Growth of functional magnetic and superconducting materials by Focused Beam Induced Deposition techniques

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Focused Electron Beam Induced Deposition (FEBID) and Focused Ion Beam Induced Deposition (FIBID) techniques are single-step high-resolution lithography techniques capable of growth of functional nanomaterials on arbitrary substrates.[1] Our group has addressed the growth of magnetic and superconducting nanostructures using FEBID and FIBID. The use of $Co_2(CO)_8$ and $Fe_2(CO)_9$ precursors has allowed us to grow a large variety of magnetic nanostructures with high magnetic metal content (80-100%).[2] In particular, we single out the growth of two-dimensional ultra-narrow magnetic nanowires and Hall probes[3] (shown in Figure 1), the growth of three-dimensional magnetic nanowires[4] (shown in Figure 2) and the growth of magnetic nanostructures on cantilevers (shown in Figure 3).[5,6] Such functional magnetic deposits can be applicable in memories, logic and sensors.[2] Through tuning of the growth parameters, we have grown thickness-modulated magnetic deposits using the abovementioned precursors as well as thickness-modulated superconducting deposits using the $W(CO)_6$ precursor. As shown in Figure 4, this approach has been used to create highly-dense arrays of isolated individual magnetic nanowires (2,5 x 10^7 nanowires/cm).[7] The superconducting nanostructures with thickness modulation have been designed to produce one-dimensional pinning potential for the vortex lattice occurring when a perpendicular magnetic field is applied.[8] On the other hand, narrow (50 nm) W-based superconducting nanowires exhibit remarkable finite-size effects.[9] Recent results on these topics (still unpublished) will be additionally described.

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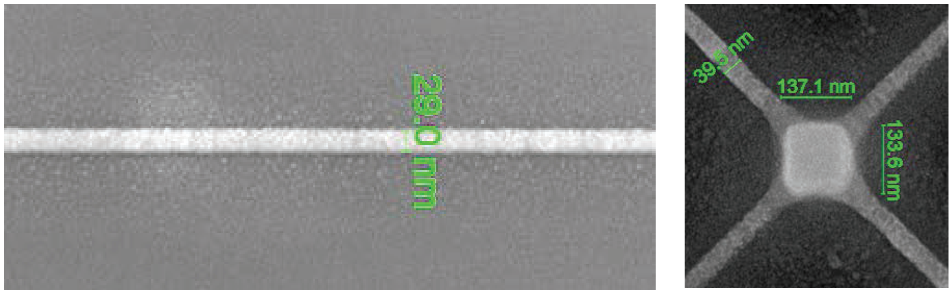

Figure 1. Examples of two-dimensional ultra-narrow magnetic nanostructures grown by FEBID. *Left*: Cobalt nanowire. *Right*: Cobalt Hall-cross probe.

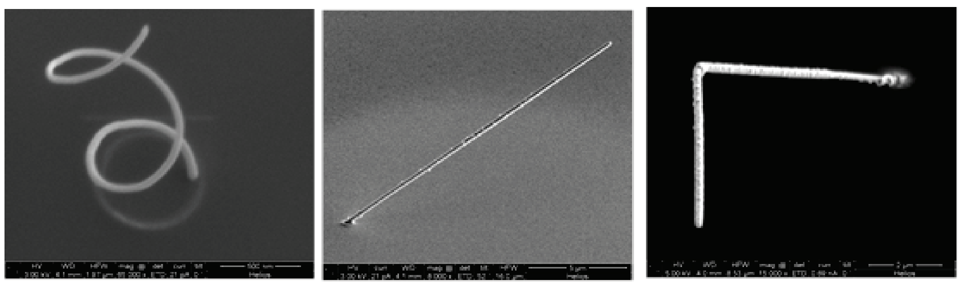

Figure 2. Examples of three-dimensional cobalt nanowires grown by FEBID: *Left*. Two-loop spiral nanowire. *Middle*: High aspect-ratio nanowire forming 45º with the substrate surface. *Right*: Nanowire with a 90º turning point.

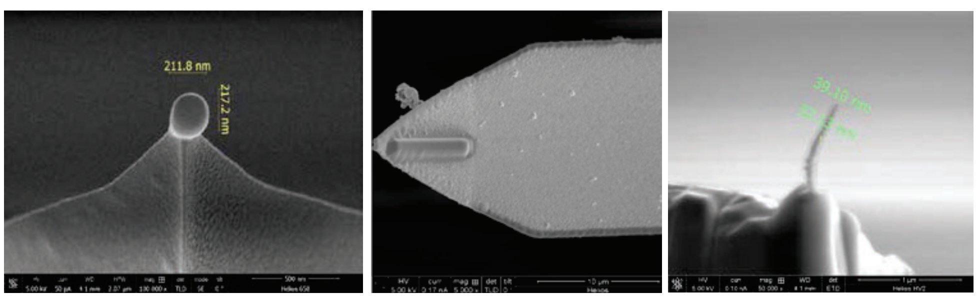

Figure 3. Examples of cobalt nanostructures grown by FEBID on unconventional surfaces: *Left*. Cobalt nanosphere on the tip of an ultra-soft cantilever for Ferromagnetic Resonance Force Microscopy studies. *Middle*: Cobalt nanowire on the tip of a piezoresistive cantilever. *Right*: Nanowire on a tip for Magnetic Scanning Probe Microscopy applications.

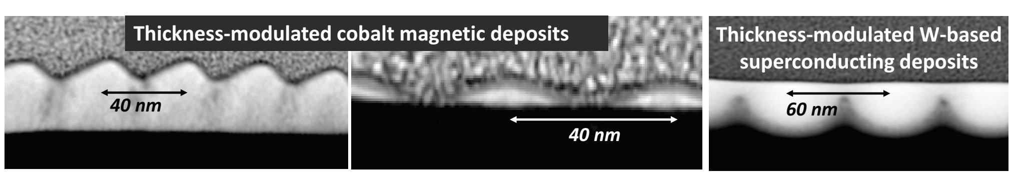

Figure 4. Cross-sectional images of functional magnetic and superconducting materials with thickness modulation. *Left*. Arrays of closely-spaced magnetic cobalt nanowires grown by FEBID. *Middle*: Arrays of isolated cobalt nanowires obtained from the previous thickness-modulated deposits after Ar^+ milling. *Right*: W-based superconducting nanostructures with thickness modulation for studies of nano-superconductivity.