

## Capping-layer-induced magnetic coupling in a two-dimensional nanostructured system

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The magnetic polarization of a Pt capping layer leads to an increase of the interisland magnetic coupling in a two-dimensional array of Fe islands. For small superparamagnetic islands, Pt deposition leads to a superparamagnetic–ferromagnetic transition. For larger ferromagnetic but weakly coupled islands, Pt deposition produces a stronger interisland coupling. Polar Kerr spectroscopy measurements and simulations evidence the magnetic polarization of Pt in contact with Fe. The described effects and their interpretation are supported by the use of a nonpolarizable Al capping, where both the superparamagnetic-to-ferromagnetic transition and the increase of the interisland coupling are absent. © 2004 American Institute of Physics. [DOI: 10.1063/1.1689739]

In order to design magnetic materials for specific applications, it is important to understand how their macroscopic properties arise from the interplay of microscopic parameters such as grain size,<sup>1,2</sup> intergrain coupling,<sup>3,4</sup> and anisotropies.<sup>5,6</sup> Furthermore, for the continuous increase of magnetic storage density,<sup>7–9</sup> it is crucial to know to what extent the independence of individual storage units can be maintained in the presence of intergrain coupling. In this sense, the high fraction of atoms at the surface of nanograins (that differ from “bulk” atoms) makes critical the nature of the interface; large changes in the collective behavior may be expected by changing the particle’s environment from that of a free particle, to that of a particle supported on a surface or even a particle embedded in a matrix. As a consequence, dramatic changes in the magnetic behavior (superparamagnetism, random anisotropy, single-domain behavior) can be driven by small variations in grain size, intergrain distance, and magnetic correlation across grain boundaries; this last effect, as will be shown in this letter, is also modified by the type of material used as capping or matrix. To study these effects magneto-optical characterization is one of the best-suited techniques because of its high sensitivity to small amounts of material and to modifications of the morphology<sup>10</sup> and electronic structure<sup>11</sup> of the system. In addition, *in situ* experiments allow one to monitor the evolution of the magnetic properties during the different steps of growth. This makes it possible to determine, for example, the influence of the capping layer in a much more direct way than if *ex situ* techniques were used. Within this scope, the aim of this work is to show how capping materials of differ-

ent magnetic polarizability such as Pt and Al determine the magnetic properties of Fe (110) nanoislands onto which these cappings are grown.

The system considered in this work consists of (110) bcc Fe islands sputtered at 700 °C on Al<sub>2</sub>O<sub>3</sub> (0001). Details about the fabrication, structure, morphology, and magnetic properties of these islanded films can be found elsewhere.<sup>12–14</sup> A 2.5-nm-thick Pt or Al capping layers were deposited keeping the samples at room temperature to minimize intermixing. The size of the islands was adjusted by controlling the deposition time and checked by atomic force microscopy (AFM). In this work we present results on two types of islands: type 1 are islands with in-plane diameter  $d=10$  nm and height  $h=1$  nm; type 2 have  $d=12$  nm and  $h=3$  nm. AFM measurements performed in uncapped and capped samples yield very similar morphologies and island sizes, confirming the conformal nature of both Pt and Al overlayers. Figures 1(a) and 1(b) show the topography images for uncoated and Al-coated Fe islands of type 2. The small changes in island size observed are probably due to two factors: (i) The AFM images correspond to different samples (the *ex situ* character of AFM does not allow the comparison between the morphologies of the same uncapped and capped sample). (ii) In addition, an increase of the uncapped islands’ volume can be a consequence of the Fe surface oxidation.

To separate the intrinsic magnetic behavior of free Fe islands from the possible changes induced by the capping layers, transverse Kerr loops were measured *in situ* before and after deposition of Pt and Al. The results are shown in Fig. 1(c) for Fe islands of type 1. Both uncoated and Al capped islands exhibit a clear superparamagnetic behavior. Al capped islands were also measured *ex situ* applying larger

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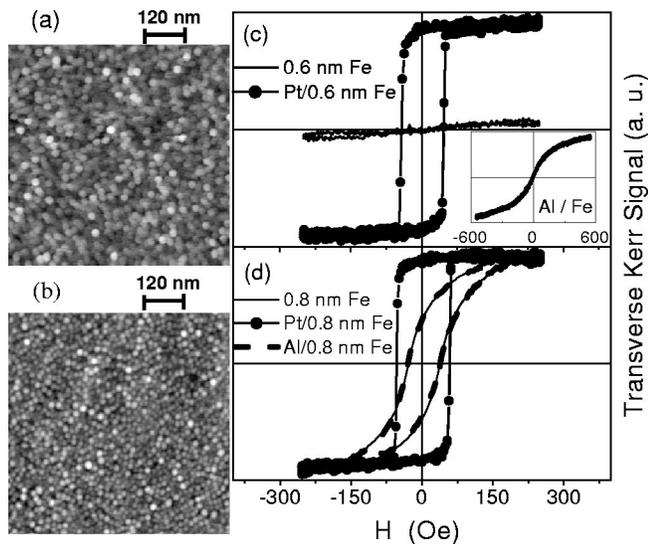


FIG. 1. (a) and (b) AFM image of uncoated and Al coated Fe islands with 12 nm average diameter. (c) *In situ* transverse Kerr loops of uncovered (solid curve), Pt-covered (dotted curve) islands with 10 nm diameter. Inset shows *ex situ* transverse Kerr loop of Al-covered Fe islands with 10 nm diameter. (d) *In situ* transverse Kerr loops of uncovered (solid curve), Pt-covered (dotted curve), and Al-covered (dashed curve) Fe islands with 12 nm diameter.

magnetic fields [inset of Fig. 1(c)]. In this case, the Fe islands do not coalesce, being magnetically isolated from each other and small enough to be superparamagnetic at room temperature, which is consistent with the average volume of the islands. In contrast, the Pt deposition on top of the islands leads to the appearance of hysteresis with a sharp reversal of the magnetization, indicating a collective switching of all islands' magnetizations. This change is due to a magnetic connection between the Fe islands mediated by the Pt capping layer, and is attributed to the magnetic polarization of Pt, which becomes weakly ferromagnetic at the interface with the Fe islands and transmits the exchange interaction between them. The effect of Pt and its contrast with Al is further shown in Fig. 1(d), where similar results for Fe islands of type 2 are displayed. For this island size, hysteresis is already present in the uncapped situation, indicating the presence of magnetic entities larger than for the type 1 Fe islands case. Again the hysteresis loop remains unchanged upon deposition of Al while deposition of Pt leads to a more squared loop, due to a stronger magnetic interaction between Fe islands and simultaneous magnetization reversal for most of the sample, confirming the magnetic connection effect induced by the Pt. Another interpretation for the observed loops in the uncapped and Al capped cases would be the presence of perpendicular magnetic anisotropy, but polar Kerr loops measured *ex situ* exclude this possibility.

As mentioned before, we interpret these observations as due to the magnetic polarization of Pt layer that acts as an exchange transmitter layer. It is well known that Pt has a large susceptibility and becomes polarized in the presence of a ferromagnetic material. In Pt/Fe multilayers<sup>15</sup> or Pt films grown on Fe,<sup>16</sup> an induced Pt magnetic moment of  $0.5 \mu_B$ /atom has been measured up to 5 atomic layers (about 1 nm) at the Pt/Fe interface. Taking this polarization depth as a reference, two islands laterally separated by approximately

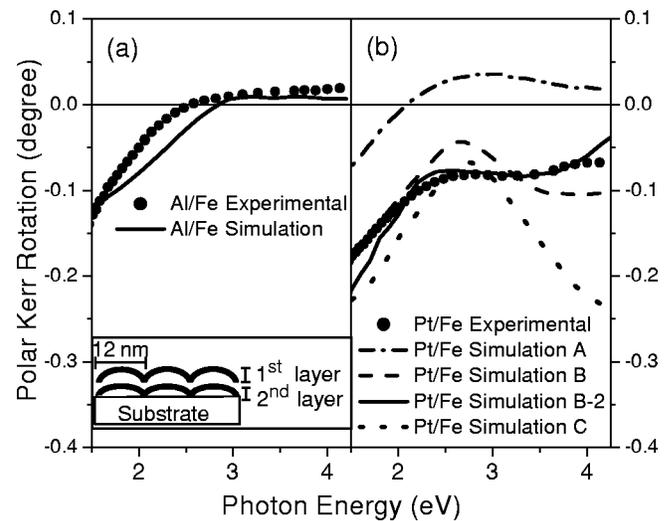


FIG. 2. (a) Polar Kerr spectrum for the Al covered islands of  $d=12$  nm together with the corresponding simulation: The inset shows the structure considered in the simulation. Two different layers have been considered: the first one is Al (or Pt) islands embedded in air at 50% with a height of 3 nm and the second consists of Fe islands embedded in Al (or Pt) matrix at 40% with 2 nm height. (b) Polar Kerr spectrum for the Pt covered islands with  $d=12$  nm together with four simulations. Simulation A: Pt is not magnetically polarized; simulations B and B-2: only the Pt in the second layer is magnetically polarized, and simulation C: Pt is magnetically polarized in the two layers. Simulations B and B-2 are performed using the magneto-optical constants of magnetically polarized Pt from Refs. 23 and 24, respectively.

2 nm could be magnetically connected through polarized Pt (each island would polarize 1 nm of Pt).

Additional evidence of the magnetic polarization of Pt can be obtained from polar Kerr spectra. In Fig. 2(a) we present the spectrum for type 2 Fe islands capped with Al together with a simulation assuming the structure shown in the inset of Fig. 2(a). The dielectric tensor of the islands layers were obtained using an effective medium approximation<sup>17</sup> with the diagonal components of the dielectric tensors of Fe and Al given in Ref. 18 and the magneto-optical components of the dielectric tensor of Fe.<sup>19</sup> The simulations were done using a transfer matrix formalism.<sup>20</sup> As can be seen in Fig. 2(a), there is a reasonable agreement between experiment and simulation, confirming the validity of the assumed structure and simulation formalism.

Similarly, the Kerr rotation spectrum of Pt capped type 2 Fe islands with identical morphology to those shown in Fig. 2(a) is shown in Fig. 2(b). Despite the similar dielectric constants of Al and Pt, the experimental spectra are very different. In particular, in the ultraviolet region the sign of the rotation for the two samples is opposite while being the same in the visible-infrared region. We associate these differences to the magnetic polarization of Pt, and therefore to the appearance of an additional magneto-optical activity not present when the capping layer is not polarized. Such additional magneto-optical activity of Pt has been observed in other Pt related systems like Pt/Co multilayers.<sup>21,22</sup> The magneto-optical constants of Pt magnetically polarized by Fe are not known, but a rough idea of them could be obtained from the Kerr rotation and ellipticity of FePt<sup>23</sup> alloys by assuming that the 50% alloy is an effective medium composed of Pt magnetically polarized particles (spheres) and Fe particles (spheres). In Fig. 2(b) we present the experimental

and simulated Kerr rotation spectra for Fe particles with a Pt capping having different degrees of magnetic polarization. Curve A corresponds to a simulation where Pt is not magnetically polarized, the calculated spectrum is very similar to the one obtained for Al, but very different from the experimental one. On the other hand, if the Fe particles are embedded in a Pt magnetically polarized matrix (second layer) and covered with no magnetically polarized Pt (first layer), the simulated spectrum (B) is more similar to the experimental case. And finally, if we assume that additionally the Pt in the first layer is magnetically polarized, the calculated rotations (simulation C) are negative in the whole spectral range, but too far from the experimental data. Therefore the simulation suggests that the strong variations in magnetic properties of Pt/Fe in comparison with those of free Fe islands or Al/Fe islands can be mainly attributed to the magnetic polarization of the Pt layer in the Pt/Fe interface region. As can be observed there are some differences between the simulated spectrum of curve B and the experimental data. We attribute these differences to the magneto-optical constants of Pt. For example, if instead of using the values of the Kerr rotation and ellipticity of FePt given in Ref. 23 we use the values given in Ref. 24 to obtain the magneto-optical constants of Pt, a much better agreement can be obtained (see curve B-2).

In conclusion, we have shown that the deposition of Pt on top of very close to each other superparamagnetic Fe islands yields to a superparamagnetic-to-ferromagnetic transition suppressing their intrinsic superparamagnetic character. When the Fe islands have bigger sizes and interact weakly, the Pt capping layer increases significantly the magnetic interisland interaction. Both effects are due to the magnetic polarization of the Pt layer that has been evidenced by measured and simulated magneto-optical Kerr rotation spectra, demonstrating that this magnetic polarization is limited just to the region near the Fe islands, the outer Pt region remaining unpolarized.

In the case of a nonpolarizable capping layer (Al), no change is observed between the magnetic properties of capped and uncapped Fe islands. These results exemplify the importance of the *in situ* characterization of magnetic nanostructures and open a method to tailor magnetic systems with different properties just by changing the capping material.

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