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Magnetic and magnetotransport properties of Fe nanoparticles embedded in Ag matrix

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Abstract

$Fe_{20}Ag_{80}$ and $Fe_{30}Ag_{70}$ granular thin films have been prepared by the pulsed laser deposition technique under different parameter conditions of pulse frequency and target angular speed. Their influence on the microstructure of the sample, through the analysis of the hysteresis loops, magnetotransport response and magnetooptical Kerr effect, has been investigated. The $Fe_{20}Ag_{80}$ samples present a superparamagnetic phase, composed of spherical Fe clusters with a mean diameter of 3 nm. The number of Fe nanoparticles increases as both laser pulse frequency and target angular speed increase, thus enhancing their giant magnetoresistance response. The $Fe_{30}Ag_{70}$ thin films have anisotropic magnetic behaviour and their magnetotransport measurements show giant magnetoresistance and extraordinary Hall effect. These anisotropies suggest the presence of Fe planar particles, which give rise to shape magnetic anisotropy that increases with increasing the target angular speed for a given laser pulse frequency. The planar shape of the Fe particles could be in the origin of the dominant extraordinary Hall effect.

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1. Introduction

Granular systems composed of magnetic nanoclusters embedded in a non-magnetic matrix present giant magnetoresistance (GMR), that is, their electrical resistance decreases under an applied magnetic field [1]. This phenomenon is very sensitive to microstructural changes (size, shape and number of magnetic particles [2,3]), because it is governed by the spin-dependent scattering of the conduction electrons at the magnetic clusters interfaces. Thus, knowing the microstructure of the samples is an essential point in order to understand their macroscopic behaviour.

In this work we have analysed $Fe_{20}Ag_{80}$ and $Fe_{30}Ag_{70}$ granular thin films obtained by the pulsed laser deposition technique. We have studied the influence of the deposition conditions (in particular, the laser pulse frequency, ν, and target angular speed, ω) and the composition on the magnetic and magnetotransport responses of the samples. We have observed that the superparamagnetic (SPM) behaviour found in the $Fe_{20}Ag_{80}$ samples is suppressed in the $Fe_{30}Ag_{70}$ ones, where coercivity and magnetic anisotropy appear. The magnetotransport features also change with increase in the Fe content, lowering the GMR values and showing a dominant extraordinary Hall effect (EHE).

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2. Experimental

The samples have been prepared by the pulsed laser deposition technique using a LAMBDA PHYSIK Compex 102 Laser ($\lambda = 248\,\text{nm}$, 155 mJ per pulse) onto glass substrates at room temperature and 2×10^{-5} mbar in the deposition chamber. The target is a rotating disc divided into sectors of Fe and Ag whose areas are proportional to the nominal composition of the desired final sample, in our case, $Fe_{20}Ag_{80}$ and $Fe_{30}Ag_{70}$. Different samples were obtained by varying the laser pulse frequency, v (Hz), and the target angular speed, ω (rpm). These samples will be named in the following as a function of the deposition parameters v/ω. The thicknesses of films were measured by profilometry. Magnetic measurements were performed in a SQUID magnetometer under a magnetic field of up to 7 T, applied parallel and perpendicular to the film plane. The variation of the resistance with the applied magnetic field has been also measured with the magnetic field applied parallel and perpendicular to the sample plane. In the parallel configuration a giant magnetoresistance behaviour was found. The magnetoresistance, defined as $\text{MR}\% = 100 \times [R(\mu_0 H) - R(\mu_0 H = 0)]/[R(\mu_0 H = 0)]$, has been measured using the well-known four probe technique, at 10 K the $Fe_{20}Ag_{80}$ samples and at room temperature the $Fe_{30}Ag_{70}$ ones. In the perpendicular configuration, a GMR response was found in the $Fe_{20}Ag_{80}$ samples but in the $Fe_{30}Ag_{70}$ ones a dominant extraordinary Hall effect was found. The Hall effect measurements were performed in the usual Hall magnetic and electric configuration at room temperature. Finally, magnetooptical Kerr effect (MOKE) measurements were performed at room temperature in longitudinal geometry [4] with an applied magnetic field of up to 10 mT.

3. Results and discussion

Fig. 1 shows the in-plane magnetization loops of $Fe_{20}Ag_{80}$ films performed at 300 K. No differences have been found between the in-plane and out-of-plane magnetization curves: in both cases no saturation is reached even at such a high magnetic field as 7 T and no remanence and/or coercivity is observed. These features are typical of the superparamagnetism. As explained in previous works [5,6], these magnetization curves can be fitted with a Langevin law, $\mathscr{L}(a)$, weighted by a log-normal cluster size distribution function, $f(D)$:

$$M^{\text{SPM}} = M_s^{\text{SPM}} \int_0^{\infty} f(D)\mathscr{L}(a)\,\text{d}D. \tag{1}$$

The magnetic analysis reveals that all the $Fe_{20}Ag_{80}$ films are composed of Fe magnetic nanoclusters with mean

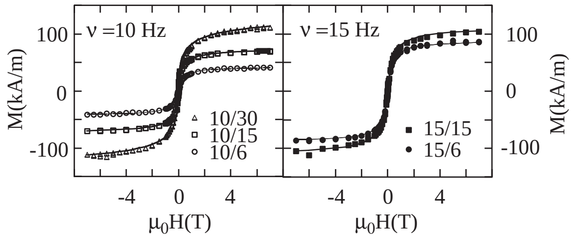

Fig. 1. In-plane magnetization loops measured at 300 K of $Fe_{20}Ag_{80}$ thin films deposited at different laser pulse frequencies v (Hz) and target angular speeds ω (rpm). The lines are the fittings following the Langevin law.

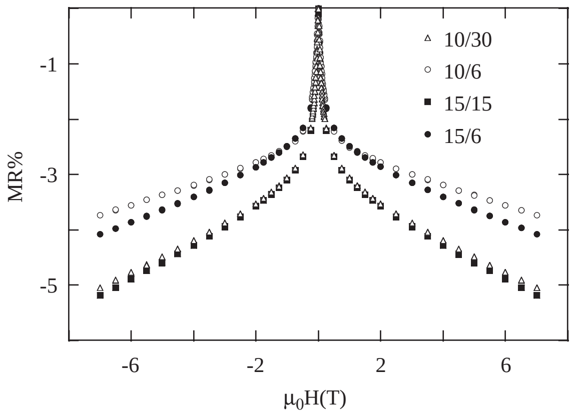

Fig. 2. In-plane giant magnetoresistance response measured at 10 K for the $Fe_{20}Ag_{80}$ thin films.

diameter of ≈ 3 nm and standard deviations of ≈ 1 nm, regardless of the deposition parameters. On the other hand, the saturation magnetization, M_s^{SPM}, obtained from the fit, increases with both the laser pulse frequency (v) and the target angular speed (ω). This indicates that the percentage of Fe forming the SPM phase, defined as $\%\text{SPM} = \frac{M_s^{\text{SPM}}}{M_s^{\text{BCCFe}}} \times 100$, depends on the deposition conditions, varying from 14% for the 10/6 sample to 36% for the 15/15 one. The rest of the Fe atoms should be diluted in the Ag matrix.

Fig. 2 displays the in-plane giant magnetoresistance (GMR) response of the $Fe_{20}Ag_{80}$ films measured at 10 K. The GMR response is isotropic: no differences have been found between the in-plane and out-of-plane measurements. The GMR increases with increasing v and ω. This enhancement of the GMR can be related to the increment of the concentration of Fe nanoclusters, the 15/15 sample being the one with the highest GMR value, 6%.

On the other hand, the $Fe_{30}Ag_{70}$ thin films display different magnetic and magnetoresistance responses