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Investigación

Perpendicular Magnetic Anisotropy of Co-Pt and Co-Pd Granular Films

Anisotropía Magnética Perpendicular en Películas Granulares de Co-Pt y Co-Pd

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Resumen

En este trabajo se describen las fascinantes propiedades de anisotropía magnética perpendicular de multicapas granulares de Co-Pt y Co-Pd. Dichas propiedades se observan por medidas de magnetometía SQUID convencional, con el campo magnético aplicado en dos direcciones perpendiculares. Las muestras estan formadas por aleaciones de Co-Pt y Co-Pd con estructura $L1_0$ en las distancias interatómicas en el corto alcance. La fuerte anisotropía magnética perpendicular observada en estas muestras se atribuye a la presencia de dicha aleación ordenada, lo que resulta relevante para aplicaciones en sistemas de grabación magnética.

***Palabras Claves*:** Anisotropía Magnética Perpendicular, Multicapas Granulares, Grabación Magnética.

Abstract

The fascinating properties of perpendicular magnetic anisotropy of granular Co-Pt and Co-Pd multilayer systems are described. These properties are observed by conventional SQUID magnetometry, measured with the applied field in two perpendicular directions. The samples are formed by Co-Pt and Co-Pd alloys, respectively, with $L1_0$ structure at short range distances. The strong perpendicular magnetic anisotropy observed in these samples has been ascribed as due to the presence of such ordered alloy, and is relevant concerning applications in magnetic recording.

***Keywords*:** Anisotropía Magnética Perpendicular, Multicapas Granulares, Grabación Magnética.

1. Introduction

The magnetic anisotropy of nanometer-sized metallic clusters determines the stability of their magnetic moments against thermal fluctuations. Therefore, this magnitude plays a crucial role for applications, since, in fact, it limits the minimum size that a particle must have to store information. For instance, the future of magnetic storage requires small magnetic particles with narrow size distribution and perpendicular magnetization of the storage material considering that perpendicular recording can deliver more than three times the storage density of traditional longitudinal recording.[1] Granular films exhibiting Perpendicular Magnetic Anisotropy (PMA), a property which favors the easy axis of magnetization along the film normal direction, have demonstrated to be good candidates for such applications. It is then fundamental the understanding and control of the magnetic anisotropy of these kinds of films.

Ordered Co-Pt and Co-Pd alloy multilayers and granular films are intensely investigated in this respect given the PMA properties that have been reported in both systems.[2,8] In this context, we have prepared and characterized granular multilayers of Pt- and Pd-capped

Co-nanoparticles, where we have observed PMA. The multilayers are formed by sequential sputtering deposition of Co and the capping metal (M = Pt or Pd) on amorphous alumina. The Co coalesces into clusters, the capping metal alloys with these Co particles, and we obtain a system of self-organized Co-M alloy nanoparticles (NPs). In this paper, we describe the strong PMA properties in these granular samples, as observed by conventional SQUID magnetometry measured with the magnetic field applied parallel and perpendicular to the film plate. This behavior has been correlated to the formation of Co-Pt and Co-Pd alloys, as they crystallize in the chemically ordered $L1_0$ phase, which has very high magnetocrystalline anisotropy for the bulk.[3]

The paper is organized as follows. The preparation and structure of the samples, as well as the experimental details of the magnetic measurements are listed in Sec. 2. The results of the magnetic characterization are described and discussed in Sec. 3. Finally, we summarize the main results of our work in Sec. 4.

2. Samples and experimental details

The samples were prepared at the Unité Mixte de Physique CNRS/Thales by sequential sputtering deposition of alumina, cobalt and the capping metal (M =Pt or Pd) on a Si substrate, following the same procedure as it is described in previous works on metal capped Co nanoparticles. [4,5] The Al_2O_3, Co, and M are deposited using Ar plasma, the metals in DC mode and the insulator at a RF power of 2.2 W/cm^2. The substrate temperature is kept constant at 293K and the Ar pressure is 2×10^{-3} Torr. The formation of Co aggregates on the amorphous alumina is the result of three-dimensional growth because of the different surface energies between alumina and Co. [6] Aggregation occurs below a certain threshold of the nominal thickness of Co, $t_{\rm Co}$, that the layer would have if it were continuous. The Co clusters are subsequently capped with a M =Pt or Pd layer, for which the nominal thickness is denoted by $t_{\rm Pt}$ and $t_{\rm Pd}$, respectively. A new alumina layer of about 3 nm is deposited on top of the Co-Pt or Co-Pd system. This sequential deposition process is repeated N times in order to get a multilayer system, following the formula Al_2O_3/(Al_2O_3/Co/M)$_N$/Al_2O_3. The samples studied here are Co-Pt and Co-Pd granular films with a fixed $t_{\rm Co} = 0.7$ nm, $t_M = 1.5$ nm, and $N = 25$.

The morphology and structure of the Co-Pt NPs have been examined by high resolution transmission electron microscopy and extended X-ray absorption fine structure measurements, results described elsewhere.[7] It has been observed that Pt tends to alloy with the Co particle with a composition close to $Co_{0.5}Pt_{0.5}$ in the ordered $L1_0$ phase. In addition to this alloy, there is a remnant of the original Co cluster formed on the alumina matrix, and an excess of the capping Pt that fills the interparticle spaces. In the Co-Pd granular films, evidences of Co-Pd alloy are also found.

Magnetization measurements were performed with a SQUID magnetometer equipped with the high resolution (RSO) option. Both magnetization as a function of the applied field, $M(H)$, and as a function of temperature, $M(T)$, were measured in two configurations: (1) with the field applied parallel, and (2) perpendicular to the substrate plane. The $M(T)$ curves were measured after zero-field cooling (ZFC) and field cooling (FC) the sample. Temperature was varied between 5 K and 400 K, and a 200 Oe field was applied. Hysteresis loops were measured at several temperatures from 5 to 350 K, under applied fields up to 50 kOe.

3. Results and discussion

The magnetic properties of the Co-Pt and Co-Pd granular systems are those of strongly ferromagnetically coupled particles. This is revealed by the ZFC-FC curves measured in the perpendicular configuration, as shown in Figs. 1 and 2 for the Co-Pt and Co-Pd granular films, respectively. For the ZFC curve, an increase of the magnetization with temperature is observed until $T_1 \approx 140$ and 150K, for the Co-Pt and Co-Pd system, respectively, which corresponds to the first shoulder observed in the ZFC curves in Figs. 1 and 2. Above T_1, the Co-Pt particles follow a collective ferromagnetic behavior up to $T_f \approx 350$ K, where both ZFC and FC curves decrease again, overlap, and follow a Curie-Weiss law. The Co-Pd particles behave likewise, though T_f is not clearly identified from these measurements, but it could be around 370 K.

The magnetization as a function of field measured at $T = 5$ K in both configurations for the Co-Pt and Co-Pd granular multilayers are shown in Fig. 3 and Fig. 4, respectively. The magnetization is expressed per substrate area, as a usual practice in magnetic recording media. At low temperatures the hysteresis curves measured in the perpendicular direction are rather square, which indicates the presence of a ferromagnetic hard component, with a quite high coercive field, $H_{\rm C} = 4$ and 6.5 kOe for the Co-Pt and Co-Pd, respectively. $H_{\rm C}$ decreases monotonically for increasing temperature and disappears between $150-200$ K for both Co-Pt and Co-Pd systems. A soft magnetic component is also present

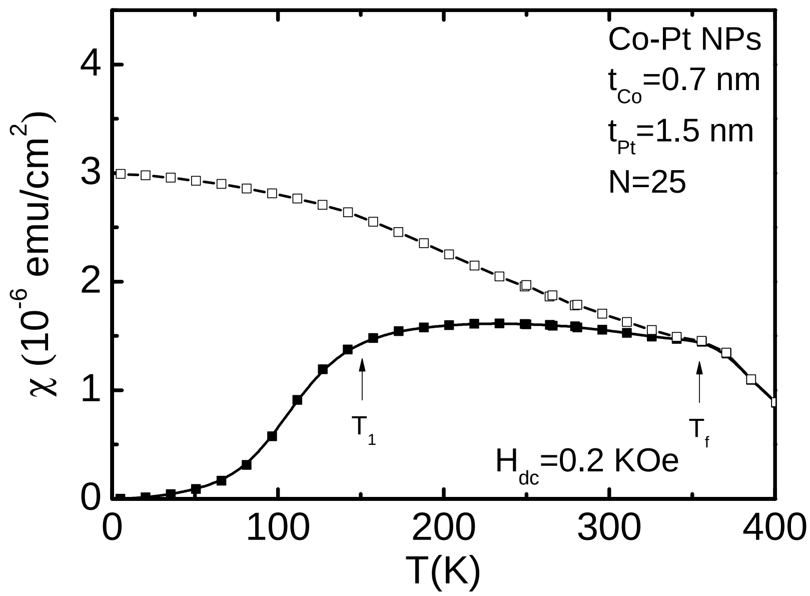

Fig. 1. Magnetization as a function of temperature measured in the SQUID magnetometer on the Co-Pt NPs sample with $t_{\rm Co} = 0.7$ nm and $t_{\rm Pt} = 1.5$ nm. A magnetic field of $H_{\rm dc} = 0.2$ kOe was applied in the direction perpendicular to the film.

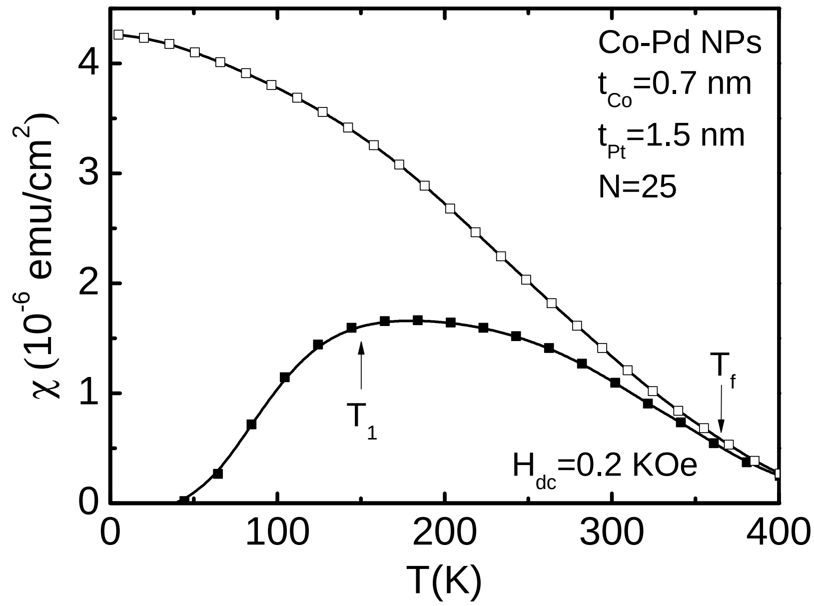

Fig. 2. Magnetization as a function of temperature measured in the SQUID magnetometer on the Co-Pd NPs sample with $t_{\rm Co} = 0.7$ nm and $t_{\rm Pd} = 1.5$ nm. A magnetic field of $H_{\rm dc} = 0.2$ kOe was applied in the direction perpendicular to the film.

in the Co-Pt samples up to T_f, which has been ascribed to the magnetic behavior of the Co rich core of the particles. This soft magnetic component is not observed in the Co-Pd granular system.

In contrast, the hysteresis loops measured in the parallel configuration direction at $T = 5$ K show a much lower coercivity, being 0.85 and 1.7 kOe for the Co-Pt and Co-Pd NPs samples, respectively (see Figs. 3 and 4). Such differences between the magnetization curves measured in orthogonal directions (with the bias field applied parallel and perpendicular to the substrate plane) evidence the presence of perpendicular magnetic anisotropy (PMA) in both Co-Pt and Co-Pd NPs systems. The easy magnetization direction

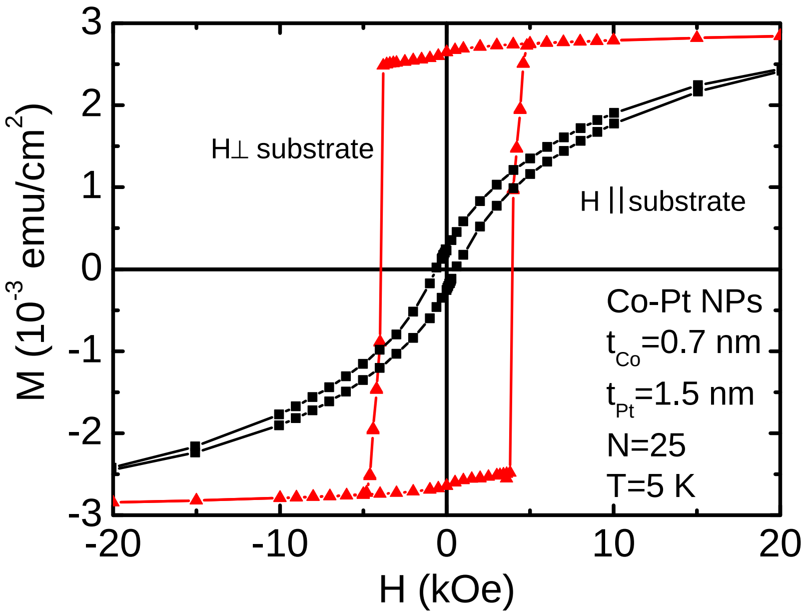

Fig. 3. Hysteresis loops at $T = 5$ K for the Co-Pt granular sample with $t_{\mathrm{Co}} = 0.7$ nm and $t_{\mathrm{Pt}} = 1.5$ nm. (■) H perpendicular to the substrate, (▲) H parallel to the substrate.

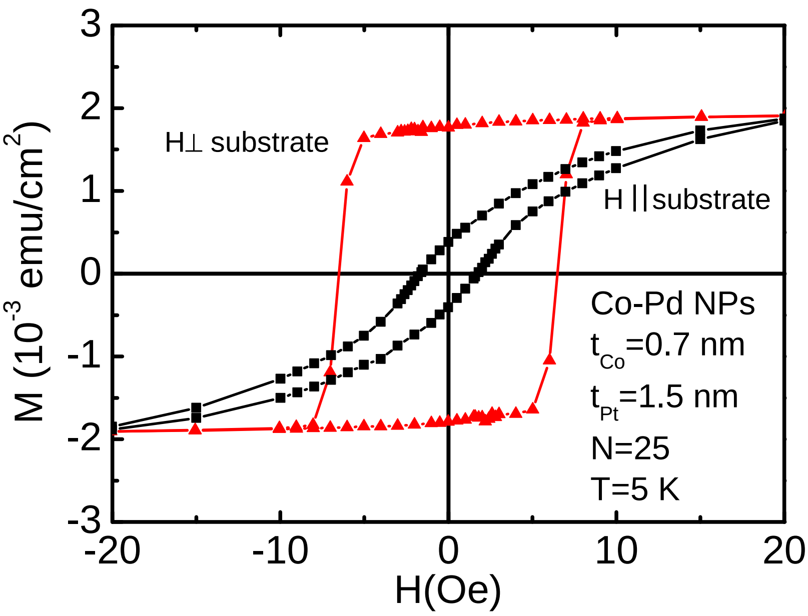

Fig. 4. Hysteresis loops at $T = 5$ K for the Co-Pd granular sample with $t_{\mathrm{Co}} = 0.7$ nm and $t_{\mathrm{Pd}} = 1.5$ nm. (■) H perpendicular to the substrate, (▲) H parallel to the substrate.

has been identified to be the one perpendicular to the substrate, as observed in different Co-Pt and Co-Pd systems.[2,8,9,10,11]

The magnetic anisotropy of the Co-Pt and Co-Pd granular films can be quantified by analysis of the curves in Figs. 3 and 4. The magnetic anisotropy energy can be estimated from the area enclosed by the two curves measured in the parallel and perpendicular configurations, in the first quadrant of the $M(H)$ curve.[8] This area, calculated after removing the hysteresis of the loops by averaging the two branches of each curve, yields the quantity $K_{\mathrm{eff}}t$, with K_{eff} the effective anisotropy constant and t the film thickness. We have found values of $K_{\mathrm{eff}}t = 12(1)$ and 3.4(3) erg/cm^2 at $T = 5$ K for the

Co-Pt and Co-Pd granular films, respectively. These results reveal stronger anisotropy properties for the Co-Pt system compared to the Co-Pd one.

The properties of PMA in Co-Pt systems have been explained as due to the presence of Co-Pt alloy with a highly anisotropic phase. In most of the cases it corresponds to the ordered $L1_0$ $Co_{0.5}Pt_{0.5}$ alloy, which is the one present in our Co-Pt system. The crystal structure of this alloy phase consists of alternating layers of pure Co and Pt atoms, stacked along the (001) direction, corresponding to the easy axis of magnetization.[12] Alloy films grown of this $L1_0$ $Co_{0.5}Pt_{0.5}$ phase have their c-axis perpendicular to the substrate surface, in order to favor the PMA properties. The anisotropy constant for these systems is on the order of $K_{\mathrm{eff}} = 10^7$ erg/cm^3,[9] which results in values of $K_{\mathrm{eff}}t$ higher than those estimated for our Co-Pt granular films (e.g. for a $Co_{0.5}Pt_{0.5}$ alloy film of 40 nm, $K_{\mathrm{eff}}t \approx 100$ erg/cm^2). This difference may be understood from the low crystallographic order in our Co-Pt granular films compared to the high quality alloy films reported in the literature.

The observed PMA in our Co-Pd granular films results from a similar mechanism due to their crystallographic order, as it has been observed for highly anisotropic Co-Pd alloy films.[13] Values of K_{eff} in these systems have been reported to be, indeed, lower than the case of the Co-Pt films, i.e., around $K_{\mathrm{eff}} = 5 \times 10^5$ erg/cm^3.[13] The quantitative differences between the anisotropic properties of the Co-Pt and Co-Pd systems may lie on the electronic structure of the atoms forming the alloys.

4. Conclusions

The magnetic behavior of the Co-Pt and Co-Pd granular films is described as that of ferromagnetically coupled particles. Their properties of perpendicular magnetic anisotropy are correlated with the presence of the ordered $L1_0$ $Co_{0.5}Pt_{0.5}$ and $Co_{0.5}Pd_{0.5}$ alloy, respectively. These anisotropic properties are stronger in the case of the Co-Pt than in Co-Pd system. The large perpendicular magnetic anisotropy observed in the two granular films described here make them very attractive for applications in magnetic recording systems, once it is held up to room temperature. Further research in this direction is currently being performed.

Acknowledgments

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