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Fabrication of 3D nanoarchitectures by focused particle beams

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Extending 2D structures into the third dimension has become a general trend in various areas, including photonics, plasmonics and magnetics. This approach provides a means to modify conventional and to launch novel functionalities by tailoring vector potentials inducing anisotropic and chiral effects. Recently, there has been significant progress [1] in the fabrication of free-standing ferromagnetic and superconducting nanostructures by focused particle direct-write techniques, as in part reviewed in [2]. In this respect, 3D shell structures such as framed tubes, spheres, Swiss rolls and helices are especially interesting as they offer unprecedented prospects for nanomagnetism [3] and superconductivity [4] because of topology and geometry-controlled effects. Namely, in magnetism, curvilinear geometry brings about two exchange driven interactions - effective anisotropy and antisymmetric vector exchange, i.e. an effective Dzyaloshinskii-Moriya interaction. In addition, another magneto-chiral contribution emerges due to the dipole-dipole interaction. In the case of superconducting nanostructures, the combination of low-dimensionality with a curvilinear geometry allows in principle for the observation of topology-driven effects, such as unconventional phase slips, reversible and irreversible switching, fractional flux-flow instabilities, and the Berezinskii-Kosterlitz-Thouless transition.

In my talk, I will introduce focused ion and electron beam-induced deposition, FIBID and FEBID, respectively, as direct-write techniques suitable for the fabrication of free-standing 3D nanoarchitectures with a resolution in the sub-nm range vertically and 10-20 nm laterally. Next, I will dwell on selected proof-of-concept experiments, technological limitations, and future prospects of using 3D hybrid ferromagnet / superconductor structures with pre-defined shape and curvature in such research areas as microwave engineering [5], superconducting spintronics [6], magnon fluxonics [7], as well as graded-refractive-index spin-wave nano-optics [8].

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