From (almost) every angle: 3D magnetic nano-/micro-objects under X-ray scrutiny

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Magnetic (ultra)thin films and multilayers thereof have been under the spotlight for several decades, owing notably to the score of applications (sensors [1], memory devices [2], ...) that they enable. This being said, the considerable research efforts devoted to such systems have also been fuelled by the availability of a large number of experimental techniques suitable for their investigation. Examples range from magnetic force microscopy [3] to magneto-optical approaches [4] through recent developments such as nitrogen-vacancy-based stray-field microscopy [5].

In this presentation, I would like to show that geometries well beyond the typical flat, thin films can not only be produced but also probed with appreciable sensitivity and resolution. The focus will be placed on X-ray-based magnetic microscopy techniques that use X-ray Resonant Magnetic Scattering (XRMS) [6, 7] in order to access magnetization even in the volume of 3D samples.

To begin with, I am going to review some studies on ferromagnetic domains and domain walls in nanowires [8, 9] and nanotubes [10] where the better-known aspect of XRMS was used, namely X-ray Magnetic Circular Dichroism. Thereafter, I will show that its phase contrast counterpart, X-ray Magnetic Circular Birefringence, can be used with techniques such as Fourier Transform Holography, as my colleagues and I recently demonstrated in a vector tomographic experiment on a 800 nm thick multilayer [11]. In a manner of prospect, I will conclude with our recent work using Coherent Diffraction Imaging [12] with hard X-rays on micron-sized CoGd beads, with vector magnetic imaging as objective.

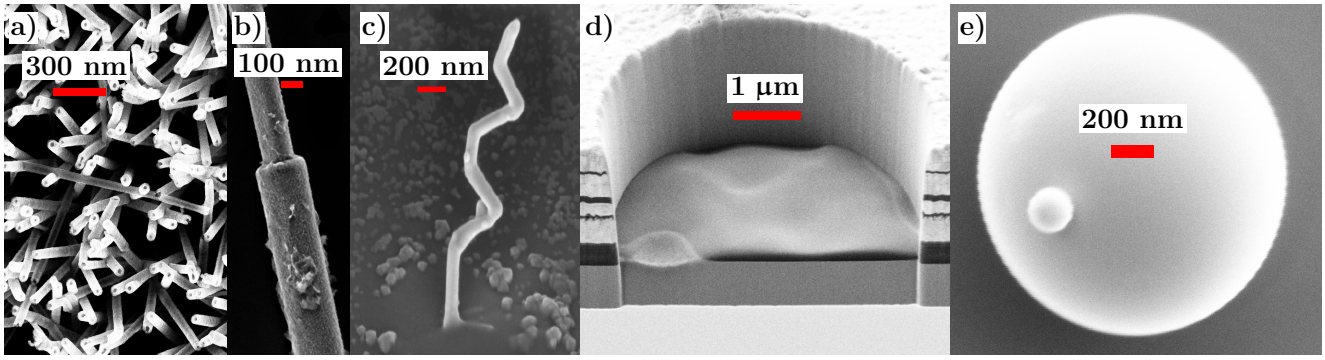

Figure 1: Scanning electron micrographs of 3D magnetic objects. a) Electroless-deposited cylindrical CoNiB nanotubes. b) An electroplated cylindrical NiFe nanowire. c) Core-shell Co@Pt nanowire grown with Focused-Electron-Beam-Induced Deposition (FEBID). d) A thick Fe/Gd multilayer (bottom) with a Ti/Au holography mask (top) grown on a SiN membrane. e) A pair of CoGd beads.

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