Microstructure and magnetic properties of Co/Ag superlattices grown by MBE on MgO(001)

Enrique Navarro[1], Ana Ruiz[1], Daniel Margineda[1], María Alonso[1], Pilar Ferrer[2],
F. Javier Palomares[1], Federico Cebollada[3], Jesús Mª González[4]

[1] Instituto de Ciencia de Materiales de Madrid-CSIC. Cantoblanco. E28049-Madrid. Spain.
[2] SpLine-ESRF. 6, Rue Jules Horowitz. BP 220. F38043 Grenoble Cedex 09. France.
[3] Dpto. Física Aplicada a las Tecnol Inform., Universidad Politécnica. E-28031Madrid. Spain.
[4]Unidad Asociada ICMM-CSIC / IMA-UCM, Cantoblanco, 28049 Madrid, Spain.
anaruiz@icmm.csic.es

The renovated interest in the Co/Ag system is not only related to properties like giant magnetoresistance or perpendicular magnetic anisotropy, but also to spin-transfer torque effects and magneto-plasmonic applications. Previous works in the literature have shown the singular and still controversial behavior of the Co/Ag system as compared to other metallic multilayers. An example is that perpendicular magnetic anisotropy and oscillations of the magnetoresistance and exchange coupling have only been reported for samples in which the Co layers thickness lies below 1nm. Microstructure seems to play a relevant role on the magnetic behaviour of Co/Ag multilayers. The formation of a granular system has been suggested to arise when Co layers are extremely thin, in order to explain some of the magnetic results.

We report here on the microstructure and magnetic properties of molecular beam epitaxy (MBE) grown samples consisting of a periodic repetition of Co/Ag layers on MgO(001) substrates. Substrate preparation by Ar+ ion bombardment and annealing is performed prior to growth, so as to obtain clean and ordered surfaces. Growth takes place at room temperature under moderate Co and Ag fluxes (r_g<0.5 Å/s) and is monitored by reflection high-energy electron diffraction (RHEED). Several series of samples have been prepared, changing the Co/Ag ratio per period while maintaining the total Co content within a similar range for all the samples. The thickness of the Co layers in a period is restricted to the 1-12 Å range, and Ag layers are 5 to 40 Å thick. In order to compare results on different substrates and orientations, as well as *with* and *without* buffer layers, selected structures have been simultaneously grown on MgO(111) substrates mounted side by side, or have been deposited with a buffer layer (Ag, 40 nm thick) on clean MgO(001) and Si(111)-7x7 surfaces.

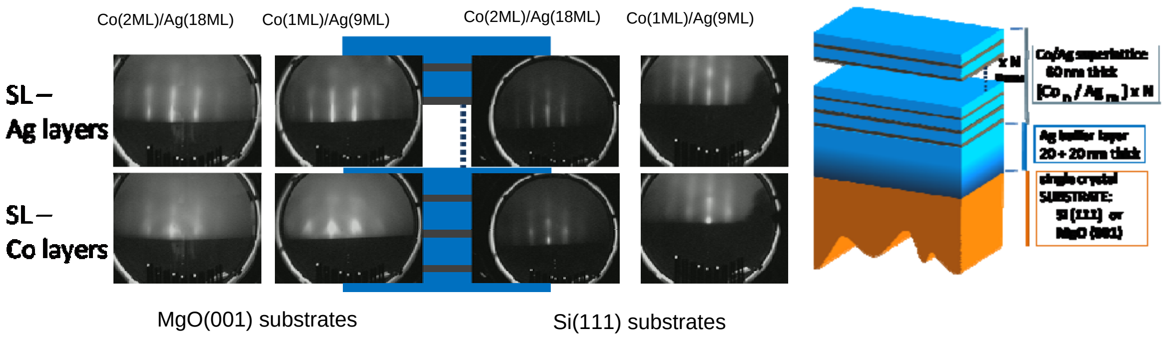

Figure 1*: RHEED patterns during the MBE growth of Co and Ag layers of different superlattice (SL) samples, all of them with extremely thin Co layers per period (about 1 or 2 atomic monolayers, ML). Results for similar layer structures grown either on Mg(001) or 7x7-Si(111) substrate surfaces are shown. In both cases the SL was grown on top of a 40 nm thick Ag buffer layer. Rigth panel: sample sketch for the multilayers of Figs. 1-3.*

Besides RHEED (Fig. 1), several techniques such as low energy electron diffraction (LEED) and Auger electron spectroscopy (AES) were used *in-situ* to assess the crystallinity and composition of the samples after growth. The microstructure and periodicity of the layers was studied by X-ray diffraction, X-ray reflectometry and reciprocal space mapping using conventional sources and synchrotron radiation (Fig. 2). Field emission scanning electron (SEM) and atomic force (AFM) microscopies were employed to investigate surface sample morphology.

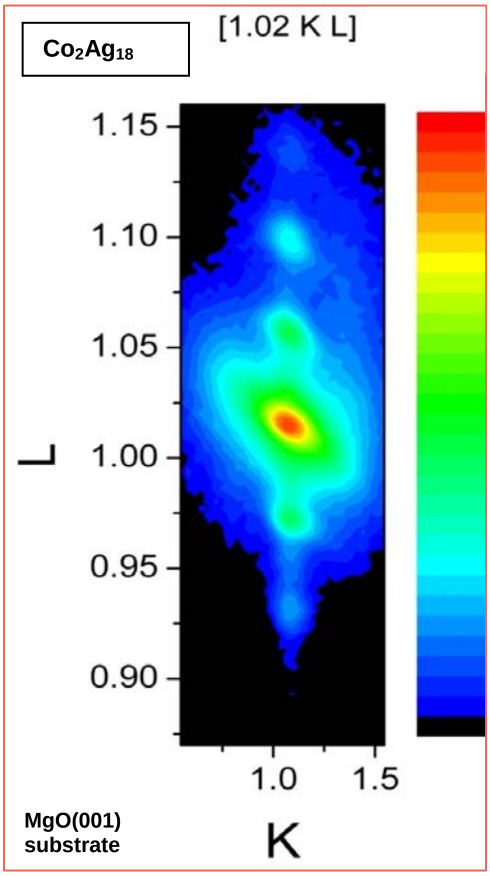

Figure 2. *Reciprocal space map measured with synchrotron radiation (E= 15 keV, λ= 0.82657 Å) around Ag(111) for a multilayer [Co(2ML)/Ag(18ML)]x15 grown on MgO(001). The superlattice extra-spots (L-2, L-1, L+1, L+2, L+3) along L direction can be clearly distinguished.*

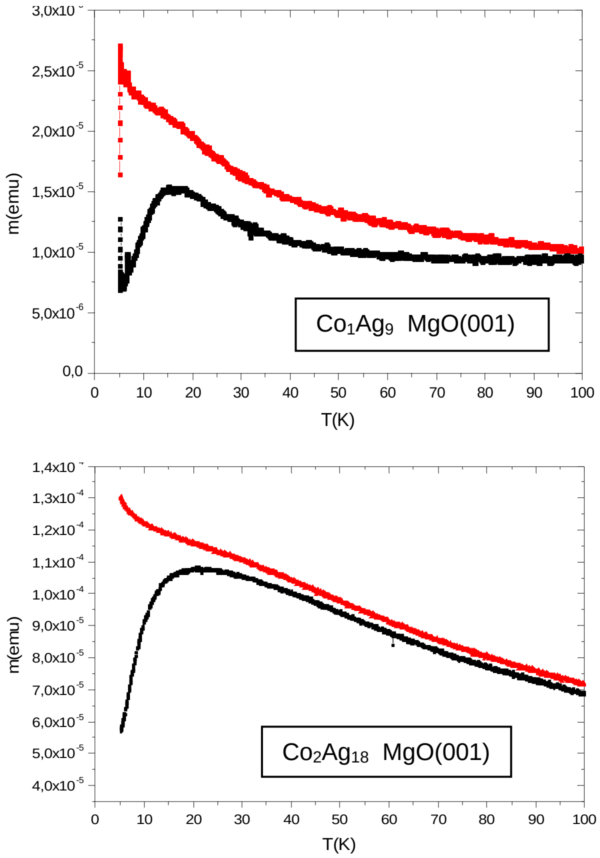

Figure 3: *Low field temperature dependence of the magnetization, measured after zero field cooling (ZFC) and field cooling (FC) the samples, for two MBE-Co/Ag multilayers on MgO (001), both of them with very thin Co layers (1 or 2 ML).*

The magnetic properties (magnetization and hysteretic parameters) were measured versus temperature, down to 5 K, by means of a vibrating sample magnetometer (VSM). Results obtained for the low field temperature dependence of the magnetization, measured after zero field cooling (ZFC) and field cooling (FC) the samples, are also presented (Fig. 3).

Samples with extremely thin Co layers (in the range of 1-2 atomic monolayers per period) exhibit magnetic order up to room temperature (confirmed through the measurement of the thermal dependencies of the remanence and the coercive force). Interestingly, they also show blocking-like temperatures in the range of 15 to 35 K (Fig. 3), being such behavior observed for all the substrate materials and orientations here investigated. Moreover, and in contrast to most of the previous reports for this thickness range, our MBE samples generally display superlattice features (Fig. 2), which are remarkably clear for films grown on the MgO(001) substrates. Magnetic results are discussed in relation to sample growth details and the morphological/structural analysis.

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