MA 8: Focus Session: Magnetic structurally and compositionally modulated nanowires and nanotubes

There is an increasing scientific activity on magnetic nanowires and nanotubes with tunable circular section (as opposed to nanostripes). Length, diameter, shell thickness and materials can be selected from a wide range of magnetic alloys and elements. Axially and radially modulated structured can be synthesized. These families of cylindrical wires and tubes are currently proposed in a number of applications ranging from specific media for magnetic memory applications (*race-track*), microwave applications (*stealth* absorbing materials), magnetic sensing elements and logic devices at the nanoscale (nano-technology), or for applications based on their magneto-thermo-electrical properties (*energy conversion and harvesting*). Other relevant applications include their organic functionalization for a number of biomedical applications. Most of those applications derive from their unique magnetic characteristics namely the magnetic configuration (e.g., magnetic domains), demagnetization process (e.g., nucleation and depinning of transverse or vortex domain walls; coherent/non-coherent rotational processes), and frequency dependent behaviour (e.g., microwave absorption phenomena). In short, the motivation of this Mini-colloquium is to bring together specialists and scientists interested in novel applications of anisotropic nanostructures to discuss and exchange ideas on both fundamental and applied issues of these nanowires and nanotubes.

Organized by: Manuel Vazquez (ICMM-CSIC, Madrid), Michael Farle (U. Duisburg-Essen), Kornelius Nielsch (IFW Dresden)

Time: Monday 15:00–18:30 Location: H 1012

Invited Talk MA 8.1 Mon 15:00 H 1012

Multiple nanostructures based on anodized aluminium oxide templates — •Yong Lei — Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau, 98693, Ilmenau, Germany

New physical phenomena and superior properties in solids usually involve couplings of adjacent materials and architectures in nano-scale. Binary nanostructure arrays, capable of introducing intimate interactions between different sub-component arrays, could raise a new horizon of nanotechnology. Here we proposed a concept to achieve diverse binary nanostructure arrays with high degrees of controllability for each of the sub-components, including material, dimension, and morphology. This binary nano-structuring concept originates from a distinctive binary-pore anodic aluminum oxide template that possesses two dissimilar sets of pores in one matrix. Moreover, the binary-pore template is evolvable to multi-pore (ternary and quadruple) templates with higher pore densities and more morphologic options. Binary nanostructure arrays with different material and morphology combinations were explored, and shall lead towards applications such as in catalysis, energy conversion and magnetic devices. [1] Wen L., Xu R., Mi Y., Lei Y., Nature Nanotechnology, 12, 244, 2017.

MA 8.2 Mon 15:30 H 1012

3D cobalt nanotubes grown by focused electron beam induced deposition — Javier Pablo-Navarro[1], •César Magén[1,2], Amalio Fernandez-Pacheco[3], Luis Alfredo Rodriguez[4], and José María De Teresa[1,2] — [1]Laboratorio de Microscopias Avanzadas (LMA), Instituto de Nanociencia de Aragon (INA), Universidad de Zaragoza, 50018 Zaragoza, Spain — [2]Instituto de Ciencia de Materiales de Aragon (ICMA), Universidad de Zaragoza-CSIC, 50009 Zaragoza, Spain — [3]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE, UK — [4]Departamento de Física, Universidad del Valle, A. A. 25 360, Cali, Colombia

Magnetic nanotubes are potential candidates for fast and low-power domain wall conduit in future 3D spintronic devices. We report for the first time the successful growth of 3D cobalt nanotubes by focused electron induced deposition (FEBID) on 3D Pt-FEBID nanowire templates of 100 nm in diameter. Cross sectional Transmission Electron Microscopy characterization has confirmed that nanotubes with a wall thickness down to 11 nm can be achieved. These cobalt nanotubes are nanocrystalline and present a metallic content of 70 at. Co%. Magnetic characterization by electron holography and MOKE magnetometry experiments on individual nanotubes demonstrate that these nanostructures are ferromagnetic, with an estimated remanent magnetic induction of 0.9 T and coercivity around 160 Oe. This work evidences that FEBID is a suitable technique to grow complex functional heterostructures in 3D with potential for application in high density magnetic memory and logic devices.

Invited Talk MA 8.3 Mon 15:45 H 1012

Towards a three dimensional curvilinear magnonic transducer — •Jorge A Otalora[1], Jürgen Lindner[2], Helmut Schultheiss[2], Kilian Lenz[2], Andy Thomas[1], Kornelius Nielsch[1,3], and Attila Kákay[2] — [1]Leibniz Institute for Solid State and Materials Research Dresden (IFW Dresden), Institute for Metallic Materials, 01069 Dresden, Germany — [2]HZDR, Institute of Ion Beam Physics and Materials Research, Bautzner Landstraße 400, 01328 Dresden, Germany — [3]Technische Universität Dresden, Institute of Materials Science, 01062 Dresden, Germany

Curving a two dimensional magnetic membrane gives rise to asymmetries in the spin-waves (SWs) properties. Magnetic nanotubes provides an example, for which the mean curvature of the tubular shape creates asymmetries in frequency and lifetime in a similar fashion like the Dzyaloshinskii-Moriya interaction in a ferromagnetic/heavy metal interface. Here, an inductive transducer composed of two coplanar wave guides and a magnetic nanotube is proposed, predicting a straightforward access to the curvature-induced asymmetric properties of SWs via detecting the reflection/transmission parameters of the device. With the presented results, it is expected to give a step further towards the implementation of curved membranes as three dimensional layouts for magnonic applications.

Invited Talk MA 8.4 Mon 16:15 H 1012

Controlled domain wall propagation in cylindrical nanowires — •Cristina Bran — Institute of Materials Science of Madrid, CSIC, 281049 Madrid, Spain

Cylindrical magnetic nanowires represent an alternative for nanotechnological applications such as 3D magnetic recording [1], actuators or sensors and logical devices where the control over the position and motion of domain wall (DW) is crucial. The nanowires present important advantages such as: the possibility to tailor the DW shape or the stability and high velocity of DW during its motion due to suppression of Walker breakdown [2]. Here we show a way of controlling DW propagation in these one-dimensional nanostructures by specific designs in geometry (i.e., modulations of diameter), or in magnetic anisotropy (i.e., modulations in the composition) [3]. In this way, the modulation will act as pinning center for nucleation, pinning and depinning of DWs. These local variations changes the typical single-domain state present in soft NWs, as well as the mono domain wall-type switching of the magnetization based on the DW nucleation and propagation. A detailed description of the magnetic configuration of individual cylindrical Co-based NWs is presented by combining XMCD-PEEM which allows resolving the surface and the internal magnetic structure of NWs, magneto-optical Kerr effect and micromagnetic simulations. [1]. S. Parkin et al., Nature Nanotechnology 10, 195 (2015). [2]. M. Yan et. al. Phys. Rev. Lett. 104 (2010) 057201 [3]. C. Bran et al., J. Mater. Chem. C 4, 978 (2016)

15 minutes break

Invited Talk MA 8.5 Mon 17:00 H 1012

Magnetic hardening of nanowires by sandwiching with antiferromagets — •Ulf Wiedwald — Faculty of Physics and Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, Germany — National University of Science and Technology MISIS, Moscow, 119049, Russian Federation

The growth of magnetic nanowires (NWs) in anodic aluminum oxide (AAO) is a nowadays well-established technique [1]. Such NWs have been suggested as rare earth-free permanent magnets or magnetoelectric logic devices [2]. Exploiting the shape anisotropy of 3d-metal NWs at aspect ratios of several hundred in principle yields in a huge magnetic energy product. However, due to vortex formation at the tips and dipolar coupling of neighboring wires it is significantly reduced.

Interfacing the tips with antiferromagnet layers is suitable to overcome such limitations as recently shown by oxidation [2]. We explore the magnetic hardening of FeCo NWs at 300 K by coating their tips with antiferromagnetic FeMn. For this purpose, free-standing tips of micron-long NWs with a diameter of 40 nm are isolated from the AAO membranes and covered with few nm FeMn. In the resulting sandwich structure, the energy product doubles at 300 K due to suppression of vortices [3]. Financial support of the Ministry of Education and Science of the Russian Federation, Increase Competitiveness Program of NUST MISiS K3-2017-022 is gratefully acknowledged.

[1] K. Nielsch et al., Appl. Phys. Lett. 79, 1360 (2001). [2] S. Liébana-Viñas et al., Nanotechnol. 26, 415704 (2015). [3] FZ. Wang et al. Nanotechnol. 28, 29 (2017).

MA 8.6 Mon 17:30 H 1012

Magnetization reversal and local switching fields of ferromagnetic microtubes with radial magnetization — •Norbert Puwenberg[1], Christopher Friedrich Reiche[1], Mishal Khan[1], Robert Streubel[2], Michael Melzer[1], Oliver Schmidt[1,3], Bernd Büchner[1,4], and Thomas Mühl[1] — [1]IFW Dresden, Dresden, Germany — [2]Lawrence Berkeley National Laboratory, Berkeley, USA — [3]TU Chemnitz, Chemnitz, Germany — [4]Technische Universität Dresden, Dresden, Germany

A simple type of three-dimensional magnetic nanostructures can be formed by rolling-up magnetic thin films. We investigated the field-dependent stray-field distribution of rolled-up Co/Pd nanomembranes [1] by multi-frequency magnetic force microscopy (MFM) under vacuum conditions. Stray field and topography were mapped simultaneously by employing mechanical and electrostatic AC excitation of the fundamental and the second flexural cantilever oscillation mode [2]. We will present MFM images showing demagnetized multi-domain states as well as homogeneous remanent states after saturation. The detailed evaluation of field-dependent MFM series shows that the spatially resolved switching fields depend on the angle between the direction of the applied magnetic field perpendicular to the tube axis and the local surface normal of the tube surface. Our data corresponds to an angle range of 0° to 65°, which points to a Kondorsky-type behavior of the magnetization reversal in our rolled up Co/Pd nanomembranes.

[1] R. Streubel et al., Nature Communications 6, 7612 (2015)
[2] J. Schwenk et al., Appl. Phys. Lett. 107, 132407 (2015)

Invited Talk MA 8.7 Mon 17:45 H 1012

Hybrid Magnetoelectric Nanowires for Nanorobotic Applications — •Salvador Pané — Multi-Scale Robotics Lab, ETH Zürich, Switzerland

Over the past two decades researchers have been working to create synthetic small-scale machines ranging from molecular entities or miniaturized structures, to more complex assemblies of micro- and nanomaterials. These machines are able to navigate in complex environments by harvesting fuel from the surrounding media or from external powersources. One of the most sought-after applications for these miniaturized machines is to perform minimally invasive interventions, in which these devices will ultimately reduce risk, cost, and discomfort compared to conventional interventions. While recent research has demonstrated the potential of these devices, a number of obstacles remain in moving small-scale robots into the operating theatre. One of the major challenges is the development of miniaturized mobile platforms capable of integrating multiple functionalities. In this talk, we will present magnetoelectric-composite nanowire-based machines that, under the same source of energy, are able to perform two different functionalities depending on how magnetic fields are applied. The magnetostrictive component enables this machine to propel, while the magnetoelectric composite can be used to wirelessly generate a piezoelectric field. We will focus on the potential biomedical applications of these magnetoelectric small-scale robots. As an example, we will show core-shell magnetoelectric nanowires, which are able to release in vitro anti-cancer drugs on-demand using the magnetoelectric approach.

MA 8.8 Mon 18:15 H 1012

Magnetism and Transport in Hybrid Magnetic Nanowires — •Roman Hartmann, Sergej Andreev, and Torsten Pietsch — Fachbereich Physik, Universität Konstanz, 78464 Konstanz, Germany

Spin-based electronics present an alternative to conventional electronic devices. For example, spin-transfer nano-devices offer higher switching speeds and greatly reduced dissipative loss but often require large operation currents and are difficult to manufacture.

Herein we present a simple but versatile concept to fabricate complex magnetic nanowire devices in a single processing step via electrodeposition into a self-organized anodic aluminum (AAO) template. We demonstrate the fabrication of heteronanowires composed of magnetic multilayers of different ferro- and paramagnetic metals and alloys (e.g. Ni, Cu, NiCu) with diameters around 30 nm, which greatly reduces the drive current. Device integration is done using lithographic methods. The static and dynamic magnetic properties are analysed via SQUID magnetometry, FMR and electron transport spectroscopy. Due to their intrinsic multilayer geometry and large number of parallel wires, these structures can be employed in magnetic nano-oscillators for microwave generation and detection with optimized output power and sensitivity respectively.