Study of the influence of the interactions in the magnetic behaviour of Fe-Ag thin films above the percolation limit

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The physical properties of nanostructures can be markedly different from those of bulk materials. This is of particular interest in the case of granular alloys composed of magnetic clusters in a metallic nonmagnetic matrix, such as the Fe-Ag systems. Depending on the Fe content, interactions can play a very important role in their magnetic behaviour mainly in the case of samples with high concentrations. In our case, we have focused on the study of the role of the interactions in Fe-Ag granular thin films with Fe contents above the percolation limit (~ 28% at.), for which Binns et al. [1] predicted an interacting-superparamagnet behaviour at high temperatures, and a progressive collective blocking as temperature decreases. Both pulsed laser deposition (PLD) and sputtering techniques have been used for comparison.

We have prepared Fe-Ag thin films (~100-200 nm) in the range of 30-55%. Their composition was determined by energy dispersive X-ray analysis (EDX). Both PLD and sputtered films were coated with ~ 10 nm silver and gold capping layers, respectively. They were deposited at room temperature onto Si(100) substrate with a native oxide layer. The microstructure was studied by X-ray diffraction (XRD), and DC and AC magnetic characterization was performed using a SQUID magnetometer as a function of temperature (5-350 K) and with frequencies in the range 1-100 Hz.

The hysteresis loops measured at 300 K and 5 K reflect that all the samples behave like soft ferromagnets with a coercive field smaller than 50 Oe. Samples deposited by PLD show an increase of the susceptibility up to ~50 K, followed by a smooth variation characteristic of a ferromagnetic state up to 150-200 K, where the susceptibility decreases in a Curie-Weiss type decay. As the volume fraction changes, these phases evolve and even new phases as a spin-glass like state at low temperatures emerge (see Fig 1, bottom). On the other hand, for the sputtered sample a clear Curie transition at 310 K, with the susceptibility dropping to zero, has been found for the lowest composition studied (30%). A slight increase of the composition makes this transition disappear (see Fig 1, top).

In order to get deeper insight of the previous collective magnetic behaviours, we have also performed zero field cooled AC magnetization measurements. Figure 2 shows the thermal evolution of the real, χ', and the complex, χ'', components of the susceptibility data measured between $1 \leq f \leq 1000$ Hz for a PLD thin film (51 % of Fe) and with an AC amplitude of 1 Oe. Above ~150 K a clear dispersionless Curie-Weiss type decay of χ' is observed, and at the same temperature range, the thermal evolution of χ'' is also independent with the frequency and it becomes completely zero at 200 K. This behaviour corroborates the presence of a magnetic phase transition with a Curie temperature due to the magnetic interactions at 150-160 K. Below the transition temperature, χ' presents a smooth variation characteristic of a ferromagnet freezing. A similar magnetic behaviour has been found in discontinuous metal-insulators multilayers [2].

In summary, the susceptibility data indicate the existence of exchange interactions between the magnetic particles besides the dipolar ones, in both both sputterd and PLD thin films. PLD samples behave like a superferromagnet with a Curie-Weiss type transition triggered by interactions (probably meditated by the Fe-Ag interface) and a reentrance into a superspinglass phase at low temperature, while for sputtered sample no decrease of the magnetization is observed until very low temperatures (~20 K), being ZFC and FC curves very similar, what indicates that even at low temperatures, most of the nanoparticles are strongly correlated.

References:

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Figures:

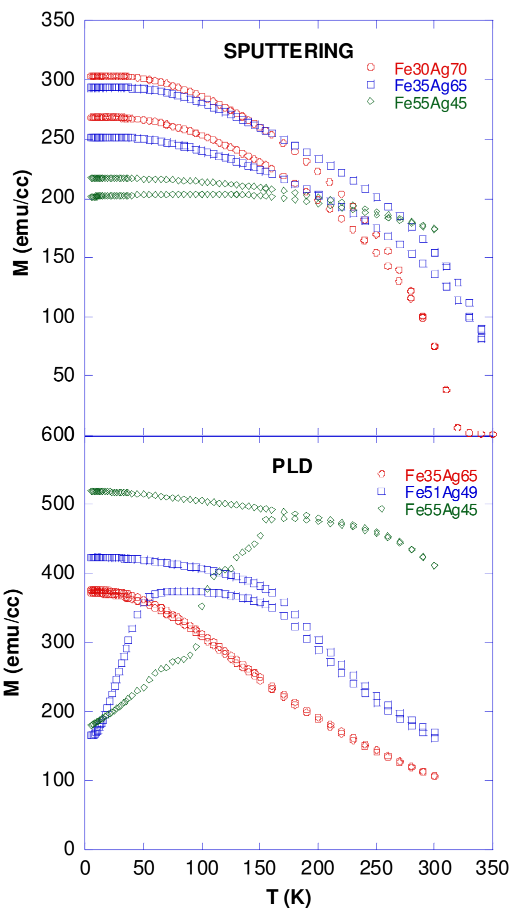

Fig1: ZFC-FC curves for (*top*) sputtered Fe_xAg_{100-x} (x = 30, 35, 55, h = 1 Oe) and (*bottom*) PLD Fe_xAg_{100-x} (x = 51, 53, 55, h = 5 Oe) samples.

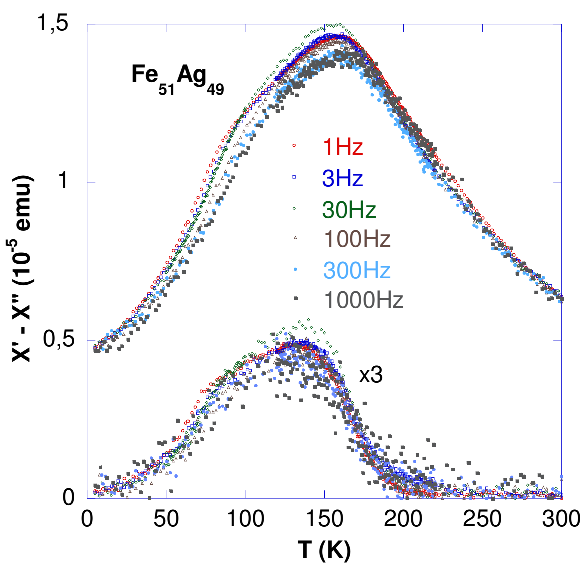

Fig2: real χ' and complex χ'' components of the susceptibility (h = 1 Oe) as a function of temperature measured at different frequencies, 1 ≤ f ≤ 100 Hz, for a PLD $Fe_{51}Ag_{49}$ thin film.