Crossover between magnetic reversal modes in ordered arrays of electrodeposited nanotubes

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Abstract One of the most important properties of magnetic nanomaterials is its coercivity. The major part of the magnetic nanomaterials' applications (permanent magnets, magnetic recording and spin electronics) requires a thorough understanding of the magnetization reversal mechanisms, which are directly related to coercivity. These are known to depend on geometric parameters (shape, length, diameter, wall thickness, spatial ordering, etc). The accurate control of such parameters combined with a detail study of the nanomaterial's magnetic properties provides new information on the correct application of each nanomagnet array. Additionally, it eases the tuning of the magnetization reversal mode by modifying external parameters, such as the direction of the applied field.

A few studies have been reported on the angular dependent magnetic properties of nanowires (NWs) and nanotubes (NTs) fabricated inside nanopore arrays (polycarbonate track etched membranes [1], inclined Si columns [2]). However, only a small number of experimental results can be found on the angular dependence of the coercivity in highly ordered NW/NT arrays [3-5].

In the present work we optimized the fabrication of Ni and Co NW and NT arrays by controlled potentiostatic electrodeposition into suitably modified nanoporous alumina templates (NpATs) after its opening from both upper and bottom sides [6,7]. Long range ordering of hexagonal symmetry of precursor alumina membranes with 105 nm interpore distance and 50 nm pore diameter were achieved by a two-step anodization process combined with controlled pore opening. The fabricated NWs/NTs had a final diameter equal to that of the pores of the template, a length of ~10 μm, and NTs wall thickness of ~10 nm. Morphological characterization was performed using a scanning electron microscope (SEM; FEI Quanta 400FEG). Figure 1 shows SEM top and cross-sectional images of the obtained NWs and NTs inside NpATs.

To investigate the angular dependent magnetization reversal processes of the Ni and Co NW and NT arrays, magnetization hysteretic loops were measured at different angles of applied external magnetic field, using a vibrating sample magnetometer (VSM; LOT-Oriel EV7). Three main modes of magnetization reversal can been identified depending on the geometry of the nanostructure: coherent mode, where all magnetic moments rotate simultaneously; transverse mode, where spins rotate progressively by the nucleation and propagation of a transverse domain wall; and vortex mode, where a vortex wall is nucleated and propagates [5,8]. In this work we used an adapted Stoner-Wohlfarth model [5,8,9] to estimate the angular dependence of the coercive field (H_c) for each magnetization reversal process. Figure 2 shows the angular dependence of H_c measured experimentally and calculated analytically. The magnetization in Ni and Co NW arrays was found to reverse by means of the nucleation and propagation of a transverse domain wall. While for NT arrays a non-monotonic angular dependent H_c was observed, evidencing a transition between the vortex and the transverse reversal mode [10]. The critical angle at which this transition occurs was found to change with the size of the NTs, in good agreement with theoretical predictions. An accurate tuning of the NT parameters would allow an enhancement of the coercive field for a given angle.

References

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Figures

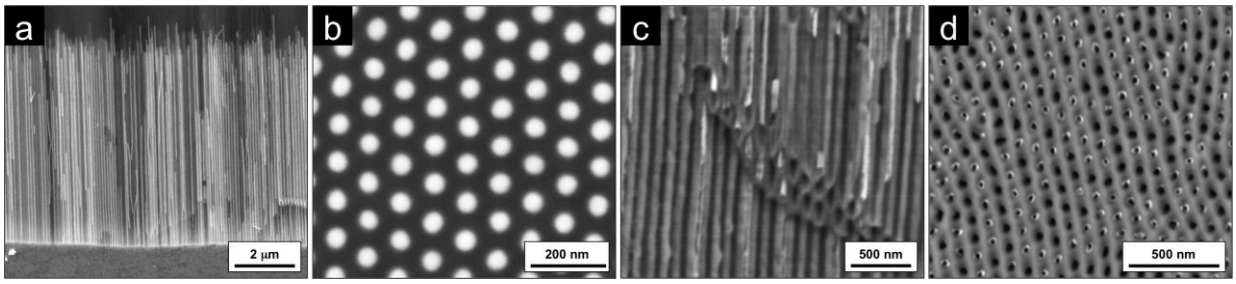

Fig. 1: SEM cross-sectional and bottom views of Ni nanowire (a,b) and nanotube (c,d) arrays in nanoporous alumina templates.

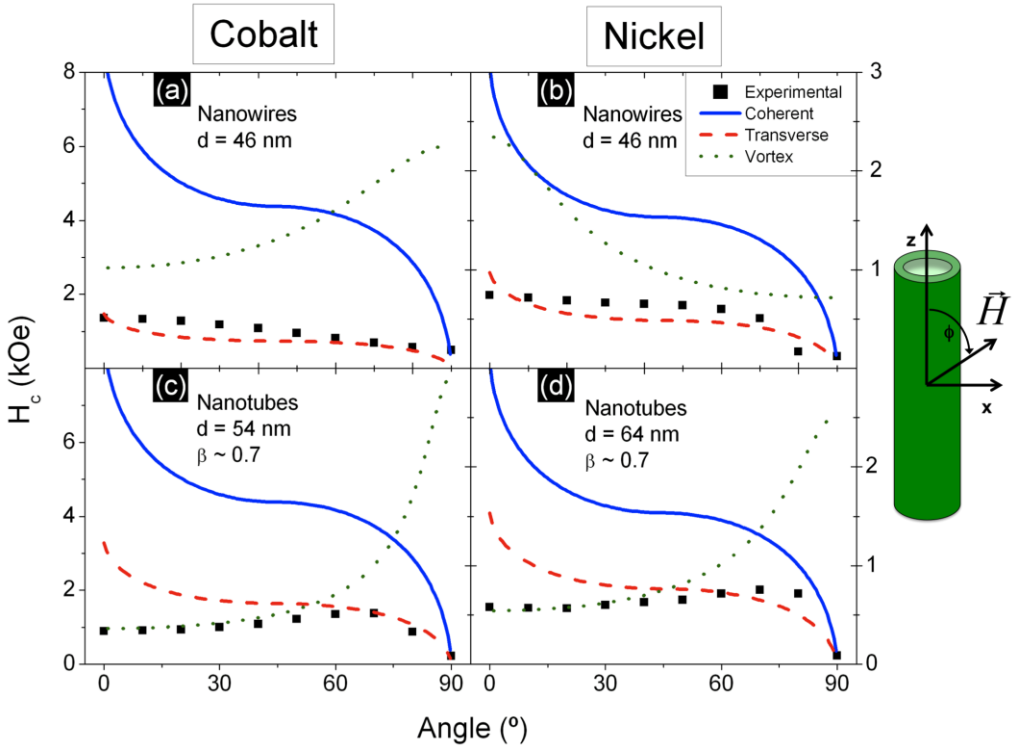

Fig. 2: Angular dependence of the coercive field measured experimentally (squares) and calculated analytically (C mode: blue solid; T mode: red dashed; and V mode: green dotted) for Co (a,c) and Ni (b,d) NW (a,b) and NT (c,b) arrays in nanoporous alumina templates.