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Characterization of Mulitilayer Ferromagnetic Nanowire Arrays Using 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, USA

Arrays of ferromagnetic nano-wires (FMNW) have been proposed for high frequency applications [1] and high-density storage media [2] due to their relative low cost of fabrication and the possibility of manipulating their magnetic properties by adjusting the composition and geometric parameters of the arrays [3]. Understanding the crystallographic and magnetic properties of individual wires is crucial for optimizing the properties of the arrays. For that purpose, the soft and high-saturation magnetization of periodic CoFeB/Cu NWs was studied as a function of the thickness and period of the magnetic and non-magnetic layers. All NWs were fabricated by pulsed-current electrodeposition in nanoporous Alumina membranes [4].

Electron holography (EH) [5] was used to investigate the local magnetic behavior of a statistical ensemble of these FMNWs and this information was compared to the results obtained from magnetostatic and ferromagnetic resonance (FMR) of macroscopic NW arrays [3]. A 300kV STEM equipped with a biprism operating at 150V was used for EH measurements. Holograms were acquired at a remanence magnetic field < 5 Oe (obtained at zero tilt by turning off the objective lens). The magnetization inside the magnetic layers was uniform over most of the wire length, except at their surfaces. Since the wires consist of nano-crystals, it is a reasonable observation that the shape anisotropy dominates the control of the magnetic properties.

The magnetic induction measured by EH for these NWs, had a relatively significant quantity even at their surfaces. In the Cu layers, the magnetic induction became weaker as a result of demagnetizing field from the magnetic layers. Magnetization components parallel and perpendicular to the applied field from the objective lens were measured as a function of the angle of the NW axis. In some cases, a NW magnetization component transverse to the applied field direction was observed, which was not the case for the arrays. This suggested that the easy axis of each magnetic layer was not always in the same direction as their adjacent layer.

Figure 1.a and 1.b show the hologram of CoFeB (50nm)/Cu(10) wire in Lorentz mode and the magnetic contour map of the same area of the wire after the reconstruction of plus/ minus 30 deg tilt holograms (the axis of the wires is almost perpendicular to the applied magnetic field). As seen in fig 1.d, at the regions where we have copper, the magnetic induction becomes weaker as a result of demagnetizing of the field in magnetic layers. As mentioned before, the magnetization inside the wire has an angle with the axis of the wire. For the case of CoFeB (9nm)/Cu (3nm)/CoFeB (9nm) the magnetic signal could be detected at some areas like vortex magnetic lines (fig 2.a).

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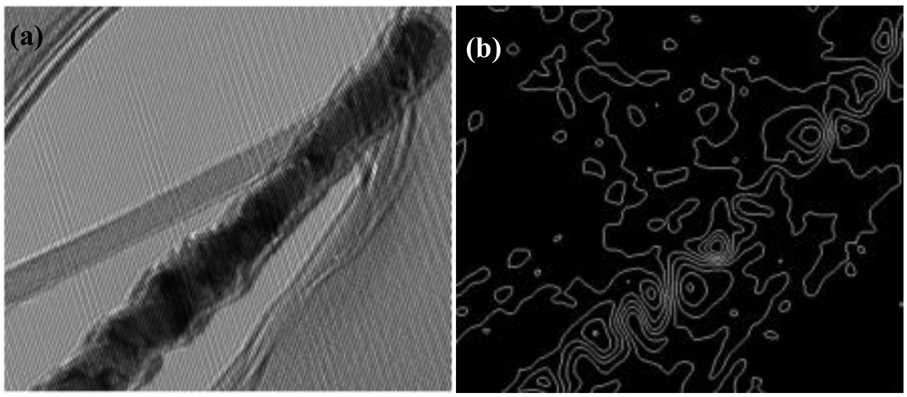

Fig (1)

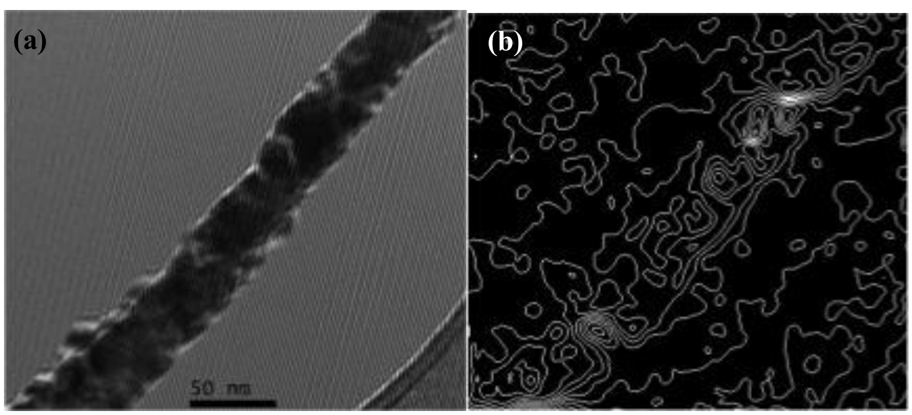

Fig (2)

(a) TEM image of nanowires in Lorentz mode and (b) magnetic contour map of same area of the wire of CoFeB (50nm)/Cu (10 nm) nanowire (fig.1) and CoFeB (9nm)/Cu (3nm)/CoFeB (9nm) (fig.2) .The contour spacing is 0.6 radians.

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