide nanoreactors for the adsorption and magnetic induction-driven degradation of organic pollutants present in real wastewaters and model compound methyl orange (MO). As shown in Figure 1 the flower-like nanoreactors (NFs) presented greater efficiencies for the degradation of MO and were selected for further analysis for the degradation of landfill leachate (LIX) and textiles industry wastewaters (TIW) under an AMF (17 kA/m, 200 kHz). Degradation reaction rates, when using the magnetic nanocatalyst as heating source, were much faster than those obtained in a common thermal reactor (90 ºC) with almost a fully decolorization of the LIX sample (90 %). In consequence, magnetic induction heating of iron oxide nanoreactors are a promising alternative to reach higher reaction yields for the effective degradation of pollutants from real wastewaters while they can also be easily separated with a magnet in contrast to the more expensive and time consuming common separation processes.

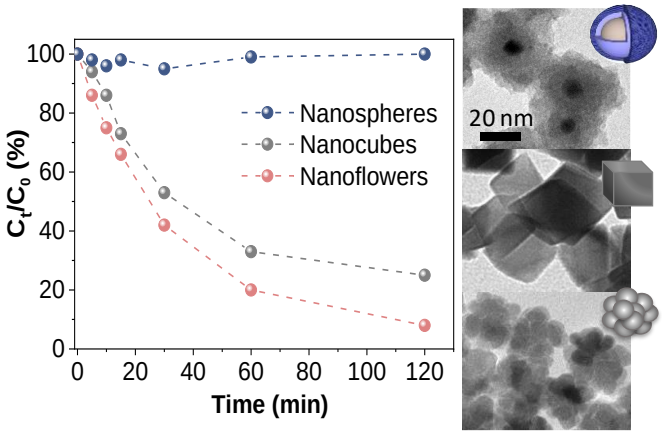

Figure. 1. TEM images of iron oxides nanoreactors and their respective efficiencies in the degradation of methyl orange at RT.

References

[1] A. S. Adeleye, J. R. Conway, K. Garner, Y. Huang, Y. Su, A. A. Keller, *Chem. Eng. J.* **286** (2016) 640–662.
[2] A. Gallo-Cordova, J. Lemus, F. J. Palomares, M. P. Morales, E. Mazarío, *Sci. Total Environ.* **711** (2020) 134644.
[3] P. Xu, G. M. Zeng, D. L. Huang, C. L. Feng, C. Huang, G. X. Xie, Z. F. Liu, *Sci. Total Environ.* **424** (2012) 1–10.

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S107

Shape-related Effects on Single Ferromagnetic Nanoparticles: A Micromagnetic Approach

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Quasi-spheroidal Magnetic Nanoparticle (MNP) systems have a magnetostatic anisotropic contribution related to the demagnetizing factor [1] that gains relevance in highly degenerated magnetocrystalline landscapes. In this way, weakly magnetocrystalline systems can have their effective anisotropies modulated as a function of shape-induced magnetostatic contributions, inferring in their magnetic properties like coercivity H_c or remanence M_r and thus modifying the general magnetic energy of the system.

Single domain uniaxial nanoparticles and even certain uniaxial thin films may follow Stoner-Wohlfarth (SW) model [2], behaving as coherent-rotation single macrospins and yielding 2-fold symmetric polar plots of coercivity H_c and remanence M_r. However, nanoparticles with weak uniaxial magnetocrystalline anisotropy in diluted distributions (hence free from interparticle dipolar interactions), may present behaviors far from SW predictions because of shape and magnetocrystalline anisotropy competition. As an extent of this behavior, nanoparticles with null magnetocrystalline contribution can show stark shape anisotropy.

This work focuses on the angular study of magnetization reversal processes in quasi-spherical (ε~1) single MNPs with different shapes and materials. Micromagnetic simulations [3] in weak magnetic anisotropy MNPs, such as in FeCo, show deviations from SW behaviour in both H_c and M_r, which can be explained by the presence of different magnetization pinning regions along the sharp edges of such geometries [Figure 1].

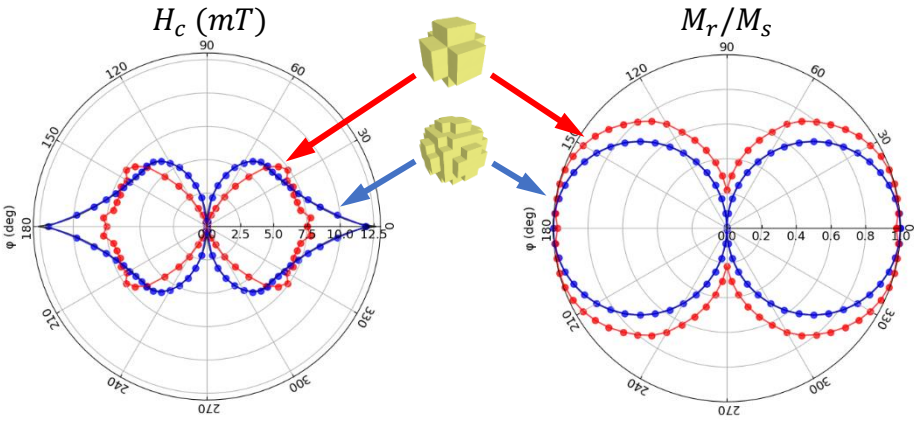

Figure 1. Polar plots of coercivity H_c of single FeCo uniaxial MNPs ($\vec{K}_u = 10kJ/m^3$, $M_s = 1.6 \times 10^6 A/m$, $A_{ex} = 10.7\ pJ/m$) for less (red) and more (blue) spherical geometries, compared with SW prediction (black line).

Index terms — Magnetic Nanoparticles, Micromagnetic Simulations, Stoner-Wohlfarth, Shape Anisotropy.

Acknowledgements

This work has been possible thanks to the MICINN, as a part of the Project MAT2015-65295-R: "Nanocomposites magnéticos para aplicaciones en energía y sensores". Rafael Delgado-Garcia thanks UCLM and Banco Santander for the scholarship for research initiation during his Master studies.

References

[1] J. A. Osborn, *Phys. Rev.* **67** (1945) 351.
[2] J. L. F. Cuñado, A. Bollero, T. Pérez-Castañeda, P. Perna, F. Ajejas, J. Pedrosa, A. Gudín, A. Maldonado, M. A. Niño, R. Guerrero, D. Cabrera, F. J. Terán, R. Miranda, and J. Camarero, *Sci. Rep.* **7** (2017).
[3] A. Vansteenkiste, J. Leliaert, M. Dvornik, M. Helsen, F. Garcia-Sanchez, B. Van Waeyenberge, *AIP Adv.* **4** (2014).

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S108

Effect of Thermal Treatments and Pressure on the Structural and Magnetic Transitions in Nickel-rich NiFeGa Ribbons

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Since the discovery of the magnetic shape memory effect, ferromagnetic shape memory alloys have drawn great research interest as potential candidates for many applications. The applicability of these systems is related to a martensitic transformation, a diffusionless first order phase transition occurring in magnetically ordered domains in the so called ferromagnetic shaper memory alloys (FSM). For Heusler type FSM, the transition takes place between austenite (with B2 or ordered $L2_1$ structure) and either a seven-layer (14 M) or five-layer (10 M) modulated or a non-modulated ($L1_0$ tetragonal), martensite structure, depending on composition and thermal history.

Among the several ferromagnetic shape memory Heusler alloys, Ni-Fe-Ga systems offer a great deal of advantage for device applications due to their better ductility compared to Ni-Mn-Ga systems. The improved ductility of these alloys has been attributed to the precipitation of the secondary γ phase. Although a low percentage of this phase would have beneficial effects, a high quantity reduces the relative amount of transformable phase and, hence the shape memory properties. In this sense, rapid quenching techniques, like melt-spinning, are able to suppress the formation of γ phase during fabrication process.

In the present work, ribbons of a $Ni_{55}Fe_{19}Ga_{26}$ Heusler alloy were prepared by melt-spinning technique. The effect of pressure and thermal treatments on magnetostructural transitions has been analyzed. It has been found that the as-spun ribbon exhibits a martensite modulated 14 M structure at room temperature. After the ribbon is submitted to an axial pressure, the modulated structure changes to a non-modulated structure, thermodynamically more stable. In fact, the pulverization of the ribbon suppresses the martensite transition, suggesting that it only occurs between the modulated and the $L2_1$ austenite structure. On the other hand, the thermal treatments promote a reduction of the martensitic transformation temperature in the investigated sample, promoting the stabilization of the austenite phase at room temperature.

Acknowledgements

This work was supported by AEI/FEDER-UE (Project MAT 2016-77265-R and Project US-1260179) and the PAI of the Regional Government of Andalucía. A.F. Manchón-Gordón acknowledges a VPPI-US fellowship.

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S109

Superconductivity-induced Change in Magnetic Anisotropy in Epitaxial Ferromagnet-superconductor Hybrids with Spin-orbit Interaction

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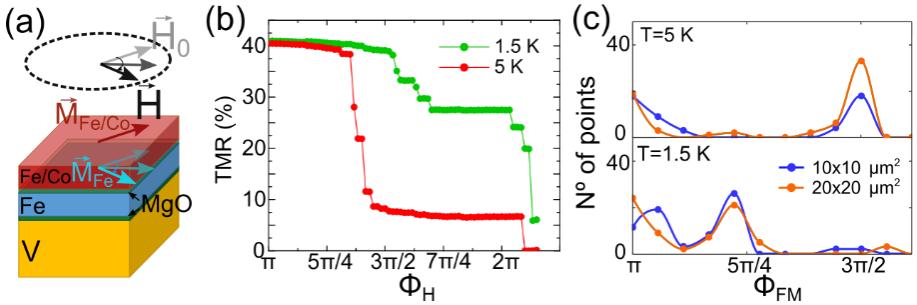
Unlike the common expectation that superconducting spintronics and long-range triplet (LRT) proximity effects require complex ferromagnetic multilayers, noncollinear/spiral magnetization or half-metals, we propose a new platform compatible with commercial spintronics. In our previous works, we have experimentally demonstrated that interfacial spin-orbit coupling (SOC) and symmetry-filtering in all-epitaxial V/MgO/Fe junctions, cooled below the critical temperature of vanadium, provide a thousand-fold increase in tunneling anisotropic magnetoresistance, supporting the LRT formation [1].

Here we report the converse effect: the transformation of the magnetocrystalline anisotropy of a Fe(001) layer driven by the superconductivity of vanadium through a spin-orbit coupled MgO interface in hybrid spin valve/superconducting junctions [2]. The samples are all-epitaxial, with a layer structure of V(40 nm)/MgO(2 nm)/Fe(10 nm)/MgO(2 nm)/Fe(10 nm)/Co(20 nm), and their lateral dimensions vary from 10x10 to 30x30 μm^2.

Under an in-plane rotation of an external magnetic field, with a magnitude in between the coercive field of the two ferromagnetic layers so we can distinguish the different configurations of the spin valve, we observe new emergent states when cooling down below the vanadium critical temperature, directed in the supposedly hard magnetocrystalline axes 45 degrees from the easy ones. We discard Meissner screening and vortex-domain wall interaction as the explanation for the observed phenomena by performing micromagnetic and superconducting simulations, and attribute the effects to an additional contribution to the free energy of the ferromagnet arising from the controlled generation of triplet Cooper pairs, which depends on the relative angle between the exchange field of the ferromagnet and the spin-orbit field. This observation offers the ability to tune magnetic anisotropies using superconductivity - a key step in designing future cryogenic magnetic memories.



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

Acknowledgements

The work has been supported by Spanish MINECO (RTI2018-095303-B-C55; EUIN2017-87474) and the Comunidad de Madrid through NANOMAGCOST-CM (P2018/NMT-4321). We acknowledge Igor Zutic, Jaroslav Fabian, Alexandre Buzdin, Jacob Linder, Lina Johnsen and Niladri Banerjee for valuable discussions.

References

[1] I. Martínez *et al*. *Phys. Rev. Appl.* **13** (2020) 014030.
[2] C. González-Ruano *et al*. *Phys. Rev. B* **102** (2020) 020405(R).

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S110

Influence of the Spatial Distribution of Iron Oxide Nanocrystals into Phospholipidic Capsules on their Magnetic Losses

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The preparation of nanostructures combining different biomedical modalities is one of the most popular research lines worldwide. For instance, the combination of nanocrystals with different physico-chemical properties is being pursuit to achieve nanostructures to fight cancer. A few approaches are being tested nowadays [1], based on the simultaneous encapsulation of nanocrystals (NCs) with thermosensitive optical and magnetic properties to control the removal of tumors by locally raising tissue temperatura. One of the main challenges to achieve this goal is how to preserve the intrinsic physical properties of the employed nanocrystals into biological matrices, especially the magnetic ones, which are generally strongly influenced by clustering and/or immobilization inside cells or tissues [2]. In this work, superparamagnetic iron oxide nanoparticles (19 ± 4 nm) and Ag_2S nanoparticles (8 ± 1 nm) are simultaneously embedded into phospholipidic capsules with typical hydrodynamic sizes around 200 nm. These capsules may act as thermal probes, imaging agents and heating mediators in biomedical applications. Transmission electron microscopy evidences the presence of the two kinds of NCs with distinct sizes inside the phopholipid capsules, where Ag_2S NCs are mainly localized into central part, surrounded by magnetic NCs. Their magnetic properties of the phospholipid capsules have been compared with individual iron oxide NCs, resulting in a surprising enhancement of the magnetic losses in the range of 30-300 kHz and 24 kA/m (see Figure 1). Therefore, the values of the specific absorption rate (SAR) of the encapsulated iron oxide nanoparticles increase more than 100%, with respect to their individual counterparts. This impressive upgrade in their magnetic losses is a direct consequence of the spatial distribution of iron oxide NCs inside the capsule resulting in spatial arrangement of dipoles leads to a nose-to-tail ordering of their magnetic moments and hence to an enhanced magnetization. Beside, the capsule aggregation has no significant effect on the AC hysteresis loops and consequently on their thermal losses under alternating fields, what is of high interest for their potential use as heating mediator for supplying an invariant thermal stress into cells and tissues. Finally, we studied the interaction of these phospholipid capsules in distinct biological fluids (PBS 1x, cell culture media and blood plasma) and its influence on the magnetic and colloidal properties.

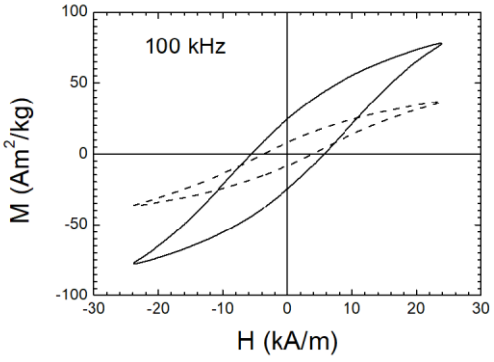

Figure 1. Comparison of mass-normalized AC hysteresis loops of phospholipid capsules dispersed in double-distilled water (solid line) and individual MNPs dispersed in 1-octadecene (dashed line). The iron content in the colloidal dispersions was 2 gFe/L and field conditions 100 kHz and 24 kA/m.

References

[1] D. H. Ortgies *et al.*, *Adv. Funct. Mat.* **28** (2018) 1704434.
[2] M. V. Zyuzin *et al.*, *ACS Applied Materials & Interfaces* **11** (2019) 41957.

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S111

Contribution to the Comprehension of the Effect of Praseodymium Substitution on Magnetic Behaviour of Nanostructured $Fe_{65}Co_{35}$

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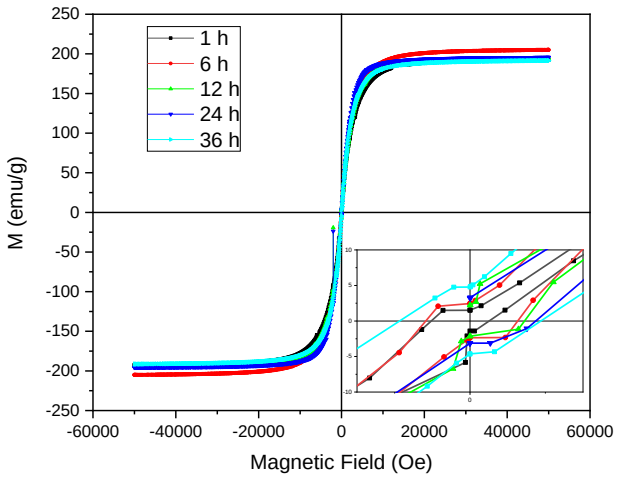
The substitution of cobalt in iron is well known to increase simultaneously the saturation magnetization and Curie temperature [1, 2]. Fe - Co alloys present excellent soft magnetic properties and especially $Fe_{65}Co_{35}$ which is characterised by the highest saturation magnetization (Ms) of all known magnetic alloys [3].

The aim of this study is to evaluate the effect of praseodymium oxide contents on structural, morphological, and magnetic properties of nanostructured $(Fe_{65}Co_{35})_{95}$ $(Pr_6O_{11})_5$ powders obtained by mechanical ball milling. For this purpose, X-ray diffraction (XRD), Scanning Electron Microscopy (SEM), and Vibration Sample Magnetometer (VSM) were used.

Results prove the substitution of the cobalt and praseodymium oxide in the iron lattice after 24h of milling, the magnetic investigation show that the addition of Pr_6O_{11} to $Fe_{65}Co_{35}$ enhances its magnetic performance with increasing its coercive field with keeping the saturation magnetisation at high values.



Index Terms — soft ferromagnetism, Fe-Co, mechanical alloying, rare earth.

Acknowledgements

I am thankful to the research team of the Instituto de Magnetismo Aplicado for the support which is appreciated.

References

[1] M. McHenry, M. Willard, D. Laughlin, *Prog. Mater. Sci.* **44** (1999) 291–433.
[2] T. Sourmail, *Prog. Mater. Sci.* **50** (2005) 816–880.
[3] D. Manh, D. K. Tung, *Sci.* **45** (2016) 2501–2507.

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S112

Non-equilibrium Path for the Light-induced Nucleation of Skyrmion Lattices

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The use of magnetic skyrmions in technological applications is constrained by the ability to nucleate, stabilize and manipulate them[1]. Small skyrmions are frequently metastable states, so that at remanence either the saturated or the stripe domain states are present and the skyrmion nucleation is not easily accessible. Recent experiments have shown the feasibility of the laser-induced nucleation of skyrmions by means of ultrafast magnetisation dynamics[2]. This technique also opens the possibility of developing less-consuming and ultrafast skyrmionic memory or logic-gate devices.

In the present work we explore the nucleation of magnetic skyrmions in realistically parametrised Pt/Co/Heavy-Metal magnetic trilayers via atomistic calculations using the software package Vampire[3]. Quasi-static simulations by following a field-cooling process produce a stable state in the form of stripe domains. Next, we model the dynamics under ultrafast femtosecond laser pulse varying the pulse duration and intensity. We present a state diagram of the magnetic states after the laser pulse action which shows the existence of a set of laser parameters leading to a skyrmion lattice. Our results unambiguously demonstrate the necessity of highly non-equilibrium dynamical path in order to nucleate a skyrmion lattice.

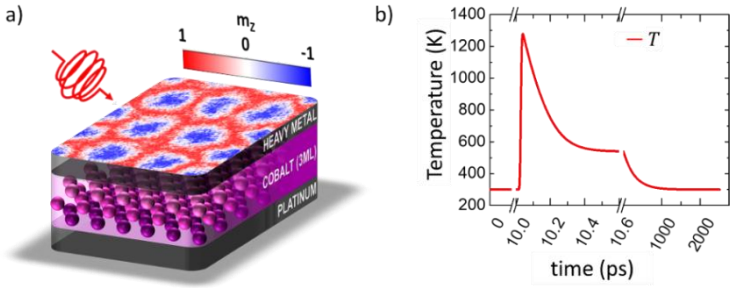

Figure 1. Ultrafast light-induced nucleation of skyrmion lattices. a) Sketch of the modelled system with a nucleated skyrmion lattice. b) Temperature profile induced by the the laser pulse.

Index terms — Magnetis Skyrmions, Thin films, Laser, Atomistic calculations.

Acknowledgements

The authors acknowledge financial support from the EU through COST Action CA17123 "Magnetofon", the European Union's Horizon 2020 grant agreement No 737093 FEMTOTERABYTE and under the FLAG-ERA JTC2019 Project SOgraphMEM (MINECO PCI2019-111867-2). The work in Spain was supported by the Regional Government of Madrid through Project P2018/NMT-4321 (NANOMAGCOST) and by the Spanish Ministry of Economy and Competitiveness (MINECO) through Projects SKYTRON (FIS2016-78591-C3-1-R and FIS2016-78591-C3-3-R) and FUNSOC (RTI2018-097895-B-C42). IMDEA Nanoscience Institute is supported by the "Severo Ochoa" Programme for Centres of Excellence in R&D, (MINECO grant SEV-2016-0686).

References

[1] A. Fert *et al.*, *Nat. Rev. Mat.* **2**(7) (2017) 17031.
[2] S.-G. Je *et al.*, *Nano Letters* **18** (2018) 7362.
[3] R. F. L. Evans *et al.*, *J. Phys.: Condens. Matter* **26**(10) (2014) 103202.

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S201

Exploring Ferromagnetism of Individual 3D Cobalt Nanotubes Grown by Focused Electron Beam Induced Deposition

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Three-dimensional (3D) nanomagnets provide a great potential to be implemented in future spintronic devices for high-density magnetic memories, nano-sensing or logic. Among these appealing architectures, ferromagnetic nanotubes (NTs) are currently being investigated for their fast and low-power domain wall conduit properties [1].

The development of novel 3D nanostructures typically requires complex synthetic methods. Moving forward in this challenging task, Focused Electron Beam Induced Deposition (FEBID), a unique one-step nanolithography technique which has demonstrated great versatility in terms of shape, composition and magnetic properties, has been explored for the growth of 3D ferromagnetic NTs [2]. Following the strategy developed for the fabrication of core-shell nanowires [3], the growth of 3D Co NTs by FEBID has been performed for the first time [4]. The heterostructured design is composed by a vertical Pt-C nanowire (≤100 nm in diameter) acting as a core, and a Co coating forming the shell with a thickness down to ~11 nm.

Furthermore, Transmission Electron Microscopy experiments reveal that these NTs present a nanocrystalline structure and a metallic content of ~70 at. %. In addition, a coercivity of ~16 mT has been obtained by Magneto-Optical Kerr Effect magnetometry, and magnetic characterization performed by Electron Holography evidences the ferromagnetic behaviour, estimating a remanent magnetic induction up to 1.3 T and detecting complex head-to-head magnetic domain walls. Finally, micromagnetic simulations have been performed for a deeper understanding of the magnetization dynamics [4].

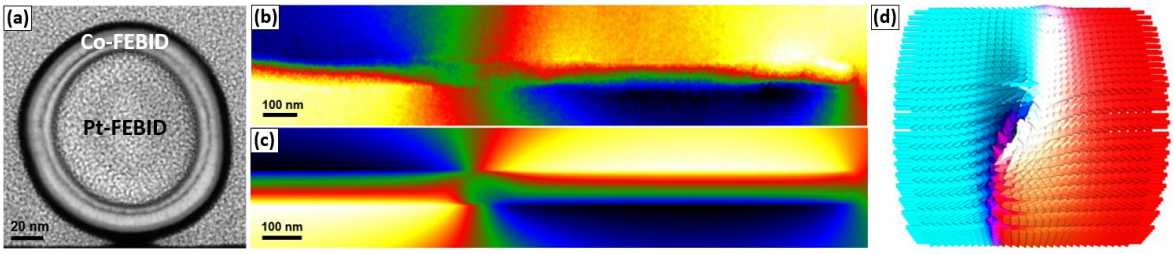

Figure 1. (a) HAADF-STEM image of a Co-FEBID NT cross-section. (b,c) Experimental and simulated magnetic phase shift around a domain wall obtained by Electron Holography and micromagnetic simulations, respectively. (d) Spin configuration obtained from micromagnetic simulations.

Index Terms — Focused electron beam induced deposition, magnetic nanowires, nanotubes.

Acknowledgements

Authors acknowledge funding from MINECO through projects MAT2017-82970-C2, BES-2015-072950, from Aragon Regional Government through E13_20R, and from the European Social Fund.

References

[1] R. Hertel, *J. Phys.: Condens. Matter* **28** (2016) 483002.
[2] J. Pablo-Navarro, *et al.*, *J. Phys. D. Appl. Phys.* **50** (2017) 18LT01.
[3] J. Pablo-Navarro, *et al.*, *Nanotechnology* **27** (2016) 285302.
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S202

Scale-up of Nanowire Synthesis for the Application in Composite Bonded Magnets

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In the last years, nanowires appear to be materials to play a key role in the development of new nanodevices in many fields of applications like recording schemes, neuroscience, water splitting... The quantity of nanowires produced in a laboratory is enough to supply material for these applications. However, applications related to nanomedicine [1] or the fabrication of composites materials [2] require the fabrication of big quantities of nanowires to go from the lab or research papers, to real industry production.

In this work, we carried out the scaling-up of the production of magnetic nanowires for applications in which large amounts are needed. There were two mean issues to focus on: to increase the number of produced nanowires and to reduce the cost of the synthesis process to make these nanostructures competitive at industrial applications. Template electrodeposition was chosen to grow the nanowires because it is a versatile and non-expensive technique that allows us the synthesis of a wide range of metallic and oxide materials [3]. There are two main process involved in the production of magnetic nanowires using electrodeposition: the alumina template synthesis and the nanowires growth by filling the pores of the template. Changing high purity starting materials for other ones with less quality and modifying the anodization and growth conditions we have managed to reduce the price, the synthesis time and to increase the production of nanowires in our laboratory and we have stablish the conditions to implement this process in industry. Also we show an application where FeCo nanowires, growth using this scaled-up procedure, combined with strontium ferrite powder were used to synthesize a prototype of composite based permanent magnet [4] whose properties were improved with respect to the strontium ferrite magnets in order to fill the gap between ferrites and rare-earth magnets.

Acknowledgements

IMDEA Nanociencia acknowledges support from the Severo Ochoa Programme for Centres of Excellence in R&D (MINECO, Grant SEV-2016-0686).

References

[1] D.Shore, S. L Pailloux, J. Zhang, T. Gage, D. J. Flannigan, M.Garwood, V. C. Pierre and B. J. Stadler, *Chemical Communications* **52** (2016) 12634.
[2] A. Alfadhel and J. Kosel, *Advanced Materials* **27** (2015) 7888.
[3] Stępniowski, W. J. & Salerno, *Manufacturing nanostructures* **12** (2014) 321–357.
[4] J. C. Guzmán-Mínguez, S. Ruiz-Gómez, L. M. Vicente-Arche, C. Granados-Miralles, C. Fernández-González, F. Mompeán, M. García-Hernández, S. Erohkin, D. Berkov, D. Mishra, C. de Julián Fernández, J. F. Fernández, L. Pérez and A. Quesada, *ACS Applied NanoMaterials* **3** (2020) 9842.

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S203

Correlation between Particle Size and Deformation and Subsequent Effects on Magneto-structural Properties

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The possibility of inducing a structural martensitic transformation by applying a magnetic field in meta-magnetic shape memory alloys gives rise to interesting properties such as magnetic actuation, giant magnetoresistance or giant inverse magneto-caloric effect, which make these alloys very attractive for practical applications in sensing and magnetic refrigeration [1]. Composites made from polymer matrix with meta-magnetic shape memory powder have been recently proposed to overcome the intrinsic brittleness of the bulk alloys [2]. The production, characterization and optimization of the properties of powder particles are therefore milestones to get valuable functional composites.

In the present work, the martensitic transformation and the magnetic properties of $Ni_{45}Co_5Mn_{37}In_{13}$ powder micro particles obtained by ball milling have been studied. Even for very large milling times, a considerable dispersion in the particle size is observed in all the samples. Nevertheless, it is found that the characteristic of the transformation and the magnetic response are exactly the same in those particles with the same particle size, irrespective of the milling time. A direct correlation between size and deformation can be then established, from which the effect of mechanically induced microstructural defects on the magnetism is analyzed. In the as-milled sate, the saturation magnetization of the austenite highly decreases with the decrease in particle size whereas just a slight variation is observed in martensite. On the other hand, while the microstructural recovery brought by high-temperature annealing leads to similar magnetization values in austenite, the magnetization in martensite is higher for the more deformed particles. The observed behavior is explained in term of stress-induced austenite retention. The effect of mechanically induced defects on the magneto-caloric effect and the viability of the use of the studied micro particles for composite elaboration are also analyzed and discussed.

Index Terms — mechanical milling, magneto-caloric effect, meta-magnetic shape memory alloys, martensitic transformation.

Acknowledgements

D. L. R. Khanna wants to acknowledge UPNA and InaMat2 for the Ph.D. Grant (Ayudas para contratos pre-doctorales adscritas a grupos e institutos de investigación UPNA). This work has been supported by the Project RTI2018-094683-B-C54 (MCIU/AEI/FEDER,UE).

References

[1] E. Şaşıoğlu, L. M. Sandratskii, P. Bruno, *Phys. Rev. B.* **77** (2008) 064417.
[2] P. Czaja, J. Przewoźnik, M. Fitta, M. Bałanda, A. Chrobak, B. Kania, P. Zackiewicz, A. Wójcik, M. Szlezynger, W. Maziarz, *J. Magn. Magn. Mater.* **401** (2016) 223–230.

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S204

Element-Specific Hysteresis Loops on Intracellular Magnetosomes Synthesized by Magnetotactic Bacteria *Magnetovibrio blakemorei*

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Magnetovibrio blakemorei is a microorganism able to biomineralize high quality magnetite nanoparticles called magnetosomes. These vibroid to helicoid cells contain a variable number of truncated hexa-octahedral magnetite magnetosomes (35×35×65 nm) aligned mostly parallel to the axis of elongation, the <111> crystallographic direction of magnetite, forming a single chain [1-2]. This chain behaves like a large single permanent magnetic dipole able to orient the whole cell along earth magnetic field. Thus, magnetosome chain is a natural paradigm of 1D magnetic nanostructure [3]. Due to the large magnetic anisotropy, such arrangements show potential as *nanobiots* for biomedical applications [4-5].

Besides the fundamental scientific interest of magnetosome chain, a precise knowledge of the magnetic anisotropy and magnetic configuration of the chain are an issue of paramount relevance for their future efficient application. Unfortunately, classically used magnetic characterization techniques, such as SQUID and VSM magnetometry are very limited in this regard. These techniques require averaging over hundreds or thousands of magnetosome chains. This precludes obtaining reliable information about the magnetic properties of isolated magnetosome chains as in these cases is difficult to control crucial parameters as the orientation of the chain itself, the relative orientation of the magnetosomes or the separation existing between consecutive nanocrystals in the chain. In order to overcome this limitation, in this work we explore the use of scanning transition X-ray microscopy (STXM), a synchrotron-based technique, to determine the magnetic configuration of a single intracellular magnetosome chain.

STXM possess comparative advantages since provides spatially-resolution combined with element specification that by using X-ray magnetic circular dichroism (XMCD) as a magnetic contrast mechanism allows direct imaging the magnetization of intracellular magnetosomes (resolution ~ tens of nanometers) [7]. The viability of STXM to study this natural system was initially demonstrated in 2010 by Lam and coworkers firstly resolving the Fe L_3-edge XMCD signal from individual magnetosomes in remanence state within a magnetotactic cell [8]. In the present work we are stepping up direct addressing the magnetization process of a magnetosome chain in an intact magnetotactic bacterium while pioneering imaging the magnetic hysteresis of its individual magnetosomes. On the basis of the Stoner–Wohlfarth model we are able to accurately reproduce the experimental hysteresis loop of a single magnetosome shedding light on its anisotropy contributions, mostly dominated by the uniaxial shape anisotropy characteristic of their elongated morphology.

Acknowledgements

L. M. acknowledges the Basque Government for her postdoctoral fellowship (POS- 2019-2-0017).

References

[1] D. A. Bazylinski, T. J. Williams, C. T. Lefèvre *et al.*, *Int. J. Syst. Evol. Microbiol.*, **63** (2013) 1825–1833.
[2] K. L. Thomas-Keprta, S. J. Clemett, D. A. Bazylinski, et al. *Proc. Natl. Acad. Sci. U.S.A*, **98** (2001) 2164–2169.
[3] I. Orue, L. Marcano, P. Bender *et al.*, *Nanoscale* **10** (2018) 7407–7419.
[4] D. Gandia, L. Gandarias, I. Rodrigo *et al.*, *Small* **15** (2019) 1902626.
[5] O. Felfoul, M. Mohammadi, S. Taherkhani *et al.*, *Nat. Nanotechnol.* **11** (2016) 941–947.
[6] M. L. Fdez-Gubieda, J. Alonso, A. García-Prieto, *et al.*, *J. Appl. Phys.* **128** (2020) 070902.
[7] A. P. Hitchcock, *J. Electron Spectros. Relat. Phenomena* **200** (2015) 49–63.
[8] K. P. Lam, A. P. Hitchcock, M. Obst *et al.*, *Chem. Geol.* **270** (2010) 110–116.

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S205

Development of Novel MnAlC-based Permanent Magnet Composite Materials by Solution Casting to Obtain Flexible Filaments for 3D-printing

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Additive manufacturing (AM) is a fabrication technology with multiple applications in high-tech sectors such as automotive, energy, and aerospace as it allows fabricating objects with tuned properties, and reduced restrictions in shape and waste of material [1]. Developing permanent magnets (PMs) by AM requires a high filling factor in the printed objects together with no deterioration of their properties along fabrication. Despite many works are focused on NdFeB [2], the research of rare earth-free alternatives shows large scientific and technological interest. Improved ferrites and the promising MnAl-based alloys with enhanced PM properties are expected to partially plug the gap between conventional ferrites and NdFeB. Furthermore, they show high availability, reduced costs and environmental impact when extracting and processing raw materials [3].

In this work composites were synthesized by embedding gas-atomized τ-MnAlC particles (provided by Höganäs AB) into an ABS matrix by solution casting (Fig.1(a) and (b)). The influence of particle size and fine-to-coarse particle ratio has been analysed. They are key factors for obtaining flexible filament (length over 10 m) with a high content of PM particles (80 wt%) (Fig.1(c)) [4]. Magnetic measurements have shown that there is no deterioration of the PM properties of the starting particles along composite synthesis nor the filament extrusion [4]. MnAlC-based filament was used for printing 3D objects (Fig.1(d)), showing that alternative PM materials can be efficiently synthesized and processed for developing novel PMs by AM (Fig.1(e)) [4].

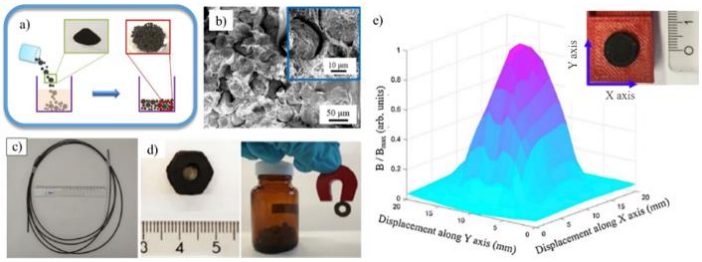

Figure 1. a) Solution casting method for composite synthesis, with representative images of the starting MnAlC powders and the resulting MnAlC/polymer composite. b) SEM image of a MnAlC (80 wt%) – ABS composite. c) Extruded MnAlC (80wt%) – ABS filament (a 20 cm ruler is included for scale comparison). d) Magnetic 3D-printed objects based on MnAlC – ABS composites. e) 3D plot of the magnetic flux density measured at the surface of a 3D-printed disc with a diameter of 10 mm.

Index Terms — Permanent magnet composite, MnAl, 3D-printing, Material extrusion.

Acknowledgements

Authors acknowledge financial support from the EU M-ERA.NET Network and MINECO through the projects "NEXMAG" (*Project Success Case* at H2020 M-era.Net Programme, Ref. PCIN-2015-126) and "3D-MAGNETOH" (Ref. MAT2017-89960-R); from the Regional Government of Madrid through "NANOMAGCOST" project (Ref. P2018/NMT-4321); and from Höganäs AB through the industrial contract "GAMMA". D.C. and J.V. acknowledge financial support from the Regional Government of Madrid (Refs. PEJD-2017-PRE/IND-4468 and PEJ16/IND/TL-1968, respectively).

References

[1] L. E. Murr, *J. Mater. Sci. Technol.* **32** (2016) 987–995.
[2] C. Huber *et al.*, *Appl. Phys. Lett.* **109** (2016) 162401; J. Jaćimović *et al.*, *Adv. Eng. Mater.* **19** (2017) 1700098.
[3] A. Bollero *et al.*, *ACS Sustainable Chem. Eng.* **5** (2017) 3243; J. Rial *et al.*, *Acta Mater.* **157** (2018) 42–52.
[4] E.M. Palmero *et al.*, *Sci. Technol. Adv. Mater.* **19** (2018) 465; *Compos. Part A Appl. Sci. Manuf.* **124** (2019) 105497; *IEEE Trans. Magn.* **55** (2019) 2101004; *Addit. Manuf.* **33** (2020) 101179.

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S206

Low-Cost Electronic System for Detection and Quantification of Magnetic Nanoparticles Based on Source Coupled Oscillators

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Bioanalysis of many samples in short times and at low cost is a challenge of modern times. These requirements are fulfilled by Lateral Flow Immunoassays (LFIA.) They are chromatographic tests based on nitrocellulose strips on which the molecule of interest is immobilized by an immunoreaction and labelled to make it visible. This provides a presence/absence response (naked eye evaluation) or a quantitative response based on optical measurements (e.g. reflectance). Unfortunately, the latter is influenced by light and color interferences like the staining of the paper strip. To overcome this issue, magnetic nanoparticles have been recently proposed as labels [2]. In previous works, reading the immunoassays involves costly equipment that adds complexity to the analysis.

Currently, low-cost electronic systems based on oscillators [3] are used to profit from the high magnetic permeability of superparamagnetic nanoparticles. These systems measure the oscillator's resonant frequency as a function of the number of nanoparticles present on the transducer, which is basically an inductor.

In this work, a different type of oscillator is proposed, tested, and compared to the previous systems. Source coupled oscillators (SCO) [4] use a resonant network known as resonant tank, which relies on the transducer inductance and stray capacitances only. This fact implies that the measurement accounts for the electric permittivity and magnetic permeability of the nanoparticles. The tested prototype succeeded in increasing the signals and sensitivity in a very remarkable way (the new sensitivity with the same transducer is 8 times the previous one.) After further optimization of the transducer design for the new working principle, we have got an improvement of the sensitivity of 32 times respect to the prototype's first version (Fig. 1).

For the measurement, electronically controlled micro-positioners perform a sweeping measurement at different points on the sample. Various prototypes for the oscillators were built and tested (see Fig. 2). All the mechanical parts except for the motor are polymer-based to avoid any spurious induction caused by metallic moving parts. The measurement and the movement are sequentially controlled to reduce magnetic field's variations produced by the power electronics that drive the motor. The best-performing prototype was tested to quantify LFIAs performed to detect neutravidin in liquid samples.

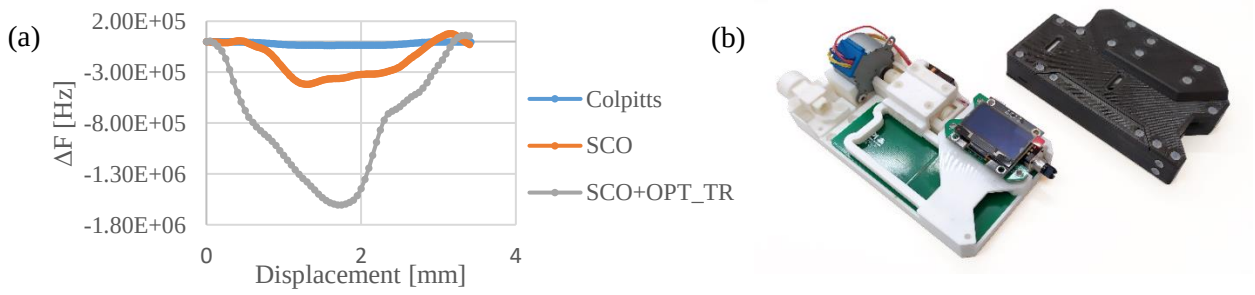

Figure 1 (a) Variation of the resonant frequency produced by the nanoparticles with the different electronics; (b) Two tested prototypes.

References

[1] X. Huang, Z. P. Aguilar, H. Xu, W. Lai, Y. Xiong, *Biosensors and Bioelectronics* **75** (2016) 166–180.
[2] D. Lago-Cachón *et al.*, *IEEE Magnetics Letters* **8** (2017) 1–5.
[3] K. Kriz, F. Ibraimi, M. Lu, L. Hansson, D. Kriz, *Anal. Chem* **77** (2005) 5920–5924.
[4] B. Koster, P. Waldowand, I. Wolff, *RF Design* **24** (2001) 58-68.

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S207

Coexistence of Dual Spin Dynamics in $GdCu_2$ Superantiferromangetic Nanoparticles

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Rare Earth intermetallics exhibit a *rich variety of magnetic structures and are highly influenced by crystal electric field effects* [1]. A typical family of these Rare Earth intermetallics are the binary RCu_2 systems (R = Rare Earth, X = non-magnetic metal), where the R^{3+}-ions couple antiferromagetically thanks to the polarization of the 3d Cu electrons (RKKY exchange). From the R series, Gd^{3+} deserves high interest, as it displays a high magnetic moment ($J = 2$, $\mu_{eff} = 7.94\ \mu_B$) but no crystal field effect ($L = 0$). For this alloy, a recent work [2] has shown how the bulk Néel transition, located at $T_N \approx 41$ K, is observed within the nanoparticle state, where a low temperature Spin Glass state also takes place at $T_f \approx 25$ K. Recent works [3-4] have shown the importance of controlling the magnetic disorder for technological applications such as in skyrmions or for Giant Magnetocaloric Effect purposes. *It becomes then, mandatory, to understand the outburst of magnetic disorder from the basis in nanoparticle systems*. In this work, *we have undergone a profound study of milled $GdCu_2$ alloys* with milling times 0.5 - 5 hours, thereby obtaining magnetic nanoparticles (MNPs) reaching sizes down to 7 nm. X-Ray Diffraction has confirmed that all samples displayed the same crystalline structure (*Imma*) as in the parent bulk alloy, with lattice parameters $a = 4.331(2)$ Å, $b = 6.896(3)$ Å and $c = 7.3499(1)$ Å. The strain factor introduced by the milling is keep below 0.90(7) %.

AC-susceptibility measurements performed by SQUID magnetometry demonstrate that, as milling time increases, the antiferromagnetic phase coexists with a growing magnetic disorder, causing the appearance of a freezing transition at $T_f \approx 25$ K, much higher than that in other RCu2 alloys, as e.g. in $TbCu_2$ where $T_f = 15$ K [5]. This transition causes the appearance of magnetic irreversibility in the thermal variation of DC-magnetisation. Additionally to the expected dissipation associated with T_f, an unexpected out-of-phase contribution is observed at $T \approx 33.5$ K. In order to attain more information about the spin dynamics in both transitions, we have performed memory effect and aging measurements following the same procedure as in [6]. Whereas the low temperature freezing transition evidences both memory effects and rejuvenation phenomena, the high temperature one reveals a slow dynamics, with no aging nor memory effects.

Given the above mentioned findings, the low temperature freezing state is driven by frustrated magnetic moments located in both the nanoparticle shell and core. These give rise together to a Super Spin Glass arrangement, where the interaction among the magnetic moments imply a quick dynamic behaviour. On the other hand, the high temperature dissipation is revealing the non-interacting behaviour of the uncompensated spins that are associated with the AF arrangement. ***Thereby, a coexistence of two spin relaxation processes with dual dynamics is found.***

Acknowledgements

This work has been supported by the MAT2017-83631-C3-R grant. EMJ thanks the "Beca de Colaboración" BOE-B-2016-33433 granted by the "Ministerio de Educación, Cultura y Deporte" and the "Beca Concepción Arenal" BOC-133-09-07-2018 granted by the Gobierno de Cantabria.

References

[1] N. H. Luong and J. J. M. Franse, (1995). Magnetic properties of rare earth-Cu_2 compounds. *Handbook of Magnetic Materials* **8**, 415–492.
[2] E. M. Jefremovas *et al*., *Nanomaterials* **10**(6) (2020) 1117.
[3] R. Rajivgandhi *et al*., *Journal of Alloys and Compounds* **815** (2020) 152659.
[4] K. Everschor-Sittte *et al*., *Journal of Applied Physics.* **124** (2018) 240901.
[5] C. Echevarria-Bonet *et al*., *Journal of Physics: Condensed Matter* **27** (2015) 496002.
[6] P. Svedlindh *et al*., Physical Review B **46** (1992) 21.

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S208

Magnetic Detection of Neural Activity in Spinal Cord Slices

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Current neural interfacing approaches are based on detecting electric potentials at the brain level, and/or triggering functional electrical stimulation (FES) through electrodes at muscular or SC levels [1]. However, these approaches present drawbacks such as the large number of cables and electrodes they require and, specially, the lack of sensory feedback. The ultimate non-contact sensing devices (magnetoencephalography) detect magnetic-field pulses generated by potentials at the brain, but require cryogenic temperatures, and, hence, are not portable. We will exploit here the enhanced properties of nanostructured materials to develop improved room temperature magnetoresistance-based high-resolution magnetic sensors [2]. In this work we will present the recent advance on the detection of neural activity in ex-vivo spinal cord slice cultures. We have overcome several issues that compromise the functionality of the end prototype, mostly the noise rejection that impedes the detection of signals as small as few nano Tesla by using a gradiometric approach (see Figure). With this approach, we have successfully recorded neural magnetic signals in laboratory conditions, with real-time monitoring and without magnetic screening. To corroborate such an activity we have performed simultaneously electrophysiological measurements in neural cultures activated by bicuculline-strychnine. As a further test we have inhibited the neural activity by perfusing tetrodotoxin in the culture and recording the activity, i.e. magnetic and electrical recordings, observing its successful inhibition. This experiment paves the way towards the incorporation of magnetic detection in neural interfaces, being key piece of research in order to achieve the final prototype of a fully implantable by-pass for neural reconnections.

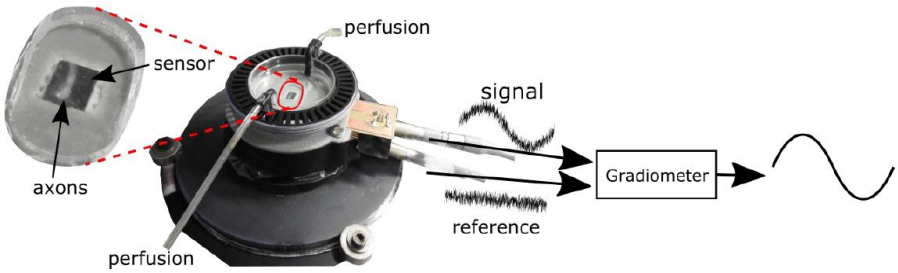

Figure 1. Set-up for the magnetic recording of neural activity. Two sensors are used in a gradiometric configuration in order to subtract the background noise from the signal.

Acknowledgements

This work was funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 737116.

References

[1] L. Gill Megan *et al*., *Nature Medicine* **24** (2018) 1677–1682.
[2] L. Caruso *et al*., *Neuron* **95** (2017) 1283–1291.

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S209

Deconvoluting Overlapped Phase Transitions in Biphasic Magnetocaloric Composites by the Scaling Laws of the Magnetocaloric Effect

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The isothermal entropy change, ΔS_{iso}, due to a second-order phase transition (SOPT) in magnetic materials collapse onto a single universal curve when a phenomenological scaling procedure is applied [1]. However, distortions from the universal curve can occur for SOPT materials when they exhibit multiphase character with phase transition temperatures near to one another. These distortions become more evident for cases where the transition temperatures and ΔS_{iso} responses of the various phases are similar to one another [2].

One such challenging case is the biphasic $Gd_{80}Pd_{20}$ composite, which comprises of similar phase fractions (Gd and Gd_7Pd_3) and the Curie temperatures of each phase are separated by ~ 45 K [3,4]. In this work, we propose a procedure to deconvolute these overlapping SOPTs of $Gd_{80}Pd_{20}$ based on the scaling laws of the magnetocaloric effect. Rescaled curves of the global response of the composite have been obtained applying the scaling procedure to each magnetocaloric peak separately. The response of each phase was then deconvoluted from the rescaled curve corresponding to the lowest field in each case. Assuming non-interacting phases, the response of the composite was reconstructed from the addition of the two deconvoluted responses. The cross effects of the two phases, i.e. the overlapping of the transitions, had to be taken into account by the application of an iterative procedure, reaching a good agreement between experimental and reconstructed responses of the composite for all values of applied field. The deconvoluted response of Gd phase was compared with the response of pure Gd to estimate the mass fraction of this phase within the composite, obtaining a good agreement with x-ray diffraction results. This procedure enables the prediction of the ΔS_{iso} response of a desired pure phase even in the presence of residual magnetic contributions.

Index Terms — Magnetocaloric effect, scaling laws, magnetic composites.

Acknowledgements

This work was supported by AEI/FEDER-UE (grants MAT-2016-77265-R and PID2019-105720RB-00), Consejería de Economía y Conocimiento of the Regional Government of Andalucía (grants US-1260179 and P18-RT-746), the Army Research Laboratory under Cooperative Agreement Number W911NF-19-2-0212 and Research Project No. 2019/03/X/ST5/00066 in 2019–2020 financed by the Polish National Science Centre.

References

[1] V. Franco, A. Conde, *Int. J. Refrig.* **33** (2010) 465–743.
[2] V. Franco, R. Caballero-Flores, A. Conde, Q. Y. Dong, H. W. Zhang, *J. Magn. Magn. Mater.* **321** (2017) 1115–1120.
[3] P. Gębara, Á. Díaz-García, J. Y. Law, V. Franco, *J. Magn. Magn. Mater.* **500** (2020) 166175.
[4] Á. Díaz-García, P. Gębara, J. Y. Law, V. Franco, *JOM* **72** (2020) 2845–2852.

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S210

Water Assisted Sol-gel Synthesis of $Ba_{1-x}Bi_xTi_{1-y}Co_yO_3$: Growth, Structure and Multiferroic Properties

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In the last few decade multiferroic materials, where magnetism and ferroelectric polarization coexist, have attracted great attention from researchers due to the interest in their potential application [1, 2]. There are a large number of ABO_3 type perovskites that exhibit ferroelectric behavior. Among all of these $BaTiO_3$ is the best and well defined ferroelectric ceramics that possess enormous multifunctional properties on doping with transition metal ions [3,4]. In the present study, we have synthesized polycrystalline samples of $Ba_{1-x}Bi_xTi_{1-y}Co_yO3$ (x=0, 0.5 and 0.075; y=0.025, 0.05 and 0.075) using the sol-gel technique. The obtained samples are characterized by X-ray diffraction (XRD) for structural study. Rietveld refinement of XRD analysis identifies the structural transformation from tetragonal to pseudocubic due to the substitution of Bi^{3+} and Co^{3+}ions on both Ba and Ti sites. The dielectric properties of Bi substituted $BaTiO_3$ were investigated as a function of Bi dopant concentration. The insertion of Bi increases the transition temperature and the value of the maximum of the dielectric constant ε_r max and reduces the dielectric losses. All samples show the behavior of a classical ferroelectric material and the Curie-Weiss law is well respected. On contrast, incorporation of Co^{2+} ions enhance the ferromagnetic properties of $BaTiO_3$.

Index Terms — $BaTiO_3$, Single phase multiferroics, Rietveld refinement analysis, ferroelectricity, dielectric properties, magnetic properties.

Acknowledgements

The authors would like to express their sincere gratitude to Instituto de Magnetismo Aplicado,UCM-ADIF for the magnetic characterizations. Authors are also thankful to Departamento de Electrocerámica, Instituto de Cerámica y Vidrio, ICV-CSIC for providing dielectric and ferroelectric characterizations.

References

[1] K. F. Wang, J.-M. Liu, Z. F. Ren, *Adv. Phys.* **58** (2009) 321.
[2] Z. H. Chi, C. J. Xiao, S. M. Feng, F. Y. Li, C. Q. Jin, X. H. Wang, R. Z. Chen, L. T. Li, *J. Appl. Phys.* **98** (2005) 103519.
[3] B. Ertuğ, *Am. J. Eng. Res.* **2** (2013) 1–7.
[4] D. Khomskii, *Physics* **2** (2009) 20.

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S211

Nanoscale Manipulation of Magnetic Domains by Interfacial Strain-induced Proximity

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Coupling between lattice degrees of freedom and the spin systems without the use of magnetic fields allows for efficient spintronic devices. In this context, hybrid nanostructures composed of a vanadium oxide undergoing a first-order, structural phase transition (SPT) and a ferromagnet (FM) offer a promising route to control of magnetism by strain-induced proximity. An enhanced coercivity response (up to 500% increase) is found in Ni/V_2O_3 bilayers in a very narrow T range [1]. By synchrotron-based X-ray microscopy we show a reconfiguration of the FM domain pattern across the V_2O_3 SPT together with changes in magnitude and direction of the effective uniaxial Ni magnetic anisotropy. In addition, the lateral correlation length of the Ni domains shows a significant increase at the SPT and a broad distribution of the local transition temperatures is found. The microscopic findings are supported by macroscopic static and dynamic magnetometry measurements as well as by micromagnetic simulations. All the above features point to nanoscale phase coexistence of Ni magnetic anisotropies induced by interfacial stress transfer with the V_2O_3 across the SPT of the latter [2].

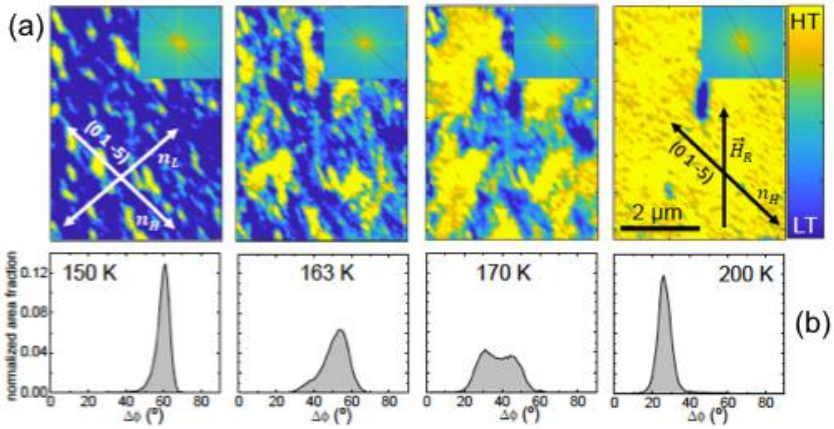

Figure 1. (a) XMCD-PEEM images recorded at temperatures below (150 K), across (163 K, 170 K) and above (200 K) the SPT of V_2O_3. The insets show their Fourier transforms. (b) Histograms of the rotation of the Ni magnetization, Δϕ, with respect to the initial high-temperature saturated state. Experimental and simulated temperature dependence of $\Delta\phi$.

Acknowledgements

This work was supported by Spanish MCIU and AEI (MAT2015-68772-P; PGC2018-097789-B-I00) and European Union FEDER funds, as well as the Office of Basic Energy Science, U.S. Department of Energy, BES-DMS funded by the Department of Energy's Office of Basic Energy Science, DMR under grant DE FG02 87ER-45332.

References

[1] J. de la Venta *et al*., *Appl. Phys. Lett.* **102** (2013) 122404; *Appl. Phys. Lett.* **104** (2014) 062410.
[2] I. Valmianski *et al*., submitted.

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P01

Spin Orbit Driven Effects and Thermal Activation of Ferromagnet Intercalated Graphene-Heavy Metal Interfaces

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The development of room temperature magnetic devices exploiting Spin Orbit effects is at the forefront of actual research. A major challenge for future spintronics is to develop suitable spin transport channels with superior properties such as long spin lifetime and propagation length. Graphene (Gr) can meet these requirements, even at room temperature [1]. However, the development of all-graphene spintronic devices requires that, in addition to its passive capability to transmit spins over long distances, other active properties are incorporated to graphene. The generation of long range magnetic order and spin filtering in Gr have been recently achieved by molecular functionalization [2,3] as well as by the introduction of giant spin-orbit coupling (SOC) in the electronic bands of Gr [4]. On the other side, taking advantage of the fast motion of perpendicular magnetic anisotropy (PMA) chiral spin textures, i.e., Néel-type domain walls (DWs) and magnetic skyrmions, can satisfy the demands for high-density data storage, low power consumption and high processing speed.

Here, we report on high quality, epitaxial Gr/Co(111)/heavy-metals (HM) (111)-oriented stacks grown on insulating oxide crystals, characterized by XPS, LEED, STEM, Kerr Magnetometrry and Microscopy, XAS-XMCD, and SP-ARPES, which exhibit enhanced PMA for Co layers up to 4 nm thick and left-handed Néel-type chiral DWs stabilized by interfacial Dzyaloshinskii-Moriya interaction (DMI) localized at both Gr/Co and Co/HM interfaces with opposite sign [5]. While the DMI at Co/Pt side is due to the intrinsic SOC [6], the sizeable DMI experimentally found at the Gr/Co interface has Rashba origin [5]. The active magnetic texture is protected by the graphene monolayer and stable at 300 K in air, and, since it is grown on an insulating substrate, amenable to transport measurements. In addition, our XPS and STM demonstrate that Co atoms evaporated on top of Gr arrange in 3D clusters and, upon thermal annealing, penetrate through and diffuse below Gr in a 2D fashion [7]. The complete intercalation of the metal occurs at specific temperatures, depending on the type of metallic buffer. The activation energy and the optimum temperature for the intercalation processes are determined. We describe a reliable method to fabricate and characterize in situ high-quality Gr-FM/HM heterostructures, enabling the realization of novel spinorbitronic devices that exploit the extraordinary properties of Gr.

Acknowledgements

This research was supported by the Regional Government of Madrid through projects P2018/NMT-4321 (NANOMAGCOST-CM) and P2018/NMT-4511 (NMAT2D) and by the Spanish Ministry of Economy and Competitiveness (MINECO) through projects RTI2018-097895-B-C42, FIS2016-78591-C3-1-R, PGC2018-098613-B-C21, PGC2018-093291-B-I00, FIS2015-67367-C2-1-P, and PCIN-2015-111 (FLAGERA JTC2015 Graphene Flagship "SOgraph"). IFIMAC acknowledges support from the ″Maria de Maeztu″ programme for units of Excellence in R&D (MDM-2014-0377). IMDEA Nanoscience is supported by the "Severo Ochoa" programme for the Centres of Excellence in R&D, MINECO (grant number SEV-2016-0686).

References

[1] W. Han, R. K. Kawakami, M. Gmitra, J. Fabian, *Nat. Nanotech.* **9** (2014) 794.
[2] M. Garnica *et al.*, *Nat. Physics.* **9** (2013) 368–374.
[3] D. Maccariello *et al.*, *Chemistry of Materials.* **26**(9) (2014) 2883–2890.
[4] F. Calleja *et al.*, *Nat. Physics.* **11** (2015) 43–47.
[5] F. Ajejas *et al.*, *Nano Letters.* **18**(9) (2018) 5364–5372.
[6] F. Ajejas *et al.*, *Appl. Phys.Lett.* **111** (2017) 202402.
[7] F. Ajejas *et al.*, *ACS Appl. Mater. Interfaces.* **12**(3) (2020) 4088–4096.

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P02

Evaluating the Heating Efficiency of Iron Oxide Nanoparticles for Photothermal Therapies

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Iron oxide nanoparticles are the most studied systems for thermal therapy in biological systems, via magnetic hyperthermia. Iron oxide nanoparticles are suitable for biomedical applications because of its biocompatibility and colloidal stability, that could be increased by coating the nanoparticles with inorganic molecules (dextran, APS, citric acid...). In the last years, many studies have shown that these nanoparticles release heat when irradiated with a near infrared laser [1][2][3]. This effect opens up new lines of investigation.

The aim of this work is to go deep on the understanding of the heating efficiency of different phases of Fe_2O_3, when subjected to an infrared laser. α -Fe_2O_3 (hematite) and γ -Fe_2O_3 (maghemite) have been synthetized using sol-gel and co-precipitation synthesis route, obtaining a mean size of 30 nm and 11 nm, respectively. Both samples have been coated with dextran to improve colloidal stability. The structural and magnetic properties have been characterized by XRD, HRTEM, and SQUID magnetometry. A Titanium:Saphire laser operating at 775 nm with 50 mW average power was used to irradiate the samples. The temperature increase (photothermal effect), has been measured with an infrared camera. The specific absorption rate (SAR) is the factor used to evaluate the nanoparticles heating efficiency.

This experimental work shows that both iron oxide phases are able to release heat. That is an interesting result because both have a gap energy above 2 eV, higher than the laser photon energy (1.6 eV), and even so they release heat. Another remarkable fact is that, in the case of γ-Fe_2O_3, the SAR decreases with increasing nanoparticle concentration (see Fig. 1); whereas in α-Fe_2O_3 the SAR has an opposite behaviour.

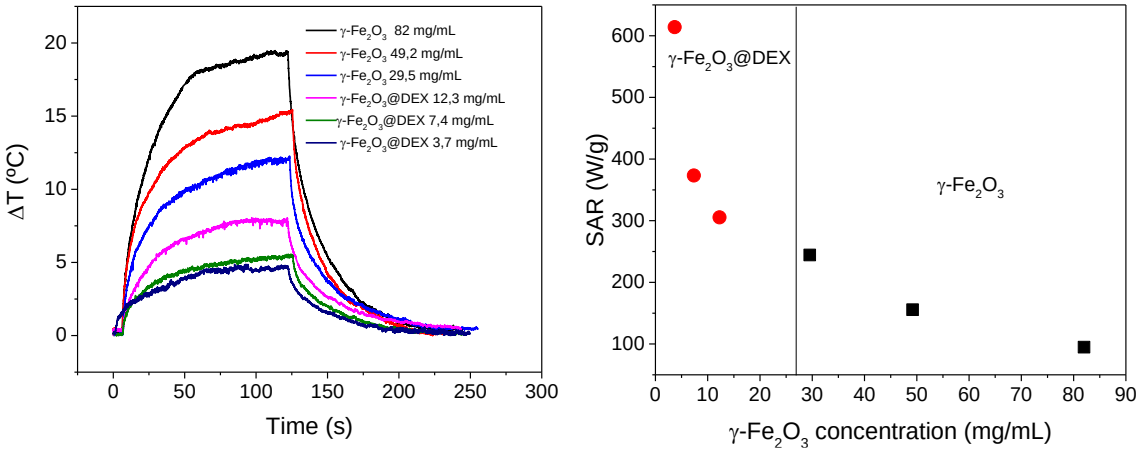

Figure 1. a) Thermal increase of γ-Fe_2O_3 nanoparticles at different concentrations. b) Dependence of SAR with the concentration.

References

[1] A. Espinosa, J. Kolosnjaj-Tabi, A. Abou-Hassan, A. Plan Sangnier, A. Curcio, A. K. A.Silva, R. Di Corato, S. Neveu, T. Pellegrino, L. M. Liz-Marzán, C. Wilhelm, *Adv. Funct. Mater.* **28** (2018) 1803660.

[2] P. Pan, Y. Lin, Z. Gan, X. Luo, W. Zhou, N. Zhang, *Journal of Applied Physics* **123** (2018) 115115.

[3] A. Espinosa, M. Bugnet, G. Radtke, S. Neveu, G. A. Botton, C. Wilhelm, A. Abou-Hassan, *Nanoscale* **7** (2015) 18872–18877.

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P03

Improved Averaging of Hysteresis Loops from Micromagnetic Simulations of Non-Interacting Uniaxial Nanoparticles

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Micromagnetic simulations [1] allow us to understand the magnetization reversal of magnetic systems, but the computational cost scales up with the size and, in the case of bulk-scale systems, it becomes an impossible task to face unless certain assumptions are made (e.g. uniform and fully saturated magnetization or simplified anisotropy). However, those simplifications do not work for more complex systems with domain walls, shape anisotropy or exchange-bias.

Macroscopic ensembles of non-interacting Magnetic Nanoparticles (MNP) can be modelled as an average of a set of isolated single-domain nanoparticles where magnetocrystalline anisotropies force the particle moments in a wide range of directions. To reduce computational time in such systems, we propose an optimized method of hysteresis loop averaging that takes advantage of high rotational symmetry of spherical particles and proves convenient for energy landscapes such as that in magnetocrystalline uniaxial systems.

This improved method reduces the number of simulations required to generate macroscopic-like non-interacting and randomly oriented ensembles of magnetic nanoparticles (i.e. a dilute powder), as compared to the usual mean arithmetic averaging of hysteresis loops. To verify the good agreement of the averaging method we have compared our results with the well-known Stoner-Wohlfarth hysteresis loop [2], thus matching magnetic properties such as coercivity, remanence and energetic product with a relatively low count of simulations [Figure 1].

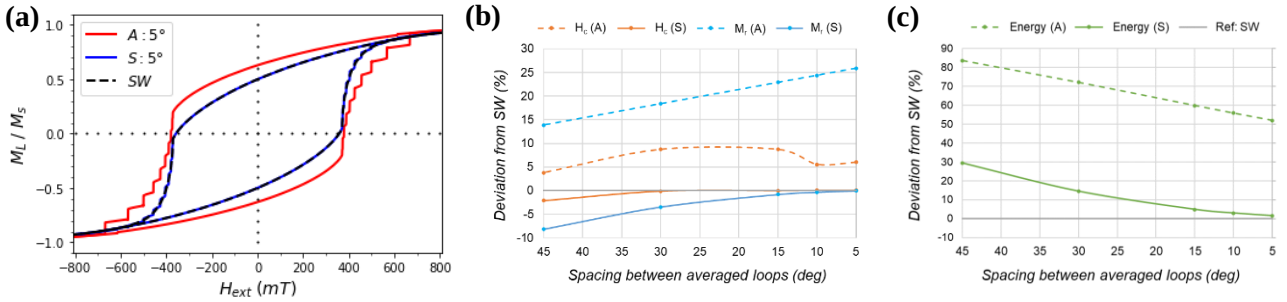

Figure 1. (a) Hysteresis loops of randomly-oriented and non-interacting Co(hcp) MNPs by mean arithmetic (A, red) and optimized spheroidal-based (S, blue) averaging methods from single MNP's hysteresis loops calculated every 5 degrees. Comparison with Stoner-Wohlfarth model is shown in black. (b) and (c) show convergence of coercive field H_c, remanence M_r and magnetic as spacing between averaged loops decreases and hence number of simulations increase (from 3 to 19 simulations for 45 and 5 degrees, respectively.

Index Terms — Magnetic Nanoparticles, Micromagnetic Simulations, Stoner-Wohlfarth, Uniaxial Anisotropy, Macroscopic Hysteresis Loops.

Acknowledgements

This work has been possible thanks to the MICINN, as a part of the Project MAT2015-65295-R: "Nanocomposites magnéticos para aplicaciones en energía y sensores". Rafael Delgado-Garcia thanks UCLM and Banco Santander for the scholarship for research initiation during his Master studies.

References

[1] A. Vansteenkiste, J. Leliaert, M. Dvornik, M. Helsen, F. Garcia-Sanchez, B. Van Waeyenberge, *AIP Adv.* **4** (2014).
[2] C. Tannous, J. Gieraltowski, *Eur. J. Phys.* **29** (2008) 475.

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P04

Rare Earth-free MnAlC Permanent Magnets Produced by Hot-pressing from ε-phase Gas-atomized and Milled Powder

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Permanent magnets (PMs) are widely used in energy, transport, and electronic applications. Criticality issues related to rare-earth elements (REEs) make MnAlC alloy a promising REE-free PM candidate able of plugging the gap between ferrites and NdFeB magnets. The first step towards this goal requires achieving a proper combination of magnetization (provided by the only ferromagnetic phase of the system: τ-MnAl) and coercivity. The synthesis of pure τ-MnAl(C) phase alloy has been widely reported in literature, providing an in-deep knowledge on the fabrication parameters involved in its synthesis [1]. This is not the case however when referring to the development of coercivity while preserving a high magnetization. We have recently shown the possibility of developing coercivity in gas-atomized MnAl powder by applying milling times as short as 30 s via the self-developed "flash milling" method [2]. A successful combination of nanostructuring and a controlled phase transformation process is behind the observed increase in coercivity [2].

In this study we have prepared ε-phase MnAlC powder by gas-atomization (in collaboration with Höganäs AB) and flash-milling. A novel result is the demonstration that MnAlC magnets can be prepared by hot-pressing taking ε-phase powder as a precursor and managing, in a single step, both the ε to τ-MnAlC phase transformation and the powder compaction to result in a high-density (93%) MnAlC magnet [3]. Figure 1(a) shows the X-ray diffraction (XRD) pattern of the magnet (hot-pressed powder) and, by comparison, that of the precursor (ε phase powder), proving the successful ε to τ phase transformation due to the combination of temperature and pressure applied during the compaction process [3]. The hysteresis loop measured for the magnet (Fig. 1(b)) shows a high coercivity close to 0.3 T and a superior magnetization at remanence by comparison with the optimally annealed gas-atomized powder. This is a promising cost-efficient route which opens the path to new possibilities for the fabrication of MnAlC-based magnets.

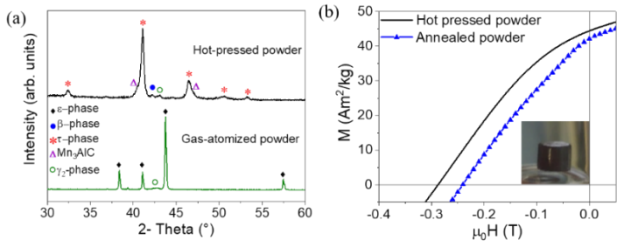

Figure 1. (a) XRD patterns of gas-atomized and hot-pressed MnAlC powders. (b) Room temperature hysteresis loops (second quadrant) of the annealed and the hot-pressed powders. Inset shows the resulting compacted MnAlC magnet.

Index Terms — Permanent magnets, MnAlC alloy, Nanostructured material, Gas-atomization, Hot-pressing

Acknowledgements

IMDEA acknowledges financial support from EU M-ERA.NET and MINECO through the projects "NEXMAG" (Project Success Case at H2020 M-era.Net Programme, Ref. PCIN-2015-126) and "3D-MAGNETOH" (Ref. MAT2017-89960-R); Regional Government of Madrid through "NANOMAGCOST" project (Ref. P2018/NMT-4321); and Höganäs AB through the industrial collaboration "ECNanoManga".

References

[1] V. Øygarden *et al.*, *J. Alloys Compd.* **779** (2019) 776.
[2] J. Rial *et al.*, *Acta Mater* **157** (2018) 42; *Engineering* **6**(2) (2020) 173.
[3] C. Muñoz-Rodríguez *et al.*, *J. Alloys Compd.* **847** (2020) 156361.

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P05

Spin Waves in Cylindrical Nanowires in the Vortex State

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Magnetic nanowires (NWs) have recently received considerable attention due to their potential applications in magnetic storage technology. While their static magnetic properties have been well investigated, their magnetization dynamics have received less attention [1,2]. Due to their reduced dimensions, the possibility to control spin wave (SW) confinement in the direction perpendicular to the NW´s axis and the possibility to couple electromagnetic waves to the magnetization textures with non-trivial topologies (e.g. the vortex state), designates these patterned structures as good candidates to next generation SW based information processing technologies.

Here we present experimental results of dynamic stimulation of hexagonally ordered arrays of Fe28Co63Cu10 NWs with 120 and 150 nm diameter, 300 nm lattice constant and few tens of microns in length. Microwave permeability investigated with DC and microwave magnetic fields perpendicular to the nanowire axis shows enhanced losses in the low frequency range range for magnetic field below 2 kOe.

In order to understand this behavior, we have simulated spin waves in 1-5 micron long range. We observed the formation of a vortex state on the NW ends for a field close to the one with experimental losses. We have also carried out a detailed investigation of how the excited SW modes depend on the NW length, as well as its evolution as a function of the distance from the NW end and the product of vortex polarity and vortex chirality. Our simulations are able to distinguish between two different types of the SW modes: lower frequency modes localized close to the NW ends and higher frequency delocalized modes, which are described as plane waves with a finite pinning at the NW ends. The simulation results are in qualitative agreement with the analytical model based on the generalized Thiele equation for the vortex core string. The model accounts for the exchange and non-local magnetostatic interactions.

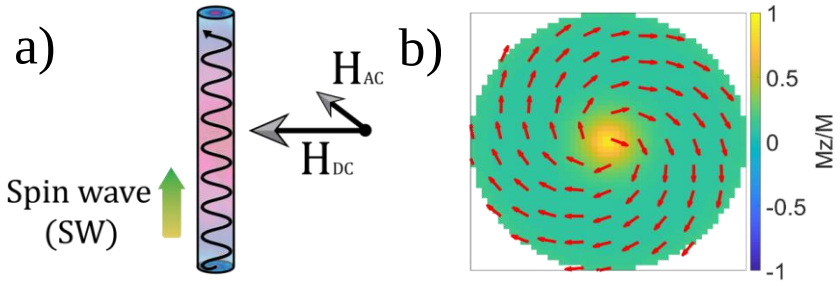

Figure 1. a) Sketch of a cylindrical NW with dc and ac magnetic fields applied in the transverse direction. b) Magnetization distribution at the ends of the NW showing a vortex state.

Acknowledgements

The work has been supported by Spanish MINECO (RTI2018-095303-B-C55; EUIN2017-87474) and the Comunidad de Madrid through NANOMAGCOST-CM (P2018/NMT-4321). DC acknowledges contract PEJ-2018-AI/IND-10364 from Comunidad de Madrid.

References

[1] C. Bran *et al.*, *ACS Nano* **12** (2018) 5932−5939.
[2] J. A. Fernandez-Roldan *et al.*, *Nanoscale* **10** (2018) 5923.

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P06

Modelling of Magneto-thermoelectric Response from a Domain Wall

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Thermal magnetometry is a novel rapidly developing tool which makes use of the fact that thermoelectrical response of a nanostructure depends on its magnetic state. The use of nanometric local heat spots, e.g. from an actively and controllably heated scanning probe, with localized thermal gradients allows a nanoscale magnetization mapping of localized spin textures such as pinned domain walls [1]. The measured voltage is a convolution of magnetization and temperature distribution in the presence of several spin-caloritronic effects and thus its interpretation is not straightforward. Here, we model the thermoelectric response of Néel and Bloch domain walls in FeCoB nanostripes with or without a lithographed notch. The heat distribution is modelled by solving the Poisson heat equation for different positions of the heated probe across and along the stripe. Thermal modelling is used as an input for large scale thermal micromagnetics using the Landau-Lifshitz-Bloch approach [2]. Our modelling shows that at room temperature both Neel and Bloch domain walls represent energetically stable configurations, pinned at the notch. The presence of localized an asymmetric heat source forces the domain wall to widen and curve. Additionally, Bloch structures appear locally inside the Néel domain wall. With the aim to understand different responses, we model separately electric response of both domain walls in the presence of anomalous Nernst (ANE), perpendicular and parallel Seebeck (SE) effects and study their symmetry. The comparison with recent experiment demonstrates that only the response of the Neel domain wall under the action of both ANE and SE is compatible with the symmetry of the experimentally measured voltage.

References

[1] P. Krzysteczko *et al*., *Phys. Rev. B* **95** (2017) 220410 (R).
[2] O. Chubykalo-Fesenko *et al*., *Phys. Rev. B* **74** (2006) 094436.

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P07

Mild Electro-mechanical Processing of Water-quenched Amorphous Microwires for Property Improvements

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The rapidly solidification techniques to fabricate amorphous microwires generate strong mechanical stresses which, coupled to magnetostriction, determine their magnetic properties in competition with exchange interaction plus shape anisotropy energy terms [1]. However, most technological applications employing amorphous microwires rely on the quality of their geometrical and compositional homogeneity [2]. In this concern, small variations of the fabrication parameters can result in inhomogeneities that degrade the magnetic properties. Thus, in this work a novel mild electromechanical treatment is demonstrated to improve their morphology without damaging their structural and magnetic properties.

Amorphous microwires with zero-magnetostriction composition $(Co_{0.94}Fe_{0.06})_{72.5}Si_{12.5}B_{15}$ (130 μm diameter) were prepared by the in-rotating-water-quenching technique. The microwires also exhibit an undulating shape due to quench instabilities arising from the conditions such as the pressure of the ejecting gas, the drum rotation velocity and the melt ejection temperature.

The as-quenched wires were subjected to an electromechanical annealing that passes an electrical current through the microwire (maximum current density of 50 MA/m^2) for ~140 seconds in a vertical configuration under constant tensile stress (maximum of 130MPa). The structural and magnetic changes induced by the electromechanical treatments were assessed by DSC, TGA, electrical resistivity and VSM probes.

After annealing the samples showed a nicely straight shape, losing both natural and undulating morphology (Fig. 1). In addition, the microwires were confirmed to be amorphous, with partly relaxed structure, and maintained ultrasoft magnetic behavior with a coercivity of about 130 mOe (Fig. 2). This mild electromechanical annealing is demonstrated to be successful for the precise control over the morphology, structure and magnetism of amorphous microwires to optimize their technological applicability.

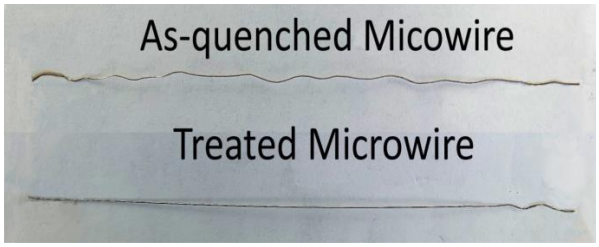

Figure 1. Images of the microwire in as-cast and after annealing (current density of 47 MA/ m^2).

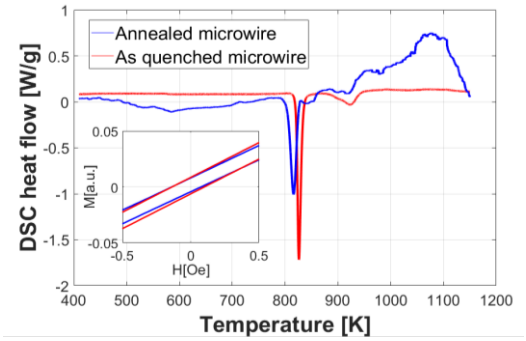

Figure 2. DSC for as-quenched and annealed microwire. Difference between treated and as-quenched samples.

Index Terms — Amorphous magnetic microwires, Thermal treatment, Quality control, Relaxation.

Acknowledgements
This work was supported by "Fulbright España" Program and the Regional Government of Madrid (Spain).

References

[1] M. Vazquez (2007). *Advanced Magnetic Microwires, in Handbook of magnetism and advanced magnetic materials*. Ed. H. Kronmüller & S. Parkin, John Wiley & Sons, Cambridge, **4** (2007) 2183−2223.
[2] M. Butta, M. Vazquez, R. Perez del Real, E. Calle, *AIP Advances* **10** (2020) 025114.

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P08

Tuning Microwave Absorption Property of Few-layered Graphene/ Magnetic Microwires Composite Materials for Electromagnetic Interference Shielding

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In this work a microwave absorbing material (MAM) based on few-layered graphene (FLG)/ magnetic microwire composite is studied using free-space measures in an anechoic chamber. Magnetic microwires consisting in an amorphous metallic alloy nucleus covered by a borosilicate shell has a well-known microwave absorbance [1, 2]. FLG was obtained by a novel dry ball milling method and fully characterized with XRD, SEM, TEM, FTIR and Raman spectroscopy and Uv-Vis light absorbance techniques [3].

Graphene based materials (GBM) such as FLG are suited as reinforces in composite materials thanks to their high specific surface, excellent mechanical properties and chemical resistance, although standalone GBMs exhibit poor microwave absorbing performance [4]. Recently combinations of GBMs with other MAM have attracted broad research interest due to synergetic effects that improves their microwave absorbance.

FLG and magnetic microwires were dispersed on a commercial indoor paint and a thin layer was deposited on a dielectric substrate. The reflection loss parameter (RL) of these paints was measured using two horn antennas in a bandwidth of 2-18 GHz, obtaining 40-50 dB absorptions of the incident wave. Furthermore, different compositions proved that the maximum absorbance can be tuned to a specific frequency.

These results are currently under study and yet to be published. The use of graphene in this material is expected not only to reduce its cost but to add new features such as the frequency tuning here presented.

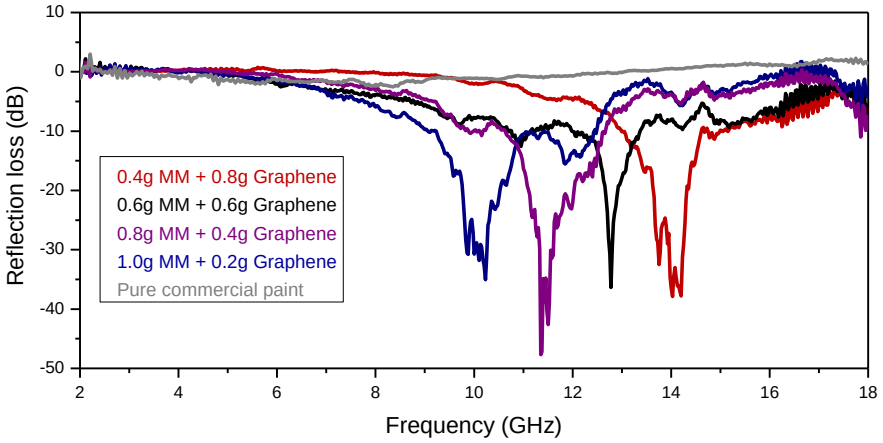

Figure 1. Microwave absorbance of different compositions of the FLG/ magnetic microwire composite material.

References

[1] P. Gueye, J. López, E. Navarro, A. Serrano, P. Marín, *ACS Appl. Mater. Interfaces*. **12** (2020) 15644−15656.
[2] P. Marín, D. Cortina, A. Hernando, *IEEE Transactions on Magnetics*. **44** (2008) 3934−3937.
[3] A. Peña, E. Navarro, J. López, P. Marín, D. Matatagui, M. C. Horrillo, *Patent nº* ES 2779151 A1 (2020).
[4] F. Meng *et al.*, *Composites Part B.* **137** (2018) 260−277.

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P09

Controlling the Magnetic Bubbles Configuration in CoPt multilayers

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Perpendicular Magnetic Anisotropy (PMA) multilayers have been intensely studied in the past due to their applications in magnetic recording [1]. More recently, this kind of materials has renewed its interest due to the discovery of the DMI (Dzyaloshinskii-Moriya Interaction) that appears in the interfaces of ferromagnetic and heavy metals multilayers [2] [3]. DMI interaction promotes the development of exotic configurations so called "skyrmions" and bubbles of great interest in spintronics [4].

In this work, CoPt nanostructures with different shapes and sizes are fabricated by electron beam lithography. The CoPt multilayers are grown by sputtering over Si/SiO_2 substrates. Apart from the macroscopic characterization of the CoPt thin films, the nanostructures have been studied by AFM (Atomic Force Microscopy) and MFM (Magnetic Force Microscopy). The goal of this work is to control the nucleation, motion and annihilation of the magnetic bubbles by applying external magnetic fields and current. Nanometer size magnetic bubbles are created in these PMA multilayer nanostructures as demonstrated by the MFM imaging experiments. Besides the MFM imaging in remanent state, a Variable Field MFM system has been used to obtain images under in-plane or out of plane magnetic fields [5]. By applying an *in-situ* out of plane magnetic field in the VF-MFM system, we are able to control the density of bubbles due to their annihilation. The shape and the size of the bubbles is also analyzed as well as the dependence with the geometry of the nanostructures.

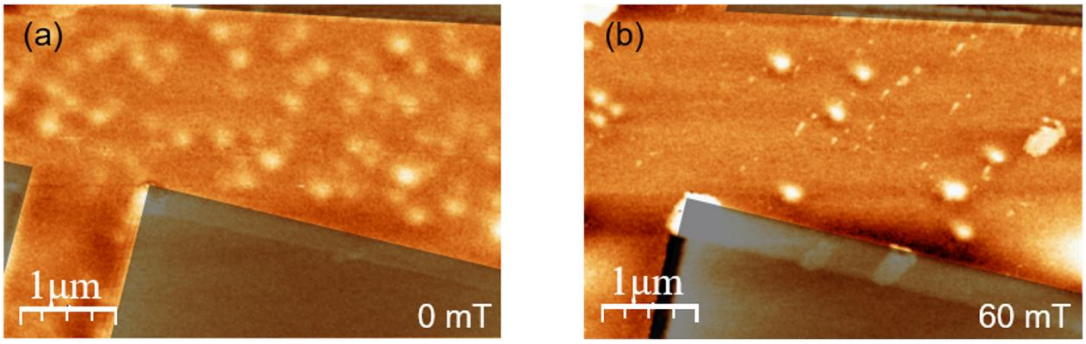

Figure 1. MFM images in remanence of a selected area of a nanostructure (a) after the nucleation of the bubbles and (b) after applying a perpendicular field of 60 mT antiparallel to the bubble magnetic moment.

Index Terms — PMA multilayers, magnetic bubbles, Variable Field Magnetic Force Microscopy.

Acknowledgements

This work has been supported by the Spanish Ministry of Economy and Competitiveness (MINECO) under Project MAT2016-76824-C3-1-R and from the Regional Government of Madrid under Project S2018/NMT4321 NANOMAGCOST-CM. J. M.-M. acknowledges the Spanish Ministries of Science, Innovation and Universities through FPU Program No. FPU18/01738.

References

[1] A. Kirilyuk *et al.*, *J. Magn. Magn. Mater*. **171** (1997) 45−63.
[2] I. Dzyaloshinskii, *J. Phys. Chem. Solids* **4**(4) (1958) 241−255.
[3] T. Moriya, *Phys. Rev. Lett.* **4**(5) (1960) 228−230.
[4] J. Sampaio *et al.*, *Nat. Nanotechnol.* **8** (2013) 839−844.
[5] M. Jaafar *et al.*, *Ultramicroscopy* **109**(6) (2009) 693−699.

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P10

Superferromagnetic Behavior on Ordered Superlattices of Uniaxial Nanoparticles: A Micromagnetic Approach

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Magnetic nanoparticle (MNP) systems can experience multipolar-based magnetostatic contributions that gain relevance as the concentration of the system increases. Consequently, their response to magnetic fields can switch from individual to supermagnetic behaviors, such as super-spin glass (SSG) or superferromagnetic (SFM) states [1]. For nanostructured superlattice MNP arrays, spacing between nanoparticles can be controlled by non-magnetic coatings in core-shell schemes avoiding exchange interactions between MNPs.

We have performed micromagnetic simulations [2] of superlattice arrangements of Co(hcp) randomly oriented MNPs, studying lattice anisotropy effects in remanent state and hysteresis loops for a variety of superlattices, including simple cubic (SC), body-centered cubic (BCC) and face-centered cubic (FCC) orderings with major testing of parameters such as lattice parameter and layer growth.

Results [Figure 1 (a)] have shown decreased coercivity and increased remanence in (100) direction from Stoner-Wohlfarth behavior (valid for non-interacting uniaxial nanoparticles) [3], evidencing the contribution of multipolar interactions due to the high ordering of the MNPs in the superlattice structure. This magnetostatic contribution gives rise to a lattice anisotropy that orients the NP's magnetic moments into the plane, as polar plots of remanence have shown [Figure 1 (b)], and hence reduces the total magnetic energy of the system.

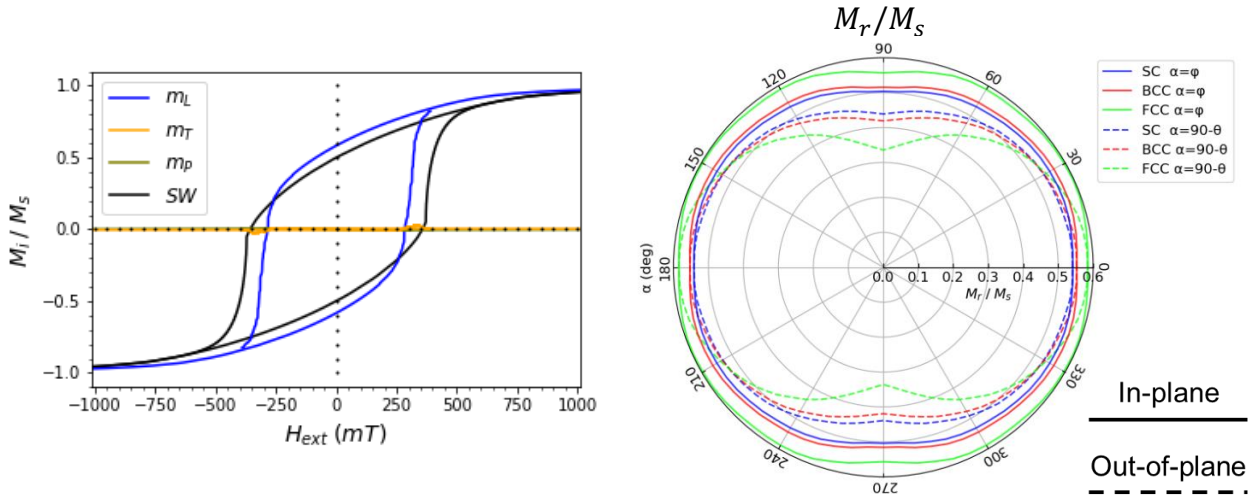

Figure 1. (a) Hysteresis loop in (100) direction of a single layer FCC superlattice of randomly oriented Co(hcp) NPs with lattice parameter of 14 nm. Comparison with Stoner-Wohlfarth is shown in black. (b) Polar plots of reduced remanence M_r/M_s of in-plane and out-of-plane angular swepts in SC, BCC and FCC superlattice orderings.

Index Terms — Magnetic Nanoparticles, Superlattices, Stoner-Wohlfarth, Anisotropy, Dipolar Interactions.

Acknowledgements

This work has been possible thanks to the MICINN, as a part of the Project MAT2015-65295-R: "Nanocomposites magnéticos para aplicaciones en energía y sensores". Rafael Delgado-Garcia thanks UCLM and Banco Santander for the scholarship for research initiation during his Master studies.

References

[1] S. Bedanta, O. Petracic, W. Kleemann, in *Handb. Magn. Mater*, Elsevier B.V. (2015) 1–83.
[2] A. Vansteenkiste, J. Leliaert, M. Dvornik, M. Helsen, F. Garcia-Sanchez, B. Van Waeyenberge, *AIP Adv.* **4** (2014).
[3] C. Tannous, J. Gieraltowski, *Eur. J. Phys.* **29** (2008) 475.

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P11

Magnetic Nanoparticles: Synthesis, Characterization and Applications

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Interest in magnetic nanoparticles has grown in the last years because their versatility to be used in several applications including industrial[1], environmental and biomedical applications[2]. This work is focused on the synthesis of magnetite (Fe_3O_4) to be employed as magnetic adsorbents when combined with metal organic frameworks (MOFs) to remove contaminants from water, and the synthesis of Fe_xCo_{1-x}[3] to be used as magnetic fillers in magnetorheological fluids applications.

Magnetite nanoparticles were synthesized by employing co-precipitation method with and without surfactant. Stable NPs with a mean size about 13±3 nm and a M_s of 77 Am^2/kg were achieved by employing sodium citrate as surfactant. The good dispersion of these NPs facilitates the growth of the metal-organic framework (MOF) in their surface and their M_s is enough to recover the NPs after contaminants adsorption process.

Fe_xCo_{1-x} alloy NPs were synthesized by employing chemical reduction method with aluminum and ammonium fluoride as reducing agents. All these nanoparticles showed good crystallinity and good magnetic properties. The magnetorheological fluids were prepared by employing FeCo near equiatomic as magnetic fillers. This fluid showed a strong magnetorheological response and a good reversibility after demagnetization process.

Index Terms — Magnetic nanoparticles, metal-organic framework, contaminants, recovery, magnetorheological fluids, reversibility.

Acknowledgements

This work was financially supported by the Basque Government through PI-2017-1-0043 (PIBA Program), ACTIMAT KK-2020/00099 (Elkartek Program), and IT 12126-19, 12145-19 projects. Technical and human support provided by SGIker (UPV/EHU) is also gratefully acknowledged.

References

[1] S. Genc, B. Derin, *Curr. Opin. Chem. Eng.* **3** (2014) 118–124.
[2] L. Mohammed, H. G. Gomaa, D. Ragab, J. Zhu, *Particuology* (2016) 1–14.
[3] Z. Klencsár, P. Németh, Z. Sándor, T. Horváth, I. E. Sajo, S. Mészáros, J. Mantilla, J. A. H. Coaquira, V. K. Garg, E. Kuzmann and Gy. Tolnai, *J. Alloys Compd.* **674** (2016) 153–161.

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P12

Controlling interfacial phenomena in hybrid V_2O_3/Co bilayers

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The research on hybrid systems combining dissimilar materials with artificial interfaces is among the major challenges of the nanotechnology during the last decades. Bilayers composed of a ferromagnetic (FM) layer interfaced with a transition-metal-oxide (TMO) layer can be consider as model hybrid systems. V_2O_3 is a archetypical TMO system exhibiting a first-order metal insulator transition (MIT) when the temperature is decreased below T_{MIT}= 170 K [1], from a paramagnetic metallic state to an antiferromagnetic (AFM) insulating phase, accompanied simultaneously by a structural phase transition [2]. Below T_{MIT}, several interfacial exchange-coupling effects have already been found in similar FM/V_2O_3 bilayers [3], ranging from moderate to negligible exchange bias fields, enhanced giant coercive fields and unique dynamical effects.

Here we present a detailed angular and temperature dependent angle-resolved vector magnetometry study of the system mentioned across the MIT. This provides fundamental insights on how to tailor and control the interfacial exchange effects. More specifically, we investigated the magnetic anisotropy landscape of Co/V_2O_3 bilayers, where the Co layer has a well-defined uniaxial magnetic anisotropy at room temperature (Fig.1a1 and Fig.1b1). We have studied the effects using different magnetic anisotropy configurations by setting a magnetic orientation of the FM layer across the MIT transition by means of different field cooling (FC) procedures. Just after the FC, the low temperature (50 K) loops display strong interfacial exchange coupling effects (Fig.1a2 and Fig.1b2), i.e., enhanced coercive field, clear exchange bias, and asymmetric magnetization reversal. In general, depending on the FC procedure, different angle-dependent and temperature evolutions are found, which are ascribed to the modifications of the anisotropy configuration. Our findings demonstrate that we have an effective control of the interfacial exchange phenomena in the FM/TMO heterostructures, especially across the MIT, which enables the development of novel magnetic devices with specific functionalities.

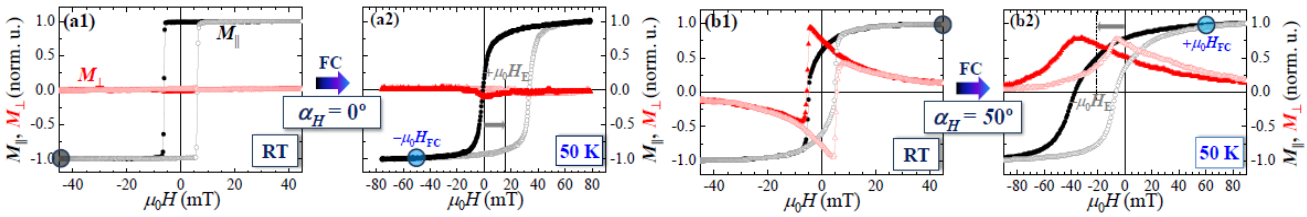

Figure 1. Representative v-MOKE loops of a V_2O_3 (100 nm)/Co (15 nm) heterostructure above (a1,b1) and below (a2,b2) the MIT transition using different field-cooling (FC) conditions: **a)** Negative-FC along the easy axis and **b)** Positive-FC around 50º off the easy axis

Acknowledgements

This research was partially supported by the Spanish Ministry of Economy and Competitiveness (MINECO) (grant numbers FIS2016-78591-C3-1-R, RTI2018-097895-B-C42, and SEV-2016-0686) and by the Regional Government of Madrid (through project NANOMAGCOST-CM). JMD acknowledges support from MINECO through FPI program (BES-2017-080617). Work at UCSD supported by the Office of Basic Energy Science, U.S. Department of Energy, BES-DMS funded by the Department of Energy's Office of Basic Energy Science, DMR under grant DE FG02 87ER-45332. We thank C. Urban, and J. Trastoy for initial work and discussions on this problem.

References

[1] M. Imada, A. Fujimori, Y. Tokura, *Rev. Mod. Phys.* **70**, (1998) 1039-1263.
[2] Y. Kalcheim, et al. *Phys.Rev. Lett.* **122**, (2019) 057601.
[3] J. de la Venta *et al*., *Appl. Phys. Lett.* **102** (2013) 122404

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