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Revealing the Magnetic Interactions of DP in Cu-Co alloys by Electron Holography

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Magnetic and magnetotransport properties of melt-spun Cu-Co alloys produced by melt-spinning have been of great interest, mainly due to high giant magnetoresistance (GMR) presented at room temperature. The main theory for high GMR has been based on the occurrence of spinodal decomposition with spin-dependent electron scattering taking place at Co-rich clusters. However, studies demonstrate a very weak magnetic response of these clusters, which do not orientate even under the action of strong magnetic fields, therefore should not affect the GMR [1]. Magnetization measurements confirm the existence of dual magnetic density because of two different Co-rich phases: small superparamagnetic (SPM) clusters or precipitates, and a ferromagnetic (FM) phase [2]. These FM should correspond to larger homogeneous precipitates but an angular dependence suggests the development of non-spherical morphology [3], question that remains open.

In a previous investigation [4] we reported that discontinuous precipitation (DP) is the main type of phase transformation in melt-spun Cu10at.%Co alloys, with Co rod-like precipitates growing anisotropic and therefore generating a magnetic anisotropy. However, this type of precipitation was never taking into account when analyzing magnetization in this alloy system, so we strongly believe that this could be the missing connection between microstructure the magnetic and magnetotransport properties.

Aiming to evaluate the effect of DP in GMR of this alloy, we investigated the relationship between DP development and GMR by means of magnetotransport measurement and microstructure characterization, including the analysis of magnetic interaction between Co rod-like precipitates at nanoscale by means of electron holography, a study never reported before. Samples of melt-spun Cu-10at%Co alloys were annealed at temperatures ranging from 450 to 650ºC during different periods of time, ranging from 5 to 60min. Microstructural analysis were performed by transmission electron microscopy in a JEOL JEM-2100 TEM/STEM. Magnetotransport measurements were performed at room temperature following the standard four-probe configuration with collinear contacts separated by 1 mm with each other. Electron holography was performed on a Phillips CM-200 FEG TEM (200kV) with an electrostatic biprism and a Lorenz minilens in order to acquire field-free imaging of magnetic samples. Holograms were recorded in opposite directions of magnetization, +30 and -30 degrees, under application of a magnetic field density of about 10kOe (the in-plane field was provided by turning-on the objective lens, which was turned-off for hologram analysis). Color-coding was used to identify the direction of magnetization.

In Figure 1 is shown bright field (BF) TEM images of well-developed DP colonies in longitudinal and cross-section configuration of the ribbons. Magnetotransport results reveal that highest GMR occurs simultaneously to the optimum DP development, as shown in Figure 2. Electron holography confirms the occurrence of antiferromagnetic (AF) coupling in the remanent state of the Co rod-like precipitates, the main requirement to GMR. Figure 3 shows the electron holography of a region with a distinct DP colony, as marked. Notice the antiparallel direction of magnetic moments of rod-like precipitates, indicating the antiferromagnetic coupling. These results support that Co rod-like precipitates are the FM phase described in magnetic analyses and responsible by the GMR of melt-spun Cu-Co alloys [5].

References:

[1] A. D. C. Viegas *et al*, J Appl Phys **82** (1997), p. 3047.
[2] A. G. Prieto *et al*, Phys Rev B **67** (2003), p. 224415.
[3] B R Pujada *et al*, Phys Rev B **64** (2001), p. 184419.
[4] N M Suguihiro *et al*, J Mat Sci **49** (2014), p. 6167.
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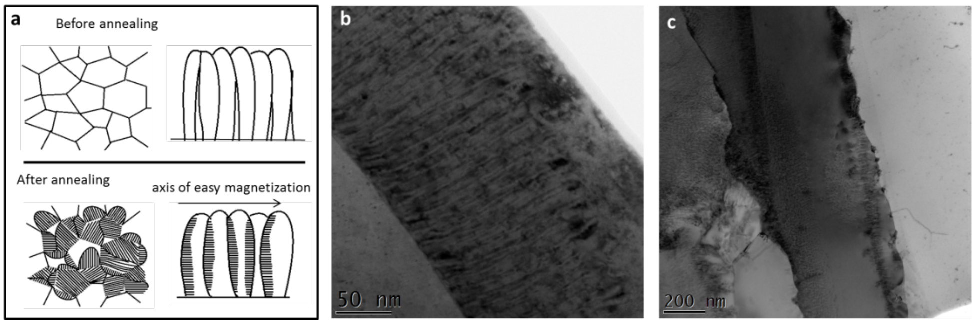

Figure 1. (a) Sketh of DP development in melt-spun Cu-10at.%Co ribbon. BF STEM images of DP colonies in (b) longitudinal and (c) cross-section configurations.

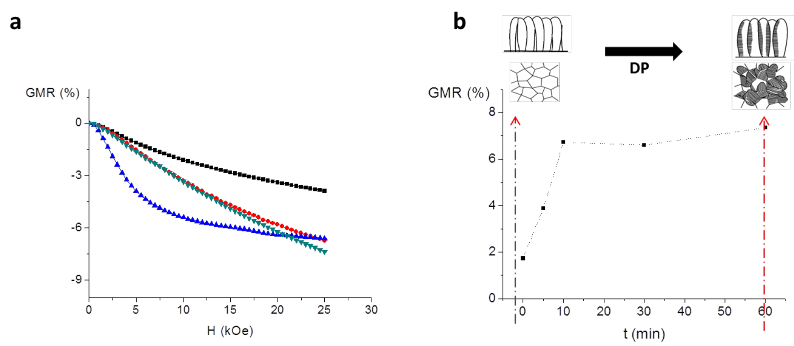

Figure 2. (a) GMR (ΔR/R) as a function of applied field and (b) GMR as a function of annealing time for samples annealed at 450ºC. Notice that GMR rises simultaneously to DP initiation, after 10min of annealing.

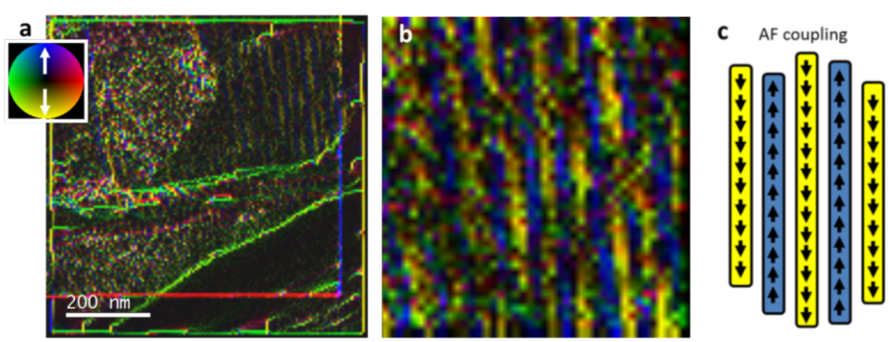

Figure 3. (a) Color-coded remanent states of magnetization through electron holography after 60min of annealing at 450ºC. (b) Higher magnification of a DP colony. (c) Sketch of the direction of magnetization of ferromagnetic Co rod-like precipitates according with (b).