Controlling the magnetic properties of CoCrPt thin films by means of thin hexagonal-close-packed intermediate layers

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CoCrPt films for longitudinal recording media were investigated as a function of substrate bias applied during the deposition. CoCrPt films were deposited on an underlayer stack consisting of glass/NiAl/CrMn with bias applied only during deposition of the CoCrPt layer. A strong dependence of the CoCrPt coercivity on the substrate bias was observed when a thin hexagonal-close-packed CoCrTa template was added as an intermediate layer between the CoCrPt and NiAl/CrMn underlayers. This effect was not observed in the absence of the CoCrTa layer. Microstructural investigation of CoCrPt thin films using grazing incidence and conventional x-ray diffraction indicated that the lattice of the CoCrPt increased in both the in-plane and normal directions as the bias was increased. A compositional analysis from both inductively coupled plasma and energy dispersive x-ray fluorescence measurements revealed that negative substrate bias applied during CoCrPt deposition changed the Pt content from 12 to 37 at. % in the CoCrPt films. The compositional change greatly improved the coercivity of the cobalt films up to 4300 Oe. At these large Pt concentrations, the CoCrTa intermediate layer was needed to reduce the lattice mismatch between the CoCrPt magnetic layer and NiAl/CrMn underlayers. This resulted in suppression of the Co (00.2) out-of-plane texture, and allowed high coercivity to be achieved. [DOI: 10.1063/1.1452255]

I. INTRODUCTION

Pt is commonly introduced into Co–Cr alloys to achieve high coercivity and good thermal stability since its addition enhances the magnetocrystalline anisotropy of the alloy. However, as the Pt content is increased, the hexagonal-close-packed (hcp) structure becomes enlarged and the lattice mismatch between CoCrPt and typical underlayers like Cr increases. Above 12 at. % Pt, the mismatch becomes too large to permit good epitaxial growth, causing an out-of-plane *c*-axis texture and poor magnetic properties.[1] Frequently lattice matching is enhanced by increasing the body-centered-cubic (bcc) lattice constant of Cr underlayers by adding V or Mn.[2,3] Introduction of a lattice matched hcp template to the underlayers to maintain better in-plane texture is also possible.[4] In this work we use such a hcp template to accommodate the compositional change of sputtered CoCrPt alloys induced by bias sputtering. The role of this thin hcp CoCrTa template in obtaing high coercivity and in-plane texture is investigated.

II. EXPERIMENT

CoCrPt magnetic thin films with a $Co_{86}Cr_{12}Ta_2$ ferromagnetic intermediate layer and glass/NiAl/$Cr_{92}Mn_8$ underlayers were rf sputter deposited onto a 1 in. glass substrate without intentional substrate heating. Glass/NiAl/CrMn/CoCrPt films were also prepared for comparison. The CoCrPt layer was prepared under various substrate bias conditions. However, the CoCrTa, CrMn, and NiAl films were deposited without substrate bias. A CoCr alloy target with bonded Pt chips was used for magnetic film preparation. The base pressure was about 5×10^{-7} Torr and the Ar sputtering pressure was fixed at 10 mTorr. Deposition was performed at about a 2.3 W/cm^2 sputtering power density. All CoCrPt films were 20 nm thick unless stated otherwise. The thicknesses of the CoCrTa intermediate layer and NiAl/CrMn underlayers were fixed at 4–5 nm and 100 nm/30 nm, respectively. The film compositions were determined by energy dispersive x-ray fluorescence (EDXRF) and inductively

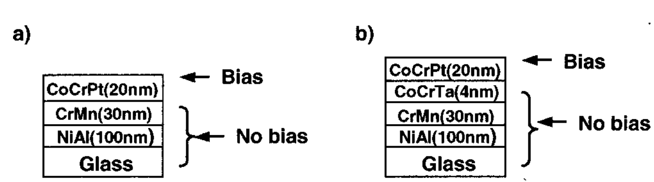

FIG. 1. Structure of the two stacks studied in this work. The CoCrTa intermediate layer was inserted in stack (b).

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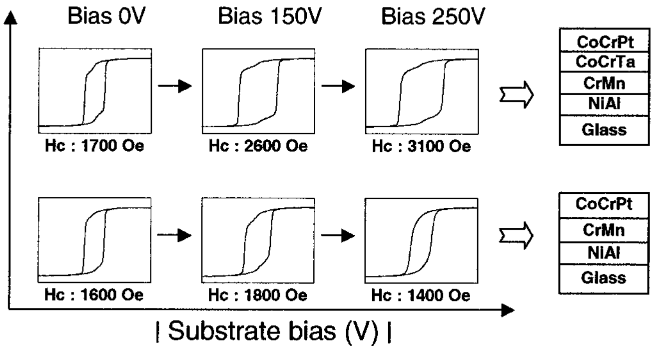

FIG. 2. Coercivity dependence of NiAl/CrMn/CoCrTa/CoCrPt and NiAl/CrMn/CoCrPt structures on the substrate bias voltage.

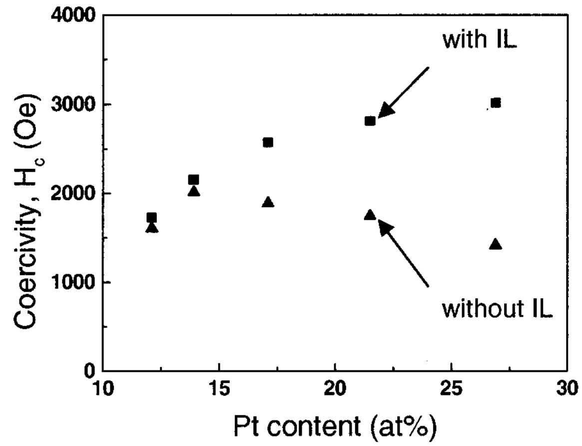

FIG. 4. In-plane coercivity (H_c) as a function of the Pt content (at. %) with a CoCrTa intermediate layer (IL) and without a CoCrTa intermediate layer.

coupled plasma (ICP) analysis. CoCrPt films approximately 300 nm thick were prepared on Si substrates by varying the substrate bias voltage from 0 to −300 V without the other layers in order to measure the composition of CoCrPt film layer. The magnetic properties of the samples were measured by an alternating gradient magnetometer (AGM) and a vibrating sample magnetometer (VSM). Structural characteristics were studied by an x-ray diffractometer (Philips X'pert Pro with a x-ray lens) using Cu $K\alpha$ radiation.

III. RESULTS AND DISCUSSIONS

The two sample structures shown in Fig. 1 were each deposited in a single pumpdown without breaking vacuum. NiAl/CrMn underlayers were used in order to induce a smaller grain size and to promote better epitaxial growth of the hcp structure without substrate heating.[3] Figure 2 shows the effect of substrate bias applied during CoCrPt deposition. The film coercivity is enhanced by bias only when the CoCrTa intermediate layer was present. The coercivity increased from 1500 to more than 3000 Oe as bias was applied. In contrast, lower coercivity was maintained in the films deposited without the CoCrTa intermediate layer. The results in Fig. 2 are for a CoCrTa thickness of approximately 4 nm. CoCrTa films with thickness greater than 4 nm resulted in a decrease in H_c, probably due to the magnetic contribution from CoCrTa, which has a lower magnetic anisotropy constant. Compositional analysis using both ICP and EDXRF techniques revealed that substrate bias applied during CoCrPt deposition led to change in the CoCrPt film's composition. The two methods agree within about 3%. Figure 3 shows the effect of bias sputtering on the film composition. With an increase in bias, the Co content decreases while the Cr and the Pt contents increase. The Pt content increased dramatically from 12 to 37 at. % when the substrate bias was changed from 0 to −300 V. The change in film composition with substrate bias can be explained by the resputtering process as Deng *et al.* illustrated in CoCrTa thin films.[5] Consistent with this, it was observed that the CoCrPt film deposition rate changed according to the substrate bias. The CoCrPt deposition rate decreased from 11 to 4 nm/min as the substrate bias was changed from 0 to −300 V.

Figure 4 shows a plot of the coercivity, H_c, vs Pt content of the CoCrPt alloy caused by bias sputtering. We observed the maximum coercivity was achieved at 26 at. % Pt in the CoCrPt layer when the thin CoCrTa intermediate layer was added between NiAl/CrMn underlayers and the CoCrPt magnetic layer. In contrast, we note that in related work the maximum coercivity was obtained at 14 at. % without the CoCrTa intermediate layer. Glijer *et al.*[1] and Ishikawa and Sinclair[6] found that the Pt contents giving the maximum in-plane coercivity in CoCrPt thin films were 13 and 12 at. %, respectively. The significant differences in the optimum Pt

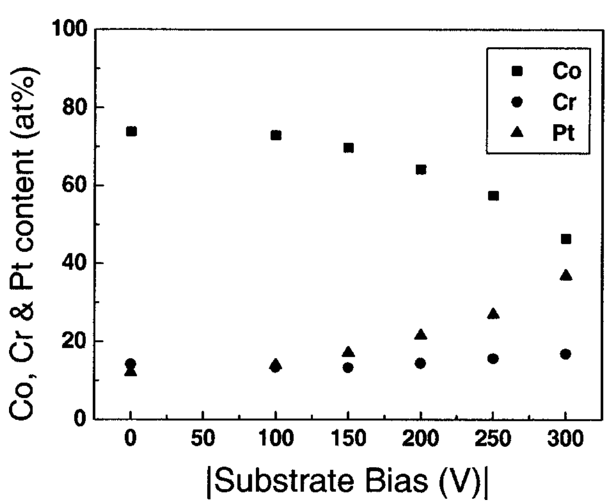

FIG. 3. Variations in Co, Cr, and Pt content (at. %) with rf substrate bias voltages for the CoCrPt films (∼300 nm thick) sputtered on Si.

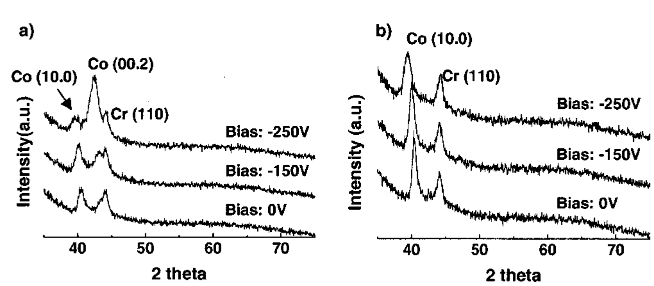

FIG. 5. XRD spectra of the two stacks: (a) NiAl/CrMn/CoCrPt and (b) NiAl/CRMn/CoCrTa/CoCrPt. The textures are strongly dependent on the CoCrTa intermediate layer.

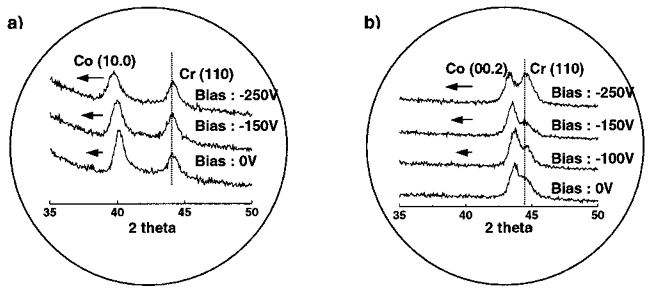

FIG. 6. XRD spectra of the CoCrPt/CoCrTa/CrMn/NiAl stack with (a) conventional x-ray diffraction θ–2θ scanning and (b) grazing-incidence x-ray diffraction θ–2θ scanning.

content of CoCrPt films with and without a CoCrTa underlayer can be explained in terms of microstructural differences in the two films. As shown in Fig. 5, the x-ray diffraction spectra for samples without the CoCrTa intermediate layer, which have lower coercivity, have a greater amount of (00.2) growth texture normal to the film's plane with an increase in substrate bias. This indicates that the *c* axis in the sample no longer lies in the plane. The diffraction intensity of the 4 nm thick CoCrTa layer was not detectable (see Fig. 5). The (10.0) reflection from a separate 30 nm CoCrTa layer was observed at a diffraction angle of $2\theta = 41.125°$ when the CoCrTa layer was deposited with glass/NiAl/CrMn underlayers. No other peaks were found at $2\theta = 35° - 90°$, indicating that this thicker CoCrTa layer was primarily of (10.0) texture, and was likely to be so-textured as an interlayer. The x-ray diffraction data indicated that the (00.2)/(10.0) diffraction peak intensity ratio increases as the substrate bias increases. In contrast, the growth (10.0) in-plane *c*-axis texture was maintained in the CoCrPt samples with the thin hcp CoCrTa intermediate layer as the substrate bias was increased. This strongly suggests that the CoCrTa intermediate layer suppressed the CoCrPt (00.2) out-of-plane texture by reducing the effect of lattice mismatch between the NiAl/CrMn underlayers and the CoCrPt magnetic layer as the Pt content was increased due to substrate bias. The Pt rich films, it appears, will only develop *c*-axis in-plane orientation when deposited on a CoCrTa intermediate layer. Upon further adjustment in deposition parameters, it was observed that coercivity values up to 4300 Oe were possible when the CoCrPt thickness was increased to 30 nm and deposited with a substrate bias of -250 V (which corresponds to 26 at. % Pt). This suggests that a strong *c*-axis in-plane texture can be sustained for a large Pt content if the lattice mismatch is reduced by introducing a hcp intermediate layer. Finally, the lower coercivity of the stack in Fig. 1(a) at high Pt content is attributed to increase of the (00.2)/(10.0) fraction in the CoCrPt with higher bias.

Confirmation of the increase in the CoCrPt lattice constant with an increase in the Pt content is shown in Fig. 6. Figure 6(a) indicates that the interplanar spacing of (10.0) in the hcp CoCrPt becomes larger with an increase in substrate bias. Moreover, grazing-incidence x-ray diffraction (XRD), shown in Fig. 6(b), indicates in-plane lattice expansion of the CoCrPt films by examination of the (00.2) reflection. This behavior arises because the lattice of normal sputtered CoCrPt films stretches as large Pt atoms become richer in the films. The measurements of *d* spacings from conventional and grazing-incidence x-ray diffraction indicated that the lattice of the CoCrPt expanded in both the in-plane and normal directions as the bias was increased. Direct measurement of the interplanar *d* spacings indicated that the hcp lattice is expanded more in the (10.0) direction than along the (11.0) in-plane direction. This is likely due to increasingly compressive stress in the films with an increase in bias. This lattice distortion may cause some of the change in coercivity associated with addition of Pt as was suggested by Glijer *et al.*[1] The improved texture of CoCrPt on CoCrTa versus that on CrMn is most likely due to the match in symmetry between hcp phases. At these compositions, the in-plane lattice parameter of the dimensions of the two interlayers is very similar. The CrMn cell on the (112) plane is 0.250 nm $\times$0.408 nm while the CoCrTa cell on the (10.0) plane is 0.253 nm$\times$0.409 nm.

IV. CONCLUSIONS

A maximum coercivity of 4300 Oe was obtained in CoCrPt films having high Pt contents caused by substrate bias. In-plane *c*-axis orientation is preserved on NiAl/CrMn underlayers by introducing a thin CoCrTa intermediate layer. Bias sputtering changed the Pt content significantly in the CoCrPt films, which, in the absence of the CoCrTa intermediate layer, induces a large mismatch and results in a Co (00.2) out-of-plane texture. However, even with Pt content up to 26 at. % in the CoCrPt, the CoCrTa intermediate layer helped the CoCrPt layer retain (10.0) growth texture by reducing the lattice mismatch between the CoCrPt magnetic layer and the CrMn/NiAl underlayers.

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