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Effect of Nb content on the microstructure and magnetic properties of CoCrPtNb/CrTi/C thin films

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Abstract

In this study, CrTi, $(Co_{68}Cr_{15}Pt_{17})_{100-x}Nb_x$ (x = 0–3.6) multilayers and carbon overcoat were sequentially deposited on glass substrate as underlayer, granular media layer and protective layer, respectively, by rf magnetron sputtering. The effects of Nb added to CoCrPt magnetic layer on the magnetic properties and microstructure of CoCrPtNb thin film media have been examined. As a result, we found that the change in c-axis orientation of CoCrPtNb from out-of-plane to in-plane enhanced H_c, S and S* as the Nb content increases up to 1.5 at.%. Further increase of Nb content decreases the coercivity. This phenomenon may be interpreted as being due to an increase in granular exchange coupling, which is due to a degraded grain-boundary structure. AFM revealed that the width of this boundary phase tended to become thinner with Nb content when Nb content was above 1.5 at.%. At the same time, it is suggested that high-performance CoCr-based recording media can be fabricated at room temperature even when using an isotropic glass substrate by adding moderate amounts of Nb and using a multilayer thin film structure.

Keywords: CoCrPtNb media; Glass substrate; Exchange coupling

1. Introduction

Although facing a challenge from the perpendicular recording [1,2] and the pattern recording [3] in achieving ultrahigh density, the Co-Cr alloy-based longitudinal recording medium is still of much interest and dominates the magnetic storage market. To achieve high-density recording, the space between magnetic heads and hard disks (flying height) must be minimized, which requires the use of ultraflat disk substrates. Glass substrates are considered to be superior to aluminum ones on this point [4]. However, glass media typically have isotropic in-plane magnetic anisotropy since circumferential texturing on glass substrates is not easily achieved [5]. Nevertheless, to meet high-density recording requirements, more specifically preferred orientation, high coercivity H_c, high coercive and remanent squareness (S* and S), low remanence-thickness product $M_r t$ and low intergranular coupling need to be attained. It has been reported that addition of Pt into sputtered CoCr-based alloy thin-film media is effective to increase coercivity and to decrease intergranular interaction through the increase of magnetocrystalline anisotropy field H_k^{grain} [6]. However, previous studies indicate that excessive Pt addition increases the stacking fault density and degrades the grain-boundary structure [7], which result in an increase of intergranular exchange interaction. Therefore, substitution of Pt by other elements is required. The objective of this article is to examine the possibility of Nb addition to increase the coercive force and squareness, and to decrease the intergranular exchange interaction. This paper reports that the effect of Nb additions to ternary CoCrPt systems with a view to varying grain size, grain morphology, crystallographic texture and magnetic properties of CoCrPtNb/CrTi/C thin films deposited on glass substrate without substrate heating and thus to improve the magnetic properties of CoCrPtNb.

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2. Experimental

The thin film media were prepared on water-cooled glass substrates without preheating by rf magnetron sputtering in a three-target sputtering system. A C seedlayer, $CrTi_{10}$ underlayer, $(Co_{68}Cr_{15}Pt_{17})_{100-x}Nb_x$ (x = 0–3.6) magnetic layer and C protective layer were deposited successively. The target-to-substrate distance was 95 mm. The CoCrPtNb and CrTi layer compositions were controlled by adjusting the number of Nb pellets on a CoCrPt target and the number of Ti chips on a Cr target, respectively. The chamber was pumped down to less than 1.0×10^{-7} Torr and the substrates were rf sputtered for 15 min prior to deposition. High-purity Ar (99.9999%) was used for deposition at a pressure of 5 m Torr. All the CoCrPtNb films reported were maintained at a constant thickness of 15 nm by controlling the precalibrated deposition time. The films' thicknesses were determined by a surface profiler. Film compositions were analyzed by electron probe micro-analysis (EPMA). The magnetic properties were evaluated from M-H loops measured by a vibrating sample magnetometer (VSM). The torque was measured by high-sensitivity automatic torque apparatus, and the magnetic anisotropy constant was obtained by a suitable mathematics method [6]. The microstructures of the films were examined by atomic force microscope (AFM). The crystallography was investigated using X-ray diffraction (XRD) with Cu Kα radiation.

3. Results and discussions

Fig. 1 shows the crystallographic texture of (CoCrPt)Nb/CrTi/C thin film media that were deposited at room temperature. XRD patterns of the CoCrPtNb films show some orientation changes depending on the Nb content in magnetic layer. This shows that better in-plane orientation,

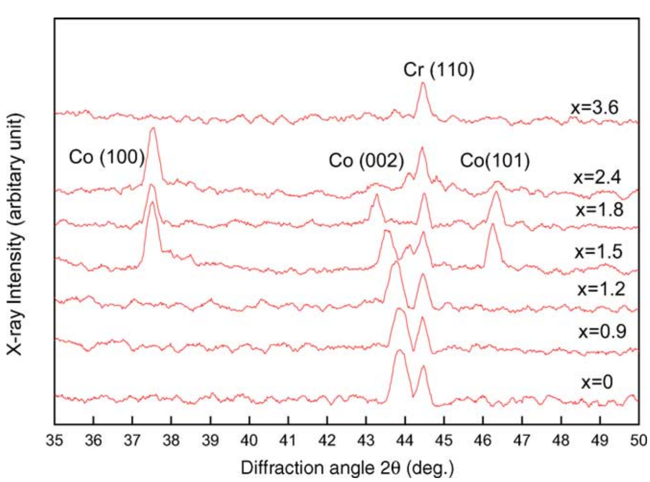

Fig. 1. X-ray diffraction patterns from the $(CoCrPt)_{100-x}Nb_x$/CrTi/C films as a function of Nb content.

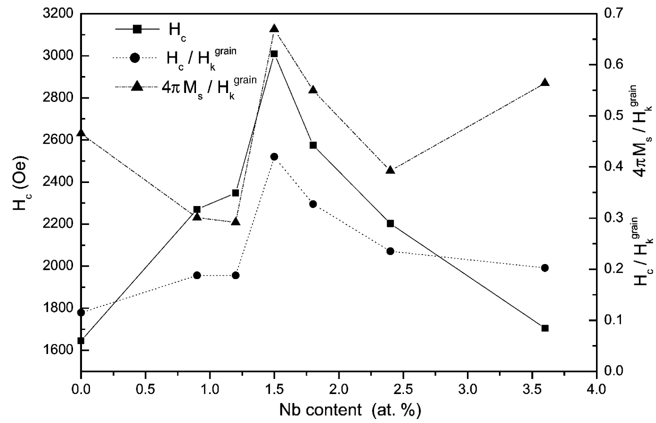

Fig. 2. Dependence of H_c, H_c/H_k^{grain} and $4\pi M_s/H_k^{\mathrm{grain}}$ on Nb content for $(CoCrPt)_{100-x}Nb_x$ thin film.

as indicated by the existence of Co(1 0 0), Co(1 0 1) peak and the reduction of Co(0 0 2) peak, was achieved as the Nb content increased from 0 to 1.5 at.%. No obvious change of crystallographic texture between 1.5 and 1.8 at.% Nb addition. Further increase of Nb content decreases the relative number of strongly diffracting grains, only (1 0 0) Co peak and (1 1 0) Cr peak were detected for the 2.4 at.% Nb sample. However, when the Nb content reached 3.6 at.%, no Co-alloy diffraction peak was presented. This implies that the films are amorphous. As the Nb content increased from 0 to 2.4 at.%, it is also clearly observed that the Co(0 0 2) peak shifted to lower 2θ angles. This indicates the expansion of Co hcp lattice is due to the Nb substitutes in the unit cell of the alloy.

Fig. 2 shows the dependence of coercivity H_c, H_c/H_k^{grain} and $4\pi M_s/H_k^{\mathrm{grain}}$ on the Nb contentration in CoCrPtNb/CrTi/C media sputtered at room temperature. Here, H_k^{grain} ($=2K_u/M_s$) is the magnetocrystalline anisotropy field of grains, K_u is magnetocrystalline anisotropy constant, M_s is the saturation magnetization, H_c/H_k^{grain} is the normal-

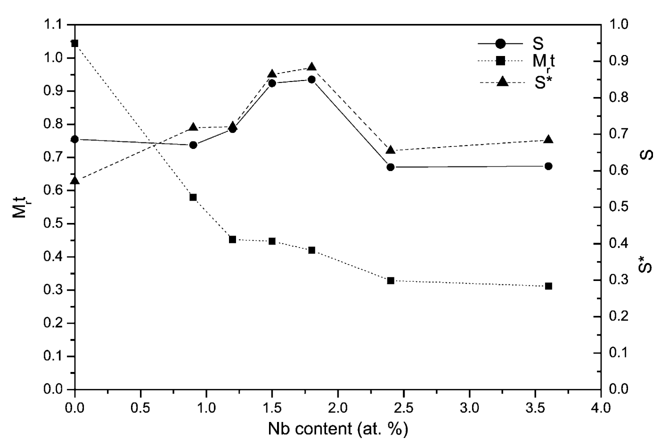

Fig. 3. Variation of S, S^* and $M_r t$ with Nb content in the $(CoCrPt)_{100-x}Nb_x$ thin film.

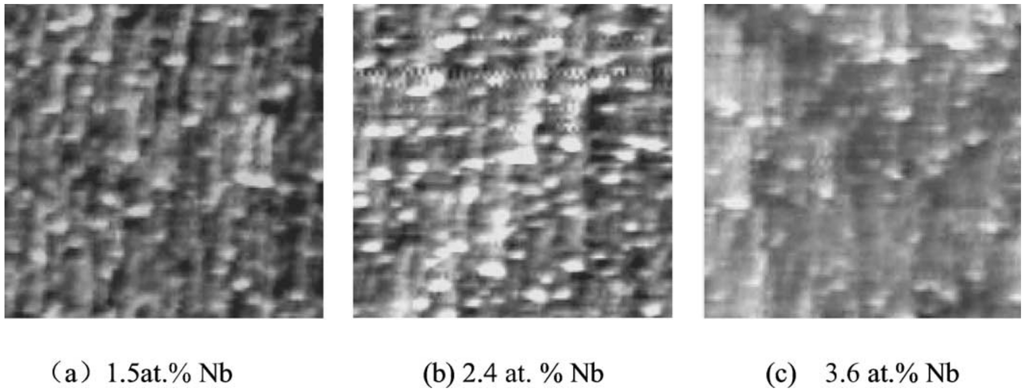

Fig. 4. Plane-view AFM images of $(CoCrPt)_{100-x}Nb_x$/CrTi/C films. The presented images show areas of 250 nm × 250 nm.

ized coercivity and $4\pi M_s/H_k^{grain}$ is the magnetostatic index, as defined as saturation flux density $4\pi M_s$ divided by H_k^{grain}. It is believed that H_c/H_k^{grain} increases with reduction in the degree of intergranular exchange coupling and $4\pi M_s/H_k^{grain}$ increases with increase in intergranular magnetostatic interaction [7]. Coercivity H_c increased linearly from 1650 to 3010 Oe with 1.5 at.% Nb addition. H_c then decreased quickly to 1700 Oe with further increase in Nb content. The increase of the coercivity is mainly caused by the change in c-axis orientation of CoCrPtNb from out-of-plane to an in-plane one. This better in-plane orientation reflects the monotonous increase of S and S^* from 0.69 to 0.84 and from 0.57 to 0.86, respectively, when Nb addition is increased up to 1.5 at.%, as depicted in Fig. 3. However, the change in H_c at comparatively high Nb content (from 1.5 to 3.6 at.%) cannot be explained by the effect of change in crystal orientation, since a strong c-axis in-plane texture can be substained for the nanocrystalline thin film with a large Nb content. The effect of Nb content on normalized coercivity was similar to that of coercivity. With increasing Nb content, H_c/H_k^{grain} initially increased to a maximum value of 0.42 at 1.5 at.% Nb, but slightly decreased to 0.20 at 3.6 at.% Nb. Compared to the change in H_c/H_k^{grain}, the change in $4\pi M_s/H_k^{grain}$ is complicated, it first decreases with increasing Nb content to minimum value (0.30), then increases abruptly to a maximum value of 0.67 at 1.5 at.% Nb, and then decreases abruptly, at last increases abruptly again. Since the X-ray diffraction results are similar, and the degree of intergranular magnetostatic interaction $4\pi M_s/H_k^{grain}$ begins to increase and then to decrease, the decrease of H_c/H_k^{grain} indicates that the decrease of H_c may be due to the increase of the intergranular exchange coupling as the Nb content increased from 1.5 to 3.6 at.%. However, S and S^*, which generally show an increase with increasing intergranular exchange coupling, show little change with Nb content increase when the Nb content is above 1.5 at.%. As the Nb content increased from 1.8 to 2.4 at.%, S and S^* decreased from maximum values of 0.85 and 0.88 to minimum values of 0.61 and 0.65, respectively. This different change might be associated with the decrease of the intergranular magnetostatic interaction [8]. As expected, the M_rt of the films decreases monotonously as Nb content increases (shown in Fig. 3). When Nb content is above 0.9 at.%, the M_rt values are in the range of 0.3–0.5 memu/cm^2 which are nearly ideal for high-density recording using GMR heads.

AFM images having been observed in the films with C seedlayer for the $(CoCrPt)_{100-x}Nb_x$/CrTi (x = 1.5, 2.4 and 3.6) are shown in Fig. 4. The mean grain size in all media is 14–16 nm. The grain size or grain-size distribution does not appear to change much with increasing Nb content. Indeed, the microstructural clusters or ‘grain-like’ features in the amorphous 3.6 at.% Nb film are not significantly different in size to the grains in the crystalline films. However, the $(CoCrPt)_{97.6}Nb_{2.4}$/CrTi/C show indistinct and sharp edge grain boundaries, compared with the $(CoCrPt)_{98.5}Nb_{1.5}$/CrTi/C media. On the other hand, no boundary phase was observed in the $(CoCrPt)_{96.4}Nb_{3.6}$/CrTi/C media. This indistinctness or absence of grain boundaries indicates that the media with high Nb content have relatively degraded Cr segregation at the grain boundaries, resulting in a stronger intergranular exchange interaction.

4. Conclusions

The effect of Nb content on the texture, exchange interaction, grain morphology and magnetic properties of $(CoCrPt)_{100-x}Nb_x$ (x = 0–3.6) film sputtered on CrTi with C seedlayer using glass substrate was investigated. H_c, S and S^* initially increase when the Nb content increases from 0 to 1.5 at.%, which was mainly attributed to texture change. On further increase of Nb content, coercivity H_c begins to decrease. This was probably due to the exchange interaction increase caused by the degraded grain-boundary structure by adding a large amount of Nb. Also, it has been shown that high coercivity H_c, high S, S^* and low exchange interaction media using glass substrate can be achieved even at room temperature.

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