



Angular dependence of coercivity with temperature in Co-based nanowires



C. Bran^{a,*}, A.P. Espejo^b, E.M. Palmero^a, J. Escrig^b, M. Vázquez^a

^a Institute of Materials Science of Madrid, CSIC, 28049 Madrid, Spain

^b Departamento de Física, Universidad de Santiago de Chile (USACH) and Center for the Development of Nanoscience and Nanotechnology (CEDENNA), Avenida Ecuador 3493, 9170124 Santiago, Chile

ARTICLE INFO

Article history:

Received 26 May 2015

Accepted 12 August 2015

Available online 14 August 2015

Keywords:

Nanowire arrays

Co and Co-based nanowires

Crystalline anisotropy

Magnetization reversal modes

Analytical calculations

ABSTRACT

The magnetic behavior of arrays of Co and CoFe nanowire arrays has been measured in the temperature range between 100 and 300 K. We have paid particular attention to the angular dependence of magnetic properties on the applied magnetic field orientation. The experimental angular dependence of coercivity has been modeled according to micromagnetic analytical calculations, and we found that the propagation of a transversal domain wall mode gives the best fitting with experimental observations.

That reversal mode holds in the whole measuring temperature range, for nanowires with different diameters and crystalline structure.

Moreover, the quantitative strength of the magnetocrystalline anisotropy and its magnetization easy axis are determined to depend on the crystalline structure and nanowires diameter. The evolution of the magnetocrystalline anisotropy with temperature for nanowires with different composition gives rise to an opposite evolution of coercivity with increasing temperature: it decreases for CoFe while it increases for Co nanowire arrays.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Magnetic nanowires are attracting an increasing interest in connection with their application in advanced spintronics, sensor devices and biomedical applications [1–3]. In this regard, the control of the magnetization reversal process of these nanostructures and their magnetic properties becomes a priority. The magnetic properties of nanowires are dependent on their size and shape, crystallographic structure and measuring temperature. Thus, the fabrication of these nanostructures with uniform dimensions profits of employing template-assisted growth. Particularly, the electrochemical route to synthesize metallic magnetic nanowires has been proved to be a successful method for the production of nanoscaled systems [4,5].

The strong magnetic shape anisotropy is a geometrical feature that makes nanowires to exhibit naturally high coercivity and remanence when magnetized along their axis. The magnetism of individual nanowires is determined by the balance between that intrinsic shape anisotropy and other magnetic anisotropy energy terms such as magnetocrystalline or magnetoelastic [6–8]. Consequently, the tailoring of such anisotropy contributions enables

the tuning of the magnetization easy axis of the system between the longitudinal and perpendicular directions with respect to the nanowire axis. When dealing with arrays of nanowires, the geometrical arrangement of the template (i.e., nanowires diameter and interdistance between them) plays an important role to determine the inter-wire magnetostatic interactions that should be taken into account [9].

While in Ni, Fe or Permalloy nanowires shape anisotropy and magnetostatic interactions mostly determine the overall magnetic response [10–12], in the case of Co-based nanowires the magnetocrystalline anisotropy plays an important role. In Co nanowires, the crystalline structure can be tuned by varying the growth parameters such as applied voltage, dimensions (diameter, length) or annealing and deposition under external magnetic fields [13–15]. Particularly, the pH-controlled electroplating enables the switching between *fcc* and *hcp*-Co crystal phases, which modifies the magnetization easy axis from parallel to perpendicular to the wires [16]. Furthermore, the magnetic properties of Co nanowires can be also tuned by alloying with other metals (for example, the alloying with Ni results in an enhancement of the longitudinal uniaxial anisotropy) [8,17,18].

CoFe alloys possess high saturation magnetization and Curie temperature, magnitudes that make them relevant in most technological applications. Bulk CoFe alloys with Fe content in the range of 60–70 wt% have a saturation magnetization up to about

* Corresponding author.

E-mail address: cristina.bran@icmm.csic.es (C. Bran).

2.4 T, significantly higher than Fe, Co, and Ni metals and FeNi and CoNi alloys [19].

Relatively less attention has been paid to the temperature dependence of the magnetic behavior of different nanowire arrays. Few reports have been reported for Ni and Co nanowire arrays in the range below room temperature [20,21]. It was found that magnetization easy axis could be switched from axial to transverse under some particular circumstances depending on the length and diameter of nanowires, or else on the effective magnetic anisotropy.

A general aim of the present work has been to analyze the temperature dependent magnetization process through modeling of the reversal mechanism. Recent micromagnetic studies on nanowires with large aspect ratio show that the magnetization reversal proceeds via nucleation and propagation of a domain wall [22,23]. Concerning the magnetization reversal process in Co and Co-based nanowires, micromagnetic simulations have been previously reported considering the magnetocrystalline anisotropy energy [24,25]. Three main modes of the magnetization reversal process have been identified through analytical calculations: coherent rotation (*C*) with all the spins rotating simultaneously; the transverse wall (*T*) in which spins reverse progressively via propagation of a transverse domain wall; and the vortex wall (*V*) in which spins reverse progressively via propagation of a vortex (curling) domain wall. The applicability of any mode depends on the geometrical characteristics. Analytical calculations have been applied particularly in the case of the angular dependence of coercivity for several nanowire compositions but always to be compared with experimental data at room temperature [8,16,26–29].

The specific objective of the present study has been to investigate the temperature dependence of magnetic anisotropy and coercivity in Co and CoFe nanowire arrays, and correlate it with an analysis of the magnetization reversal modes by micromagnetic analytical calculations. The study has been performed in the temperature range from 100 K to room temperature, for nanowire arrays with different diameters, namely 20 and 40 nm. We have considered Co and Co-rich CoFe nanowires where the magnetocrystalline anisotropy could be tailored through the crystal symmetry of each composition resulting in hexagonal *hcp* and cubic *bcc* and *fcc* phases promoting transverse and longitudinal uniaxial magnetocrystalline anisotropy, respectively.

2. Experimental details

Anodic Aluminum Oxide, AAO, membranes were prepared on high-purity Al foils by double anodization process, using different acidic electrolytes [30,31]. The anodization was carried out with oxalic acid electrolyte under a 40 V constant voltage and keeping the temperature between 4 °C and 6 °C. First and second anodization processes lasted for 24 and 20 h, respectively. A final hexagonal self-assembling of pores around 40 nm in diameter and 105 nm interpore distances was achieved. The second type of templates was synthesized in sulfuric acid electrolyte, where the first and second anodization lasted for 16 and 3 h, respectively. The duration of the second anodization, ensured a thickness of nanoporous alumina template (i.e., final pore length) of around 40 μm. Under these conditions, pores are about 18–20 nm in diameter, and the lattice constant of hexagonal symmetry takes a value around 55 nm. The diameter of pores can be subsequently enlarged using H₃PO₄ (5 wt%). For both templates, the remaining aluminum and the anodic aluminum barrier at the bottom of the foil were removed by suitable chemical etching resulting in membranes open by both sides. Subsequently, on one side of the membrane was sputtered a thin Au nanolayer to serve as an

electrode for subsequent electrodeposition of metallic elements.

CoFe alloys nanowires were grown into the nanopores of AAO templates, at room-temperature, by DC electrodeposition from sulfate-based electrolytes containing CoSO₄·7H₂O (0.12–0.16 M)+FeSO₄·7H₂O (0.02–0.09 M)+H₃BO₃ (0.16 M)+C₆H₈O₆ (0.06 M). Co nanowires were prepared as well by electrodeposition using the electrolyte: CoSO₄·7H₂O (0.36 M)+H₃BO₃ (0.16 M). The pH value was kept constant at about 3.0 in both cases. The time of electrodeposition was fixed so that, the length of the final nanowires was around 4–5 μm. For additional details about the preparation of nanowire arrays, the reader is referred to previous reports [32,33].

The structural and morphological characterization of the electrodeposited nanowires was determined by X-ray diffraction using a PANalytical X'pert Pro X-ray diffractometer in Bragg-Brentano geometry and by Scanning Electron Microscopy, SEM, using a FEI NOVA NANO 230 High Resolution Scanning Electron Microscope. The magnetic measurements were performed in a Vibrating Sample Magnetometer (VSM), in the temperature range between 100 K and 300 K (RT), under a maximum field of ± 1.8 T applied at different angles from parallel to perpendicular to the nanowires axis.

3. Structural and magnetic characterization

3.1. Structural characterization

The composition of the nanowire alloys, Co_xFe_(100-x) with 70 < *x* < 100, was determined by Energy-Dispersive X-ray spectroscopy (EDX). Fig. 1a shows the cross-section Scanning Electron Microscopy, SEM, image of Co₉₀Fe₁₀ nanowires with diameter *D*=40 nm, 105 nm inter-wires distance and about 4–5 μm in length, *L*, embedded in the AAO template.

Regarding the structural characterization, for the nanowires with *D*=40 nm we have found cubic symmetry in the whole range of compositions that evolves from body-centered cubic, *bcc*, structure for Co₇₀Fe₃₀ nanowires to face-centered cubic, *fcc*, with a (220) preferred orientation, as Co content increases. The diffraction data for Co nanowires with diameter of 40 nm is presented in Fig. 1b. However, as reported before, a mixture of Co-*fcc* and Co-*hcp* could be also present in the wires. That Co-*hcp* phase is hard to be identified due to the overlapping between *fcc* (111 and 220) and *hcp* (002 and 110) reflections [4,20,34].

The XRD data of CoFe nanowires with 20 nm in diameter indicates that the *bcc* (110) phase evolves to *fcc* (220) for 90% Co, similarly to 40 nm nanowires. For 20 nm Co wires we observe an *hcp* structure (Fig. 1c). The two different *hcp* peaks, (100) and (002), have been reported to favor the orientation of the magnetization easy axis perpendicular and parallel, respectively to the nanowire axis [16,20].

From the comparison between nanowires with diameters of 40 and 20 nm, we conclude that the only apparent difference is the change in crystalline structure of Co from mixed *fcc-hcp* to *hcp* by decreasing the diameter [32]. For complementary details, the structural characterization in the full range of Co_xFe_(100-x) composition has been recently reported [32].

3.2. Room temperature hysteresis loops

The magnetization curves were firstly measured at room temperature under applied magnetic field parallel and perpendicular to nanowires axes. The CoFe sample with higher Co content (i.e., Co₉₀Fe₁₀) shows the higher coercivity and a remanence close to saturation magnetization for parallel field configuration (Fig. 2a). An increase of coercivity and remanence is observed for the nanowires with reduced diameter (Fig. 2b). That is ascribed to the

Download English Version:

<https://daneshyari.com/en/article/1798593>

Download Persian Version:

<https://daneshyari.com/article/1798593>

[Daneshyari.com](https://daneshyari.com)