The influence of the Pt buffer layer on the perpendicular magnetic anisotropy in epitaxial FePd(001) ordered alloys grown by sputtering

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Single-crystalline FePd(001) 1000-Å-thick films were grown at 500 °C by codeposition in an UHV sputtering system. It is found that both the crystalline structure and therefore the magnetic properties strongly depend on the Pt buffer layer thickness. The films grown on Pt(100) layers 50 Å thick and thinner do not exhibit clear chemical order and show in-plane magnetic anisotropy. FePd grown on thicker Pt buffers adopts a fct structure accompanied by a strong chemical ordering, leading to a perpendicular magnetic anisotropy. © 1997 American Institute of Physics.

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I. INTRODUCTION

The study of chemically ordered binary alloys has recently found much interest due both to the magnetic and magneto-optical behavior exhibited in the presence of ordering, and for the potential technological applications for the use as magnetic storage media. The presence of the CuAu I ordered structure in FePt and CoPt leads to a strong magnetic anisotropy along the tetragonal distortion c axis, as predicted by Daalderop, Kelly, and Schuurmans.¹ So far these systems have been obtained by annealing of sputtered equiatomic multilayer precursors,² codeposition by molecular-beam epitaxy (MBE)³ or sputtering,⁴ or alternate deposition by MBE.⁵ In order to obtain single-crystalline epitaxial films, a Pt(100) seed or buffer layer is grown onto MgO(100) substrates, offering a cubic symmetry metallic surface for the alloy to grow onto; otherwise, the disordered cubic structure is obtained. The ordered CuAu I structure, being fct, grows with the square side of the lattice parallel to the Pt film plane, leaving the c axis in the perpendicular direction. Since the magnetic anisotropy in these systems is governed by the direction of the ordering c axis, perpendicular magnetic anisotropy can be obtained following this growth recipe.

In this work we demonstrate that also for FePd the perpendicular magnetic anisotropy can be obtained if a careful attention is paid to the role of the Pt buffer layer structure. In particular we observe that, for our growth conditions, a minimum for Pt layer thicknesses of 150 Å is needed in order to obtain a large perpendicular magnetic anisotropy correlated with a strong chemical ordering.

II. EXPERIMENT

The deposition of the films was performed in an UHV triode-sputtering system with a load-lock entry. The base pressure was in the low 10^{-9} mbar range, and the Ar pressure during deposition 4×10^{-4} mbar. This pressure is at least one order of magnitude lower than the Ar pressures used in standard sputtering systems. Deposition rates were around 0.1–0.3 Å/s, depending on the target. The structure of the films was checked *in situ* with reflection high-energy electron diffraction (RHEED) and *ex situ* with x-ray diffraction (XRD) using Cu $K\alpha$ radiation. The magnetic properties were

measured using vibrating sample magnetometry (VSM). The nominal composition was determined by careful calibration of the targets sputtering rates and checked by electron microprobe, confirming the equiatomic ratio within an error of order of 5%. The resulting thicknesses were cross checked using a profilometer.

The samples were grown on polished MgO(100) single crystals. Substrates were cleaned in successive ultrasonic baths of trichloroethane, acetone, and methanol. After being transferred to UHV, the MgO substrates were annealed at 700 °C for several hours using a resistive heater. The Pt seed or buffer layers of various thicknesses (10, 50, 150, 300, and 450 Å) are first grown at 700 °C, adopting a (100) orientation as determined *in situ* by RHEED. Preliminary atomic force microscope (AFM) measurements⁶ show that indeed the 50 Å Pt film is not continuous, but composed of 3D Pt islands, with little coalescence. These islands grow and coalesce for 150 Å Pt, reaching complete continuity for 450 Å. Following, a 1000-Å-thick FePd film is grown on top of the Pt at 500 °C by codeposition of Fe and Pd from independent targets both pointing to the sample. A typical RHEED pattern for one of these FePd films is shown in Fig. 1. Very sharp and intense stripes, indicative of a high-quality film,

FIG. 1. RHEED pattern of a 1000 Å FePd film grown at 500 °C on 150 Å Pt (100).

FIG. 2. Symmetric XRD scans for three FePd films grown on Pt buffer layers of different thicknesses (vertical scale is logarithmic in arbitrary units).

are observed for two azimuths 45° apart, with spacings corresponding to the growth of a squared symmetry film. Finally, after cooling the sample down to room temperature, a 50 Å Pt capping layer was grown to avoid oxidation.

III. RESULTS AND DISCUSSION

Figure 2 shows symmetric XRD scans for three samples grown onto 50, 150, and 450 Å Pt, respectively. For the sample grown on 50 Å of Pt, besides the MgO(200) substrate peak, two peaks originating from the FePd film are clearly observed. The presence of a weak FePd(001) is indicative of a low degree of chemical ordering. The positions of both FePd(001) and (002) give an average vertical lattice parameter of 3.792 Å. Since bulk FePd lattice parameters are $a=b=3.85$ Å, $c=3.731$, we can conclude that the alloy is growing with a small (-1.5%) tetragonal distortion compared to the bulk (-3.1%). On the other hand, the Pt buffer is so thin that the Pt(200) peak appears just as a shoulder on the low scattering angle region of the FePd(002). Very strong changes happen when growing the alloy on a 150 Å Pt film. Now three FePd peaks are clearly observed. The presence of strong (001) and (003) FePd peaks indicate a high degree of chemical ordering. Their positions are strongly shifted to higher scattering angles with respect to the sample grown on 50 Å Pt. This leads to an average FePd vertical lattice parameter of 3.686 Å, showing a c axis even shorter than previously reported values. On the other hand, the Pt(200) peak is now clearly observed, but its position (3.894 Å) is slightly off the bulk value. Finally, the sample grown on 450 Å Pt shows again the three intense FePd peaks, characteristic of a high chemical ordering, but shifted even to higher scattering angles, the vertical lattice parameter being now 3.676 Å. The Pt peak is now very strong, corresponding to the bulk position (3.92 Å). This behavior can be understood considering the discontinuous nature of the thinner Pt buffers. In the case of a 50 Å discontinuous Pt film, the FePd alloy grows indeed both on Pt and on clean MgO. The mismatch between MgO ($a=4.213$ Å) and FePd is so big (-8.6%), that the alloy

FIG. 3. Hysteresis loops for three FePd films grown onto Pt buffer layers 50, 150, and 450 Å thick. The vertical scale shows arbitrary units

lattice is not distorted by strain to match the substrate, but relaxes to an almost cubic phase. A 150 Å Pt shows coalescence, growing the alloy now mostly on Pt. This favors the growth of a tetragonal, highly ordered phase instead of an almost cubic one. This effect is even stronger for the growth on a continuous 450 Å Pt film, where the degree of ordering and tetragonal distortion is the highest. It can be argued that shifts in the alloy diffraction peaks can be due to deviations from the 1-to-1 nominal composition. This can be ruled out by the presence of the strong ordering peaks, which intensity would be dramatically reduced in the case of non stoichiometry. It has been observed in FePt (Ref. 7) that the intensity of these satellite peaks, and therefore the degree of chemical ordering, depends on the growth temperature, being therefore a thermally driven process. During codeposition on a (100) surface at appropriate temperatures, Fe and Pd atoms reach minimum energy adsorption sites in terraces of pure Fe and Pd, respectively, through diffusion from adjacent terraces. In our case, the discontinuous nature of the 50 Å Pt seed layer precludes the ordering process to happen in large lateral distances, limited to the lateral size of each Pt island, giving rise to very small ordered regions and many antiphase boundaries. Thicker Pt films offer larger, more continuous terraces for the Fe and Pd atoms to diffuse and order, avoiding the possibility of many antiphase domains. Finally, in plane rocking curves from the (001) and (002) FePd peaks yield full width at half-maximum values on the order of 0.7° , again indicating a high degree of orientation for ordered samples.

Regarding magnetic properties, Fig. 3 shows the magnetization curves measured by VSM at room temperature with applied fields parallel and perpendicular to the film plane for the same samples. We observe two different behaviors depending on the Pt buffer thickness. The sample grown on 50 Å Pt basically exhibits an in-plane anisotropy, reaching saturation for in plane applied fields below 1000 Oe. Neverthe-

less, the lack of squareness in the in-plane loops as well as the presence of a small but nonzero remanence obtained for fields applied in the normal direction indicates that a fraction of the sample exhibits perpendicular anisotropy. On the other hand, the samples grown on thicker Pt buffers (150 and 450 Å) show such a strong perpendicular anisotropy, that it is not even possible to approach saturation with the available magnetic fields applied in the film plane. In the perpendicular direction, though, there is a balance between the demagnetizing field and the perpendicular magnetic anisotropy which makes the magnetization saturate at 8000 and 5000 Oe (150 and 450 Å Pt, respectively). The low-field behavior, with almost no remanence, can be interpreted as due to domain formation.

The saturation magnetization was determined by means of VSM measurements at RT and corresponds to $1280 \text{ emu/cm}^3 \pm 15\%$, in concordance with Ref. 8. The anisotropy constants were estimated by magnetization curves at RT using the first magnetization method, for the ordered sample being $K_1 + K_2 = 9.0 \times 10^5 \text{ J/m}^3 \pm 40\%$. No significant in-plane anisotropy was found.

In conclusion, we have been able to grow high-quality single-crystalline FePd(001) alloy films at 500 °C by UHV sputtering. These films adopt the tetragonal CuAu I ordered phase only when grown on continuous 150 Å or thicker Pt buffers. If so, a strong perpendicular magnetic anisotropy correlated with the presence of chemical ordering is observed, confirming theoretical predictions. Growth on thinner, discontinuous Pt layers leads to an almost cubic FePd

phase with very little chemical ordering, magnetically softer, and with in-plane anisotropy. A detailed, more quantitative study on the influence of all growth conditions (buffer layer properties, deposition temperature) on the structural, magnetic, and magneto-optic properties is currently under investigation.

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