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Crystalline Phase Mapping Associated to the Magnetic Flux in Cobalt Nanowires

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Electron holography is a powerful technique for mapping of the electric, magnetic fields and the crystalline potential within a transmission electron microscope (TEM). Particularly, the possibility to extract the magnetic behavior of a sample at nanoscale, at the remanent and excited states, transforms the microscope in another lab for the measurement of physical properties of materials. Parameters such as the external magnetic field produced by the objective lens, temperature, reversal magnetization, play an important role in the understanding of the magnetic properties of individual nanostructures like nanoparticles and nanowires [1].

Recently, phase orientation mapping in a TEM is more popular to indexing electron diffraction patterns and the formation of virtual images (bright field, dark field and annular dark field) by a correlation between an electron diffraction pattern and the rest of patterns in the area of the scanned areas [2,3]. The combination of electron holography and crystalline orientation phase mapping can provide of important information not only about the magnetic behavior but the different orientation of the magnetization as function of the orientations of nano-grains in a polycrystalline structure and extract quantitative information of the easy and hard axes in the nano-domains.

In this work, we will present the analysis of a polycrystalline cobalt nanowire using both techniques, electron holography and crystalline phase orientation, in the same area. Previously the magnetic field of the objective lens (in a JEOL ARM200F microscope) was characterized by using a Hall sensor in a modified sample holder and using an external Gauss-meter for data collection. In this way, the remanent state of the objective lens at zero volts was characterized. Reversal magnetization was also performed by tilting the sample to obtain the component of the magnetic field in two different directions. In the Figure 1a we present a curve which describe contribution of the magnetic field to the sample position, in ground state we measure a field of 45 Oe, when the OL is switched off to a saturation field at the lens maximum excitation voltage. However the measurement was reproducible after applying a relaxation in the lenses, finding an error in the range of 0.25-0.35%. The magnetic measurements during the specimen loading procedure were very stable and no variations were detected. The electron hologram of the nanowire was processed using Holowork script in DigitalMicrograph, in Figure 1b a hologram is recorded, another hologram is also recorded as the reference to be used in the off-axis phase reconstruction process, its corresponding unwrapped phase image is displayed in Figure 2c.

For crystalline phase mapping we performed a scanning over the sample with a lateral resolution 2 nm using a probe size of 1.1 nm under nano-diffraction mode. The electron diffraction patterns were recorded by using a precession angle of 0.9°. For magnetic mapping we recover the phase of the hologram and amplify three times the cosine of the magnetic phase image. The results that will be discussed in the presentation will show also results of simulations of the magnetization and magnetic flux in the wire considering hard and easy axes in the hcp grains distributed along the cobalt nanowire. The correlation between the crystalline phase orientation map and the magnetization is shown in Figures 2a and 4b, respectively. The effect of the crystalline structure is clearly observed at the tip of the nanowire where the random crystal orientation of the grains induce some fluctuations in the magnetic flux. The wavy nature of the magnetization is also influenced by the grain orientation and the grain boundaries of the crystallites. In figure 4a, the Co nanowire z-orientation map is overlaid with the index map. The color key code of the orientations is depicted on the right. The Co nanowire is composed of several hcp grains with different orientations. [4]

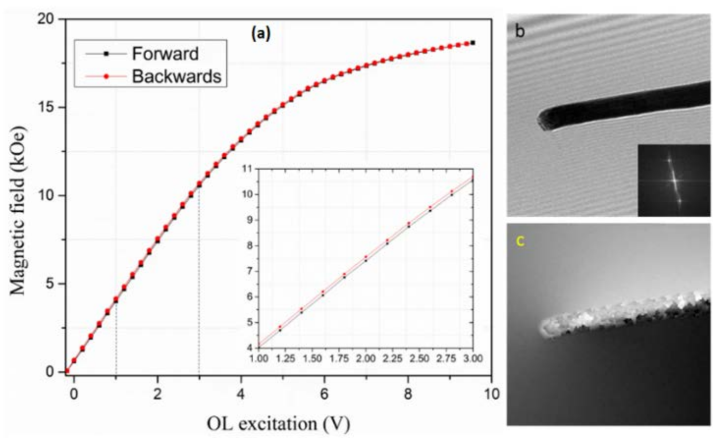

Figure 1. (a) Magnetic field in the specimen position in function of the OL excitation voltage. Black curve is the forward bias, and red is the backwards showing no significant hysteresis. The inset, shows a zoom in the linear part of the curve showing that there is some hysteresis in the lens. (b) Object electron hologram, the inset indicates the FFT from where we took one sideband to reconstruct the phase image c) Unwrapped phase image, displaying the phase variations characteristic of magnetic samples.

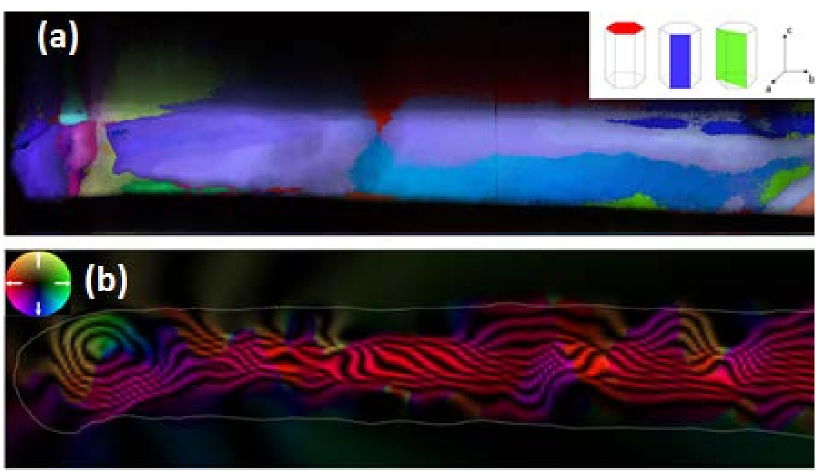

Figure 2. (a) Crystalline phase orientation map, in which an inset of the map colors of the planes is included. (b) Magnetic phase recovered from the off-axis electron hologram.

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