SYMS 1: Three-Dimensional Nanostructures: From Magnetism to Superconductivity

Time: Monday 9:30–12:15 Location: H 0105

Invited Talk SYMS 1.1 Mon 9:30 H 0105
3D Racetrack Memory — •Stuart Parkin — Max Planck Institute for Microstructure Physics, Halle (Saale), Germany

Spintronics allows for advanced memory and storage technologies that go beyond today*s charge-based devices. Most of these technologies are innately two-dimensional and rely on 2D arrays of individual memory and switches that are connected via multiple levels of complex wiring. Going beyond 2D is highly interesting. Magnetic Racetrack Memory (RTM) is a unique memory-storage device that relies on the current driven motion of domain walls along magnetic conduits. Chiral domain walls can be driven at speeds exceeding 1 km/s in synthetic antiferromagnetic racetracks by spin currents generated via the spin Hall effect in proximal metallic layers. We show how 3D racetracks can be constructed by two very different techniques. In one case freestanding membranes composed of atomically engineered thin film heterostructures, that form the racetrack, are deposited onto a sacrificial water-soluble release layer. The freestanding membranes are transferred onto protrusions that have been pre-patterned onto sapphire wafers to create 3D racetracks. The current induced domain wall motion is nearly identical in these structures as compared to the initial 2D layers. In a second approach we fabricate 3D chiral magnetic racetracks via a novel state-of-the-art multi-photon lithography system. We show how the interplay between the geometrical chirality and the spin chirality of the individual domain walls allows for domain wall diode devices.

Invited Talk SYMS 1.2 Mon 10:00 H 0105
Curved electronics: geometry-induced effects at the nanoscale — •Paola Gentile — CNR-SPIN, I-84084 Fisciano (Salerno), Italy, c/o Università di Salerno, I-84084 Fisciano (Salerno), Italy

The growing demand for next-generation electronics has favored the growth of highly adaptable electronic functional elements capable of recognizing environmental changes by responding to electrical, magnetic, optical and thermal stimuli. Central to these customized appliances is the recognized possibility to modify and fine-tune the physical properties of essentially all electronic materials through a proper exploitation of geometric deformations and curvature effects at the nanoscale. The exciting developments in the discovery and exploitation of the innovative effects induced by curvature at the nanoscale allow ultimately to define a completely new field, that of *curved nanoelectronics* [1]. We here examine in details the origin of curvature effects at the nanoscale in low dimensional systems with structure inversion asymmetry, where the interplay between nanoscale deformations and Rashba spin-orbit coupling establishes a deep connection between electronic spin textures, spin transport properties, and the nanoscale shape of the system. We illustrate the potential applications of these effects in innovative electronic, spintronic, and in particular in superconducting devices.

[1] P. Gentile, M. Cuoco, O. M. Volkov, Z.-J. Ying, I. J. Vera-Marun, D. Makarov and C. Ortix, Nature Electronics 5, 551 (2022).

Invited Talk SYMS 1.3 Mon 10:30 H 0105
Curvilinear micromagnetism — •Denys Makarov — Helmholtz-Zentrum Dresden-Rossendorf e.V., Bautzner Landstrasse 400, 01328 Dresden, Germany

Curvilinear magnetism is a framework, which helps understanding the impact of geometrical curvature on complex magnetic responses of curved 1D wires and 2D shells [1,2]. In this talk, we will address fundamentals of curvature-induced effects in magnetism and review current application scenarios. In particular, we will demonstrate that curvature allows tailoring fundamental anisotropic and chiral magnetic interactions and enables fundamentally new nonlocal chiral symmetry breaking effect [3], which is responsible for the coexistence and coupling of multiple magnetochiral properties within the same magnetic object [4]. We will discuss the application potential of geometrically curved magnetic thin films as mechanically reshapeable magnetic field sensors for automotive applications, memory, spin-wave filters, high-speed racetrack memory devices, magnetic soft robotics as well as on-skin interactive electronics. [1] D. Makarov et al., Curvilinear micromagnetism: from fundamentals to applications (Springer, Zurich, 2022). [2] D. Makarov et al., New dimension in magnetism and superconductivity: 3D and curvilinear nanoarchitectures. Adv. Mat. 34, 2101758 (2022). [3] D. D. Sheka et al., Nonlocal chiral symmetry breaking in curvilinear magnetic shells. Comm. Phys. 3, 128 (2020). [4] O. M. Volkov et al., Chirality coupling in topological magnetic textures with multiple magnetochiral parameters. Nat. Comm. 14, 1491 (2023).

15 min. break

Invited Talk SYMS 1.4 Mon 11:15 H 0105
Study of 3D superconducting nanoarchitectures — •Rosa Córdoba — University of Valencia, Valencia, Spain

Innovative approaches exploit the 3D to propel electronic component development, paving the way for advancements in material science, physics, and nanotechnology. Consequently, the potential integration of 3D nano-superconductors into future highly efficient electronic elements is promising, despite existing challenges in their fabrication and characterization. This contribution introduces a direct-write additive manufacturing technique for precise fabrication of advanced 3D nano-superconductors. Notably, we have successfully produced 3D superconducting hollow nanocylinders and nanohelices with customizable geometries, achieving controllable inner and outer diameters as small as 32 nm. These nanostructures exhibit superconductivity at 7 K, demonstrating substantial critical magnetic field and critical current density. Remarkably, the nanohelices manifest superconductivity up to 15 T, contingent upon the magnetic field's orientation relative to the nanohelix axis. This observation underscores the significant influence of helical 3D geometry and orientation in a magnetic field during the superconducting phase transition. Furthermore, experimental findings, supported by numerical simulations based on the time-dependent Ginzburg-Landau equation, reveal distinct vortex and phase-slip patterns. Additionally, our work includes experimental modulation of electric field-induced superconductivity in nanowires, with theoretical explanations grounded in the Ginzburg-Landau theory.

Invited Talk SYMS 1.5 Mon 11:45 H 0105
3D nanoarchitectures for superconductivity and magnonics — •Oleksandr Dobrovolskiy — University of Vienna, Faculty of Physics, Nanomagnetism and Magnonics, SuperSpin Lab, Austria

Traditionally, the primary field, where curvature is playing a pivotal role, is the theory of general relativity. In recent years, however, the impact of curvilinear geometry attracts increasing attention in various disciplines, ranging from solid-state physics to chemistry and biology. In this talk, I will outline some current challenges associated with 3D nanoarchitectures for superconductivity and magnetism [1,2]. Two examples of ferromagnetic and superconducting systems will be considered in more detail. In the first example [3], due to strongly nonuniform demagnetizing field, by varying the crater diameter of a 3D nanovolcano, the high-frequency spin-wave eigenmodes can be tuned without affecting the lowest-frequency mode. Thereby, the extension of 2D nanodisks into the third dimension allows one to engineer their lowest eigenfrequency by using 3D nanovolcanoes with 30% smaller footprints. In the second example [4], due to the small film area in contact with the substrate, the noise-equivalent-power for a Nb 3D nanohelix microwave bolometer is about four orders of magnitude smaller than that for a commercially available sensor made from a 2D superconducting film. Therefore extending nanostructures into 3D has become a major research avenue in modern magnetism and superconductivity. [1] D. Makarov, et al. Adv. Mater. 34 (2022) 2101758. [2] V. Fomin and O. Dobrovolskiy, APL 120 (2022) 090501. [3] O. Dobrovolskiy, et al. APL 118 (2021) 132405. [4] S. Lösch, et al. ACS Nano 13 (2019) 2948.