ESRF	**Experiment title:** GISAXS and diffuse scattering measurements on Co/Cu and Co/Au granular films	**Experiment number**: HE 840
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Report:

Spin dependent magneto resistivity, the so-called giant magneto resistance (**GMR**), has first been discovered in metallic multilayer films [l] composed of ferromagnetic and non-magnetic elements. Afterwards, GMR has been discovered in granular films made of super paramagnetic particles dispersed in a non-magnetic matrix [2]. Since then, the major hypothesis concerning the GMR effect, such as periodicity of the structure and magnetic coupling between its ferromagnetic components have been revised and more attention has been dedicated to the contribution of surfaces to spin dependent scattering [3].
The characteristics of the magneto resistive effect depend strongly on the morphology (size and interfaces) and the distribution of the magnetic particles (average distance and spatial arrangement) [2, 4]. Usually this kind of samples are grown using two immiscible metals by using techniques such as co-sputtering or rapid solidification processes. Normally, by submitting the samples to thermal annealing it is possible to induce a recrystallization and to produce small particles (mean diameter 20 – 200 Å). In our case, we obtain granular films with displaying giant magneto resistive effect ranging from 1 % to 10 % without performing any thermal treatment subsequent to deposition.
Although shape and dimension of magnetic clusters play such an important role in magneto conductivity of granular materials, they have not so far been reliably characterized.

Experimental method

We deposit by co-sputtering a multilayer structure made of 14 periods of thin layers of Co (nominal thickness from 2 to 12 Å) and about 4 times thicker non-magnetic metal layers (Cu, Ag, Au). Until now, the mean dimension of Co particles (20 - 100 Å) has been roughly estimated from room temperature magnetization data. We present data on the sample with nominally 12 Å thick Co and 48 Å thick Cu layers.

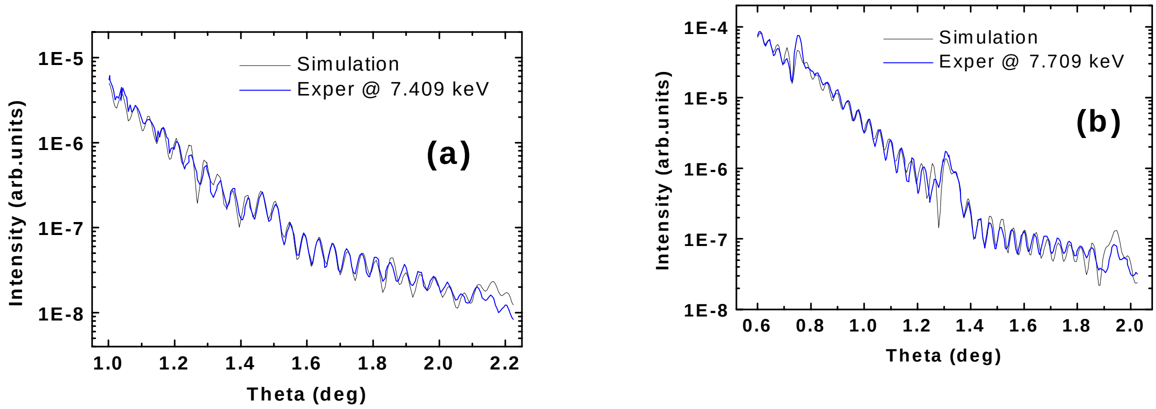

Fig. 1 Use of the anomalous scattering effect in specular reflectivity measurement at 300 eV below the edge (at 7.7409 keV) and just below the edge (7.709 keV). One can see that at the edge the signal of the super structure Bragg peaks is enhanced.

Specular reflectivity and GISAXS measurements on each film are performed at 7.709 keV, corresponding to the K edge of Co. We use contrast enhancement due to the anomalous scattering effect: near the absorption edge of Co the f' of Co and Cu have a contrast of 9 electrons, while further below the edge it is only 2 electrons. The effect is seen in the specular reflectivity scans shown in figure 1. In a) the measurement was performed 300 eV below the edge, and the measurements present no clear vertical super periodicity peak due to the Co/Cu bi-layer-stacking. In contrast, we show in figure 1b the specular reflectivity measured just below the Co edge, at 7.709 keV. Here the super periodicity peaks are clearly resolved. Simulations have been performed (fig.1) that show that the average period is 76 Å, and the average thickness of Cu and Co layers are 63 Å and 13 Å, respectively. We found a decrease of the thickness of Co as the growth proceeds: 17 Å near the substrate, and 8 Å near the surface.

In order to study the lateral and vertical correlation of the Co particles, we performed GISAXS measurements. The diffuse off-specular scattering was measure as a function of the out-of-plane $q_{||}$ for an incidence angle $\alpha_i = 1^o$ and for different exit angles α_f . As shown in Fig. 2, the diffuse scattered intensity is interpreted in terms of the correlation and form factor of the nano-clusters as given by the fit (solid line in Fig. 2). We find that the average Co cluster size is 145 Å and the lateral distance between the Co clusters is 170 Å (Fig. 2). This small difference between cluster size and average distance means that the arrangement of Co grains is densely packed in the plane. The lateral correlation length is 340 Å, only two times the lateral distance between Co particles.

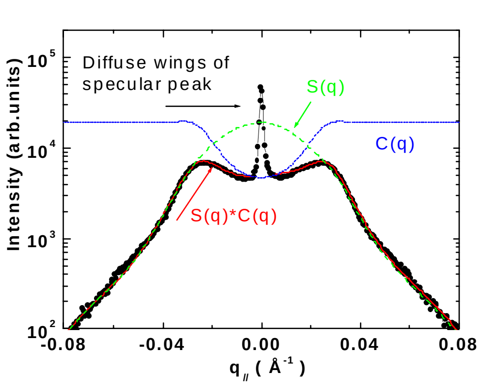

Fig.2 Diffuse GISAXS intensity as a function of $q_{||}$ for α_i=1 deg and α_f=0.6 deg. The fit (solid curve) is obtained by a product of the correlation(C) and form function (S).

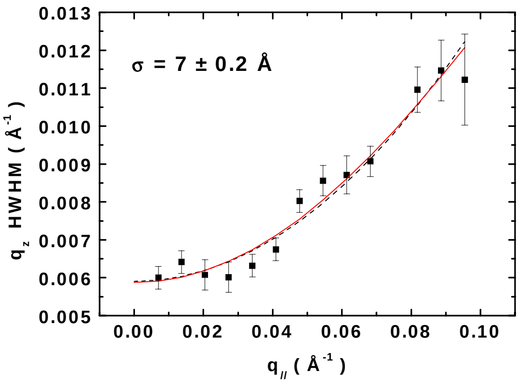

Fig.3 Plot of the dependence of the q_z FWHM of the 2nd Bragg sheet as a function of $q_{||}$. From the fit we obtain the vertical misalignment parameter σ =7 Å.

The periodicity of the vertical stacking of Co clusters layers results in resonant diffuse scattering so-called "Bragg sheets". We measure the width of these sheets as a function of $q_{||}$, in order to obtain the vertical correlation of the Co clusters, using the procedure presented elsewhere [5]. The fit curve in Fig. 3 gives a value of the vertical misalignment parameter $\sigma = 7 \pm 0.2$ Å. This parameter is related to the average deviation of two vertically adjacent Co grains. Such a small value of σ, compared with the average size of 145 Å, indicates that the Co particles are very well aligned vertically. The mechanism for this induced alignment is probably the strain due to the lattice mismatch (2%) between Co and Cu.
Further analysis is in progress to determine the depth dependence of the size and inter-grain distance and to compare the structural results to the magnetic properties for a series of samples with varying structural parameters.

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