doi:10.1017/S1431927612004400
Microsc. Microanal. 18 (Suppl 2), 2012

Measuring the Magnetic Induction of Isolated CoFeB Nanowires by Off-Axis Electron Holography

A. Akhtari-Zavareh,[1] T. Kasama, [2] L.P. Carignan, [3] A. Yelon, [3] D. Ménard, [3] R. Herring, [4] R . E. Dunin-Borkowski, [5] M. R. McCartney, [6] and K. L. Kavanagh[1]

1. Department of Physics, Simon Fraser University, BC, V5A1S6, Canada
2. Center for Electron Nanoscopy, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark
3. Department of Engineering Physics, École Polytechnique de Montréal, Montréal, Québec, H3C 3A7, Canada
4. Department of Mechanical Engineering,University of Victoria ,Victoria, B.C., V8W 3P6 Canada
5. Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons Institute for Microstructure Research, D- 52425 Jülich, Germany
6. Department of Physics, Arizona State University, Tempe, AZ 85287-1504

Ferromagnetic nanowire (FMNW) arrays have been proposed for high frequency applications [1] and for high-density storage media [2]. Understanding the crystallographic and magnetic properties of individual wires is crucial if we are to make a proper nanowire for a given application. Here, soft, and high saturation magnetization CoFeB FMNWs with diameters of 40 nm and 170 nm, were studied. Small diameter FMNWs are appropriate for applications which require a large remanence and coercivity, such as circulators or isolators. However, large diameter wires could potentially be used in microwave devices, requiring a small remanence and coercivity, such as RF inductors [3]. CoFeB FMNW arrays, tens of microns long, were fabricated by pulsed-current electrodeposition in nanoporous alumina membranes obtained by anodization of aluminum (40 nm diameter) or in commercial Whatman alumina membranes (170 nm diameter), using a procedure reported in [3].

Selected Area Electron Diffraction (SAED), Energy-filtered transmission electron microscopy (EFTEM) and Electron Holography (EH), were used to analyse the crystallographic and magnetic properties of the FMNWs. Diffraction patterns obtained from 170 nm [Fig 1.(a)] and 40 nm diameter nanowires suggest that the wires are nanocrystalline rather than amorphous. Elemental mapping indicates that the Co and Fe are uniformly distributed over the wire, whereas O and Al are present on the surface of the wires. At the end of the wires, Co and O are observed together. The presence of O is mostly due to Al_2O_3 covering the wires but is also related to Co oxides.

A 300kV STEM equipped with a biprism operating at 150V was used for electron holography measurements. Samples tilted with respect to the axis of sample holder at β + 25 deg, were first magnetized along the wire's axis at 4730 Oe and next to -2015 Oe using the objective (OBJ) lens... Holograms were acquired at remanence < 5 Oe (obtained at zero tilt and turning off the OBJ lens). The magnetization inside the wire is uniform over most of the wire length, except at the edge, as shown in Fig. 1 (b). Since the wires consist of soft magnetic nanocrystals, the magnetic anisotropy is likely dominated by the shape anisotropy. The wires have relatively large magnetizations even in the regions close to their interfaces with Al_2O_3.

Our numerical simulations suggest that the stray fields at the top of the wire (for both diameters) are well reproduced by a truncated cone model, rather than a cylinder. The magnetic induction measured by electron holography for wires with diameters near 170 nm is 1.45 T, which is somewhat smaller than the saturation magnetization extracted from static magnetometry measurements of thin films of electrodeposited CoFeB (about 1.67 T). Repeating the same procedure for the 40 nm diameter wires leads to a magnetic induction ranging from an average of 0.5 T near the tip of the wires to 1.5 T in the middle of the wires. The smaller induction near the end of the wires is attributed to the presence of a significant out-of-plane magnetic component since their tips are generally pointed out of the plane of the sample holder. This is confirmed by tilting the sample. Additionally near the tip of the wires, the increased demagnetizing field and thinner sample thickness weakens the induction.

References:

[1] A. Saib, IEEE Trans. Microw. Theory and Tech. **53**, 2043 (2005).
[2] C.A. Ross, Annual Rev. Mater. Sci. **31**, 203 (2001).
[3] L.-P. Carignan, A. Yelon, D. Ménard and C. Caloz, IEEE Trans. Microw. Theory Tech. **59**, 2568-2586 (2011).

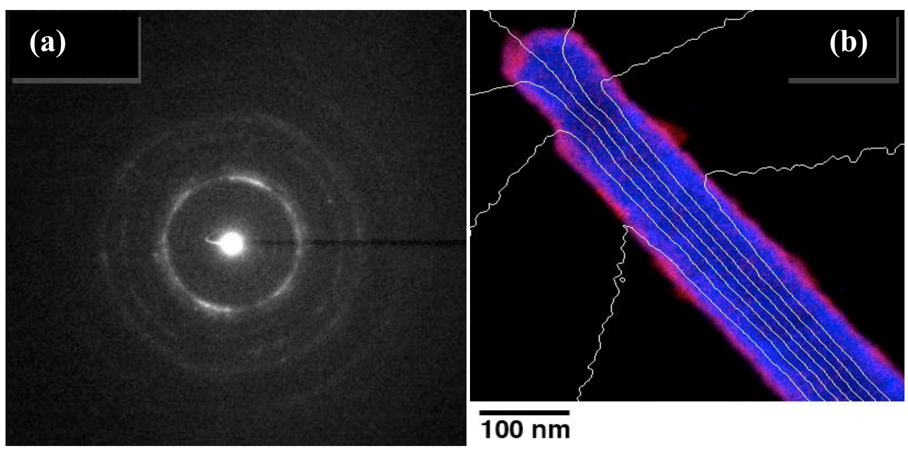

Fig. 1. (a) Electron diffraction pattern of a CoFeB wire, the d-spacings of the ring pattern are 1: 0.21 nm, 2: 0.13 nm and 3: 0.11 nm. (b) Magnetic contour image of a 170 nm diameter wire overlaid on an elemental map for Co (blue) and O (red). The contour spacing is 2 radians.