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MAGNETIC STORAGE/MEMORY AND APPLICATIONS

Co/Pt Multilayer Structures on the Crystal MgO and Si Substrate As a Media for Perpendicular Magnetic Recording[1]

P. D. Kim[a], I. A. Turpanov[a], S. V. Stolyar[b], V. I. Yushkov[a], and D. L. Khalyapin[a]

[a] *Kirensky Institute of Physics, Siberian Division, Russian Academy of Sciences, Akademgorodok, Krasnoyarsk, 660036 Russia*

[b] *Krasnoyarsk State University, Krasnoyarsk, 660041 Russia*

Abstract—In this work, the crystal structure and hysteretic magnetic properties of equiatomic single-crystal CoPt/MgO films prepared by magnetron sputtering and their modifications after heat treatment are studied. A perpendicular magnetic anisotropy is obtained in annealed films in a film thickness range of $2 < d \le 16$ nm. The correlation between the magnitude of magnetocrystalline anisotropy constant of CoPt films and the order parameter of the $L1_0$ superstructure of these alloys is ascertained. The influence of the single-crystal MgO substrate on the structure and magnetic properties of the films of equiatomic CoPt alloys is also investigated.

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1. INTRODUCTION

At present, the potential of perpendicular magnetic recording (PMR) to achieve recording densities well beyond 100 Gb/in^2 areal data density becomes obvious. As it was shown it a number of recent works, Co-based alloys are doubtless candidates for PMR media due to the high value of their anisotropy constant. In spite of the fact that now researchers try to obtain a smaller grain size for magnetic media, in our opinion single-crystal magnetic films with a perpendicular anisotropy can be an advantageous candidate for the PRM media.

CoPt alloys in the nearly equiatomic composition range during the possible $A1 \longrightarrow L1_0$ ordering process form a tetragonal uniaxial magnetic superstructure $L1_0$. The magnetic properties of this crystal-geometrical state satisfy the inequality $H_a \gg 4\pi M_s$ [1], where H_a is the magnetocrystalline anisotropy field and M_s is the saturation magnetization. According to this inequality, the achievement of perpendicular magnetic anisotropy (PMA) becomes possible in thin films of above-mentioned equiatomic alloys in the case of a (001) texture. This is the reason to regard the $Co_{50}Pt_{50}$ alloys (and also $Fe_{50}Pt_{50}$ and $Fe_{50}Pd_{50}$) as potential magnetic media for high-density storage devices. During the $A1 \longrightarrow L1_0$ ordering process, any of the ⟨100⟩, ⟨010⟩, and ⟨001⟩ axes of the fcc lattice can become a symmetry axis of the tetragonal structure. Therefore, in the absence of external actions three types of nuclei C_i (C_1, C_2, C_3) of the $L1_0$ ordered superstructure can exist [2]. To develop a magnetic media for high-density recording on the basis of these alloys, the finding of purposeful methods of obtaining the necessary microstructure of ordered (or partially ordered) $Co_{50}Pt_{50}$ ($Fe_{50}Pt_{50}$, $Fe_{50}Pd_{50}$) alloys becomes very important.

2. EXPERIMENTAL TECHNIQUES AND RESULTS

The samples of thin $Co_{50}Pt_{50}$ single-crystal films were obtained by magnetron sputtering in an argon atmosphere [3]. A working pressure was 2×10^{-4} Torr. The total thickness d of the films deposited varied from 2 to 100 nm. The films were deposited onto (001)-oriented MgO single-crystal substrates. The thickness d and the chemical composition of each film were determined by X-ray fluorescence measurements. Isothermal annealings of the films were performed in a vacuum chamber at a pressure not exceeding 5×10^{-6} Torr.

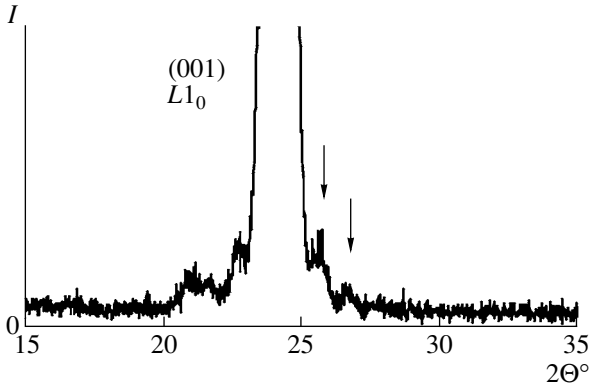

Fig. 1. The large-angle X-ray diffraction pattern for a 7-nm-thick $Co_{50}Pt_{50}$ film annealed for 3 h at $T = 873$ K.

[1] The text was submitted by the authors in English.

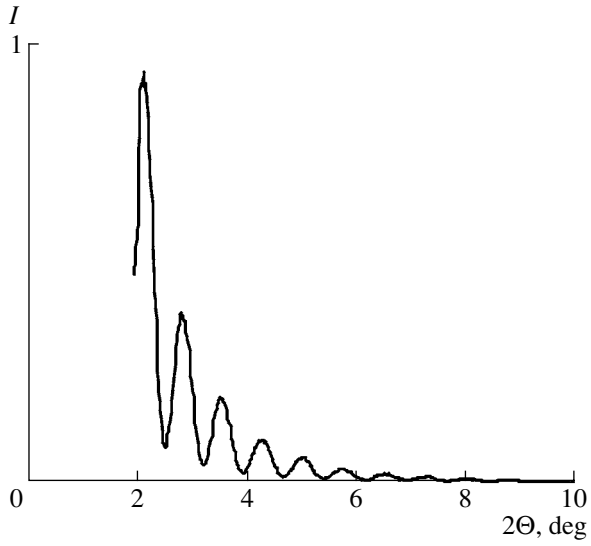

Fig. 2. Typical small-angle X-ray diffraction pattern for a 12.7-nm-thick $Co_{50}Pt_{50}$/MgO film annealed for 3 h at T = 600°C.

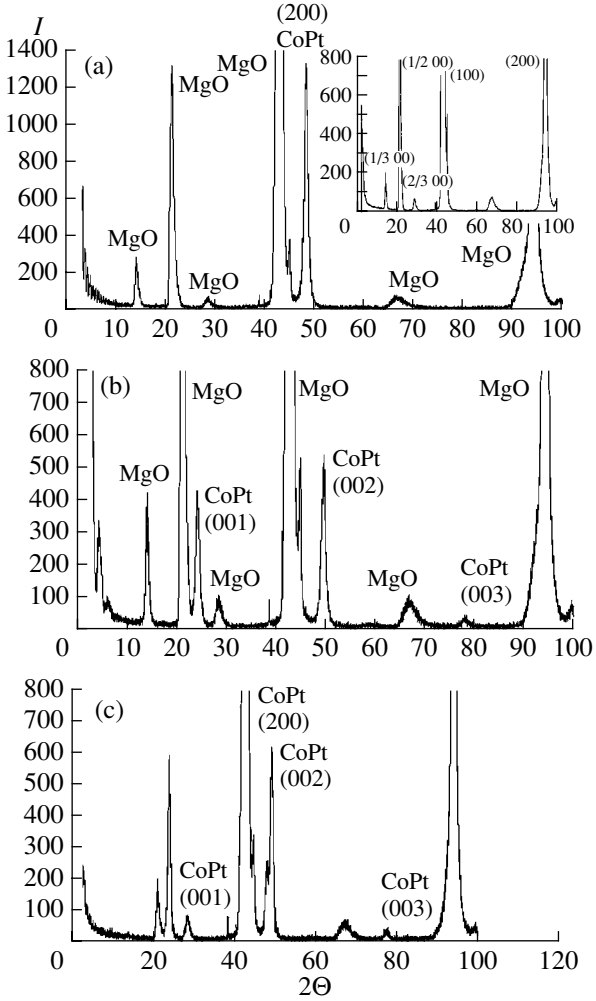

Fig. 3. X-ray diffraction patterns for $Co_{50}Pt_{50}$/MgO films: (a) as-prepared film with d = 19 nm (the inset shows an X-ray diffraction pattern for the MgO substrate only); (b) annealed film with d = 7 nm; and (c) annealed film with d = 15 nm.

The sample structure was studied at room temperature by X-ray diffraction on a DRON-4 diffractometer using Cu $K\alpha$ radiation (λ = 1.54 Å).

Figure 1 shows a large-angle X-ray diffraction pattern for a 7-nm-thick $Co_{50}Pt_{50}$ film annealed for 3 h at T = 873 K. As can be seen, the region of the (001) reflection characterizing the ordered $L1_0$ superstructure displays thickness-related oscillations of the interference contrast. Figure 2 shows a small-angle X-ray diffraction pattern for a 12-nm-thick film after isothermal annealing for 3 h at T = 600°C. The thickness-contrast measurements for these $Co_{50}Pd_{50}$ films (Figs. 1 and 2) indicate a coherent scattering through the film thickness and a homogeneous film thickness. The last fact indicates a high quality of the samples prepared [4].

Figure 3 shows X-ray diffraction spectra for the films investigated. The diffraction pattern of the as-prepared $Co_{50}Pt_{50}$/MgO(100) film with a thickness d = 19 nm (Fig. 2a) is a good evidence of a single-crystal state of the initial $Co_{50}Pt_{50}$ fcc alloy. The lattice parameter here is a = 0.377 nm. Additional peaks visible in this pattern are due to X-ray diffraction on the atomic planes of the MgO substrate. The inset in Fig. 3a shows the spectrum obtained from the substrate only. Figure 3b shows an X-ray diffraction pattern of a single-crystal $Co_{50}Pt_{50}$/MgO(100) film with d = 7 nm annealed at T = 600°C for 3 h. The presence of (001) and (003) reflections here indicates the formation of an $L1_0$ tetragonal superstructure which has a tetragonal axis parallel to the film normal **n**. The ratio between X-ray reflection intensities $I_{(001)}/I_{(002)}$ was used to evaluate the order parameter η for the $L1_0$ superstructure. The obtained dependence of η on the film thickness is presented in Fig. 4. Figure 3c shows an X-ray diffraction pattern of a single-crystal $Co_{50}Pt_{50}$/MgO(100) film with d = 15 nm. One can notice here the (200) reflection with an intensity smaller than that of the (002) reflection. This is an obvious evidence for the existence of $L1_0$ regions in the $Co_{50}Pt_{50}$ alloy film investigated where the tetragonal axis lies in the film plane.

The as-prepared single-crystal $Co_{50}Pt_{50}$/MgO(100) films, irrespective of the film thickness, have two different easy axes which lie in the film plane, along the [110] and [$\bar{1}$10] directions. The coercive force H_c for these films is also independent of the sample thickness d and has a value of about 500 Oe. Annealing at T = 600°C for 3 h leads to the formation of an easy axis parallel to the film normal **n** in the case of the film thickness d less than 16 nm. For films with d > 16 nm, the easy axis is still in the film plane after the above heat treatment. It was found that the H_c values for the films with d < 16 nm after annealing depend on the film thickness: $H_c = H_c(d)$. This dependence is shown in Fig. 5. It should be noted that the squareness of the hysteresis loop for these films is about 1: $S = M_r/M_s = 1$ (here M_r is the remanent magnetization) [5].

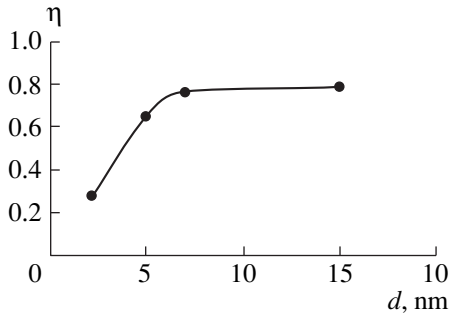

Fig. 4. Dependence of the order parameter η on the film thickness d for annealed $Co_{50}Pt_{50}$/MgO films.

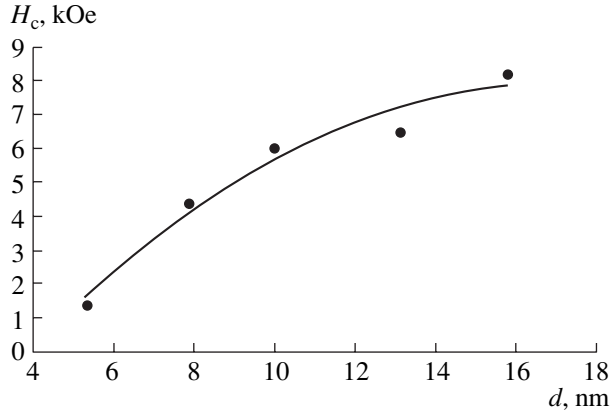

Fig. 5. Thickness dependence $H_c(d)$ measured in the easy-axis direction for annealed $Co_{50}Pt_{50}$/MgO films.

The PMA in annealed $Co_{50}Pt_{50}$/MgO(100) thin films with $d \le 16$ nm can be explained if we take into account the existence of epitaxial bonding between the substrate and the ferromagnetic alloy. The formation of the structure with a tetragonal axis along ⟨100⟩ and ⟨010⟩ crystallographic directions is difficult, because it increases the elastic extension energy. Growth of only one type of ⟨001⟩ nuclei of the ordered $L1_0$ phase is a self-organizing process which makes the elastic extension energy minimum. With increasing film thickness, a relaxation process takes place and the influence of the MgO substrate becomes negligible; for large film thicknesses, the possibility of the formation of all types of ordered C_i domains arises (see Fig. 3c). The last fact is the origin of an in-plane easy axis and magnetic isotropy in the film plane.

A rise of H_c with increasing thickness of the film of the $Co_{50}Pt_{50}$ ferromagnetic alloy results from increasing magnetocrystalline anisotropy constant $K = H_aM/2$. For films with $S = 1$, the magnitude of H_c is due to differences between the magnetocrystalline anisotropy field H_a and demagnetizing field connected with the sample shape: $H_c = H_a - 4\pi M$ [6]. An increase in K is a consequence of changing order parameter η of the $L1_0$ superstructure. Indeed, the experimental dependences $H_c(d)$ (Fig. 5) and $\eta(d)$ (Fig. 4) correlate quite well in the thickness range of $2 < d \le 16$ nm: with increasing η of the CoPt alloy, the magnitudes of H_c and K also increase. The dependence of the order parameter η of a partially ordered $L1_0$ superstructure on the film thickness also is a consequence of the strong epitaxial bonding between the single-crystal MgO(100) substrate and the $Co_{50}Pt_{50}$ ferromagnetic alloy. To understood this, one should note that during the fcc $\longrightarrow$ $L1_0$ ordering process the alloy volume remains constant: $V_{fcc} \approx V_{L1_0}$ or $a^3 = a'^2c$, where a' and c are the parameters of the tetragonal crystal lattice of the $L1_0$ phase; in this process, c decreases. For the totally ordered $L1_0$ superstructure ($\eta = 1$), the c/a ratio is equal to 0.972 [2]. Therefore, the a' value for these films should grow, but the strong film–substrate bonding prevents this. As the film thickness increases, the influence of the single-crystal MgO(100) substrate becomes weaker, and the order parameter η rises.

3. CONCLUSION

Thus, in this work we illustrated that the existence and magnitude of PMA in ordered $Co_{50}Pt_{50}$/MgO(100) films with an $L1_0$ structure are determined by the single-crystal MgO substrate in the thickness range of $2 < d \le 16$ nm. The substrate affects the formation of the crystal lattice of an ordered ferromagnetic alloy in two ways: first, it forces the tetragonal axis of the CoPt alloy to lie along the film normal and, second, it prevents the ordering process in this alloy.

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