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Magnetic Properties and Microstructures of Co-Cr-(Pt)-Ta Magnetic Thin Films Sputtered on Self-textured Substrates

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Abstract

The effects of Al micro-bumps on the magnetic properties of CoCr(Pt)Ta/Cr films deposited on glass substrates were investigated. The coercivity increased and the coercivity squareness decreased by incorporating Cr/Al underlayers. The cause of the coercivity increase is attributed to the reduction of Co(0002) texture, the increase of magnetic isolation of CoCr(Pt)Ta grains, and the refinement of CoCr(Pt)Ta grains deposited on Cr/Al underlayers. The effects of an Al overlayer on the magnetic properties of CoCr(Pt)Ta/Cr films were also studied. The decrease of coercivity squareness is ascribed to the magnetic isolation of CoCr(Pt)Ta grains.

I. INTRODUCTION

The progress in magnetic recording technology, particularly that for rigid disk drives has been dramatic. One of the key developments that led to disk drive technology was continuous progress in film disks resulting in a path to higher linear densities. The development of high coercivity and low-noise thin-films and the improvement on texturing techniques for low flying height are essential to a rigid disk for high density recording. A new method called 'sputter texturing' has been devised to satisfy these requirements simultaneously[1-2]. In this paper, we extended the study of Al micro-bumps effects on magnetic properties and microstructures of thin films. In particular, the origin of coercivity increase due to the existence of Al micro-bumps was explored.

II. EXPERIMENTAL PROCEDURES

Samples were prepared by using dc magnetron sputtering on non-textured glasses without applying substrate bias. An Al micro-bumps layer and a Cr underlayer was deposited using highly pure metal targets. A Co-13at.%Cr-2at.%Ta alloy target and Pt chips were used for depositing a magnetic layer. The chemical compositions of the magnetic films were analyzed by an Electron probe Microanalyzer (EPMA) and were $Co_{85}Cr_{13}Ta_2$ and $Co_{77}Cr_{11}Pt_{10}Ta_2$. The base pressure was 6×10^{-7}torr and the sputtering pressure of Ar gas was 10 mtorr. The magnetic properties of the films were measured by a vibrating sample magnetometer (VSM). The crystallographic textures of the films were determined by x-ray diffraction (XRD). The surface morphologies and microstructures were studied by atomic force microscopy (AFM). Auger electron spectroscopy (AES) was employed for investigating composition depth profiles of CoCr(Pt)Ta/Cr/Al films.

III. RESULTS AND DISCUSSIONS

Fig.1 shows the variation of the coercivities with substrate temperatures in CoCrTa/Cr and CoCrPtTa/Cr films with and without Al underlayer. The coercivity of CoCrTa/Cr films formed on Al bumps(700Å thick) showed a higher value than that of CoCrTa/Cr films without Al bumps when deposited at a higher temperature than 100℃ while the coercivities of both films were almost the same when deposited at a lower temperature than 100℃. The coercivity of CoCrPtTa/Cr films also increased when deposited on Al bumps at an elevated temperature. The increase was around 400 Oe in CoCrPtTa films and 300 Oe in CoCrTa films at 280℃.

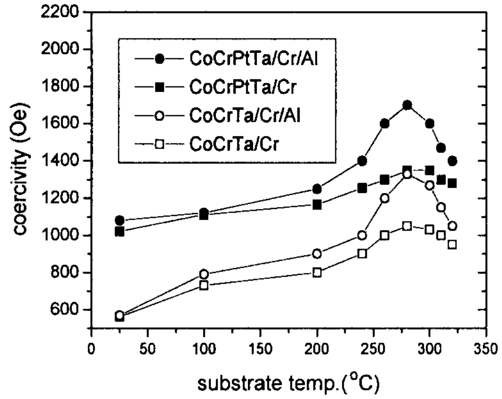

Fig. 1. Coercivity changes of CoCrPtTa/Cr and CoCrTa/Cr with and without an Al underlayer as a function of substrate temperatures.

Effects of Al micro-bumps on the preferred orientations

To examine the mechanism of the coercivity enhancement of the CoCr(Pt)Ta/Cr film with an Al layer at higher temperatures, the orientation changes of the CoCr(Pt)Ta layer was investigated by X-ray diffraction patterns (Figs. 2 and 3).

When a Cr layer was deposited on an Al layer, the peak height was reduced substantially accompanied by a line broadening and the peak position was shifted by 0.2° in the Cr/Al film. The line broadening may be associated with high angular dispersion of Cr(110) grains in the

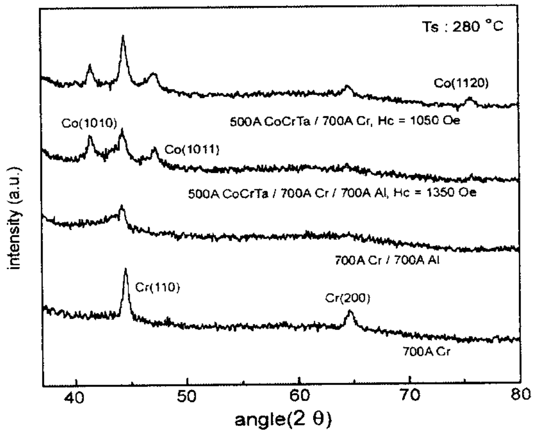

Fig. 2. XRD patterns of CoCrTa/Cr, CoCrTa/Cr/Al, Cr/Al and Cr films.

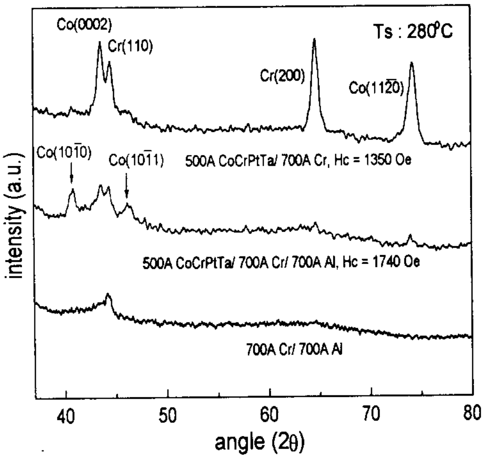

Fig. 3. XRD patterns of CoCrPtTa/Cr, CoCrPtTa/Cr/Al and Cr/Al films.

specimens with Al bumps. The peak shift to the lower values of 2θ implies an increase in the lattice spacing. AES analysis was done to clarify this. Cr/Al films sputtered at room temperature had relatively sharp transition in chemical composition. In the films sputtered at 280℃, however, Al atoms and Cr atoms were interdiffused severely resulting in observing 10at.% Al at the surface of Cr/Al films. We concluded that Cr(110) peak shift must be related to the Cr lattice expansion caused by larger Al atom diffusion.

XRD patterns of Co magnetic layers showed the variation of preferred orientation with underlayer condition. In CoCrTa/Cr films, all peaks including Cr(110), (200) and CoCrTa (1010), (1011), (1120) were appeared. To examine the effect of Cr lattice expansion, CoCrTa was deposited on Cr-10at.%Al alloy underlayer. Peak intensity of CoCrTa(1011) increased but CoCrTa (1010) decreased comparing with CoCrTa/Cr films. In our calculation from XRD peak position, the magnitude of lattice misfit reduced at the interface of Co(1011) ॥ Cr(110) while increased at Co(1010) ॥ Cr(110). This reduction in the magnitude of lattice misfit would enhance the development of Co(1011) orientation. In CoCrTa/Cr/Al films, strong (1010) in plane orientation which is believed as one of the origins of the coercivity increase of the CoCrTa/Cr/Al film is observed by replacing Co(1120).

In CoCrPtTa/Cr films, strong Co(0002) and Co(1120) peaks were observed (Fig. 3). In CoCrPtTa/Cr/Al films, strong Co(1010) and Co(1011) peaks were observed along with a reduction of Co(0002) and Co(1120) peaks. We attempted to deconvolve Co(1010), (0002), (1011) peaks and Cr(110) peak by Lorentzian curve fitting. Relative intensities of Co peaks were represented by "orientation coefficient" in table I [3]. To calculate Co peak intensities in CoCrPtTa/Cr/Al films, we subtracted the broad peak (2θ; 40° ~45°) in Cr/Al films from the XRD patterns of CoCrPtTa/Cr/Al films. The broad peak in Cr/Al films seems to be due to the amorphization or nano-scale intermetallic compounds resulting from the interdiffusion of Cr and Al at the interface of Cr/Al when Cr and Al layers deposited at an elevated temperature of 280℃.

The variations of orientation coefficients in table I clearly indicate that the introduction of Cr/Al underlayers increases Co(1010) and Co(1011) textures and decreases Co(0002) and Co(1120) textures.

Table I. Orientation coefficient of Co preferred orientations on different substrate conditions. ((A)-before subtracting broad peak in Cr/Al, (B)-after subtracting broad peak in Cr/Al)

underlayer	orientation coefficient			
	Co(1010)	Co(0002)	Co(1011)	Co(1120)
random orientation	1	1	1	1
Cr	0.30	1.67	0.12	1.91
Cr/Al (A)	2.31	0.97	0.53	0.19
Cr/Al (B)	2.79	0.52	0.48	0.21

To clarify the intensity changes in Co peaks due to an Al layer, we calculated the lattice parameters of Cr on glass and Cr on Al/glass by using XRD data. The lattice parameter of Cr (2.8951Å) in Cr/Al/glass was larger than that of Cr (2.8765Å) in Cr/glass deposited at 280℃. Cr lattice expansion in Cr/Al layers was caused by diffusion of large Al atoms[4]. The changes in the calculated lattice misfit between Co and Cr planes due to Cr lattice expansion are shown in table II. The decrease of Co(0002) textures and the increase of Co(1010), Co(1011) textures seems to be attributed to the lattice expansion of a Cr layer deposited on an Al layer. The reduction of Co(1120) was due to the reduction of Cr(200) deposited on an Al underlayer[4].

Table II. Areal misfit changes(%) between Co planes and Cr(110) planes with increasing Cr lattice parameter. (↓;decrease, ↑; increase)

Co planes	crystallographic direction	CoCrPtTa
Co(1010)	Co<0001> // Cr<110> Co<1210> // Cr<100>	1.21 ↓
Co(0002)	Co<1100> // Cr<110> Co<1120> // Cr<100>	1.13 ↑
Co(1011)	Co<1213> // Cr<111> Co<1210> // Cr<111>	1.30 ↓

The increase of the in-plane orientation of the magnetically easy axis due to the reduction of

Co(0002) could be one of the reasons for the higher in-plane coercivities of CoCrPtTa/Cr/Al films than those of CoCrPtTa/Cr films.

Effects of Al micro-bumps on the magnetic isolation

The incorporation of an Al layer increased coercivities and decreased coercivity squarenesses(table Ⅲ). To understand the effect of the addition of an Al layer on the magnetic isolation of CoCrTa(Pt) films, the coercivity angular variations of CoCrPtTa were measured as shown in Fig.4.

Table Ⅲ. Magnetic properties of thin films.

thin films	Hc (Oe)	S*	Ms · t (memu/㎠)
CoCrTa / Cr	1050	0.84	
CoCrTa / Cr/Al	1350	0.77	
CoCrPtTa / Cr	1350	0.89	2.38
CoCrPtTa / Cr•/ Al	1740	0.87	2.35
Al / CoCrPtTa / Cr	1475	0.84	2.33

In CoCrPtTa/Cr films, the magnetization reverses dominantly by domain wall motion mode. On the other hand, in Al over-coated and Al under-coated films, magnetization-reversal mechanism deviated from domain wall motion mode, which suggests the enhancement of magnetic isolation of grains[5]. The results of the angular variations of the coercivity also coincide with the decrease of coercivity squarenesses with the introduction of an Al layer.

To investigate the effect of Al atoms on the magnetic isolation of CoCrPtTa films, we examined composition depth profiles of CoCrPtTa/Cr/Al and Al/CoCrPtTa/Cr films(Fig.5). In both cases, Al compositions are almost constant through the CoCrPtTa film thickness with little reduction of Ms · t($<\sim 2\%$), which strongly implies that Al atoms diffuse into the grain boundaries of CoCrPtTa rather than inside Co grains.

The coercivities of Al/CoCrPtTa/Cr films were larger than those of CoCrPtTa/Cr films without changing preferred orientations and micro-

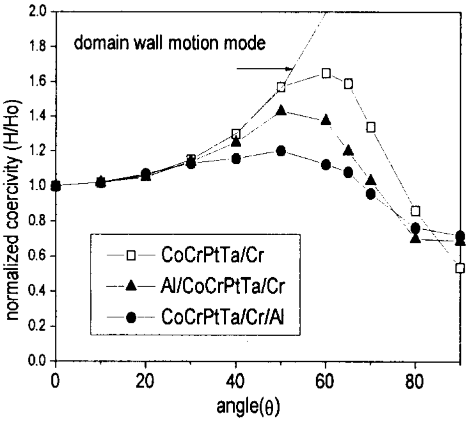

Fig. 4. Angular variations of coercivity in magnetic thin films.

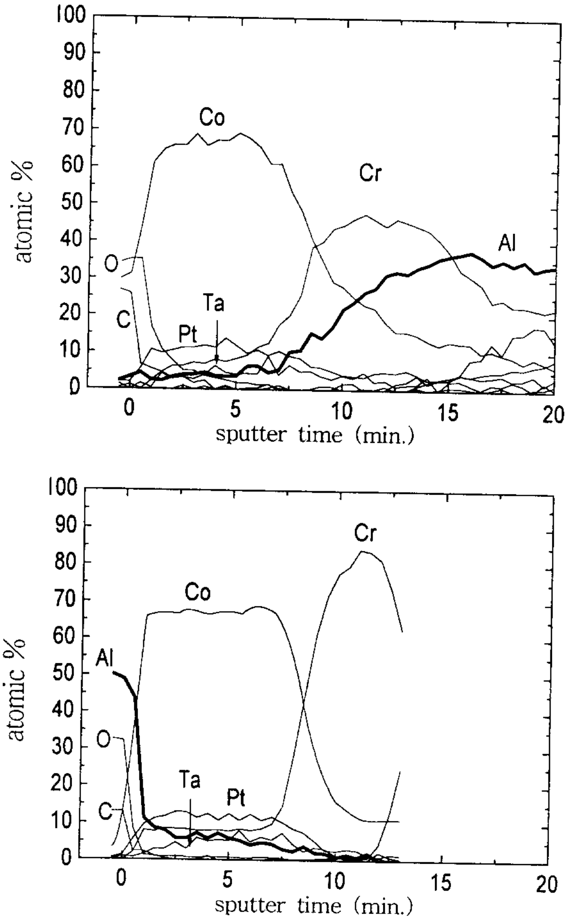

Fig. 5. AES composition depth profiles of a) CoCrPtTa/Cr/Al and b) Al/CoCrPtTa/Cr thin films.

structures. The increase was around 120 Oe. This result indicates that high coercivities of magnetic films can be achieved by magnetic decoupling of Co grains[6].

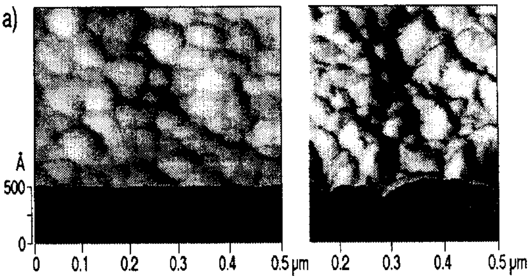

Fig. 6. AFM images of CoCrPtTa films deposited on a) Cr/glass and b) Cr/Al/glass.

Fig.6 shows surface morphologies of CoCrPtTa films deposited on Cr and Cr/Al layers. The grains of CoCrPtTa films on Cr/Al were more isolated than those of CoCrPtTa films on Cr. This morphological change shown in Fig.6 also seems to be closely related to the magnetic isolation of magnetic films[5]. From these results, magnetic decoupling induced by an Al layer is believed as one of the origins of the coercivity increase.

Effects of Al micro-bumps on grain size

The grain sizes of CoCr(Pt)Ta and Cr films were observed by AFM. The average sizes of CoCr(Pt)Ta grains and Cr grains on two different substrates were summarized in table Ⅳ. Both CoCr(Pt)Ta and Cr films deposited on Al underlayers have smaller grains than the same films deposited on bare glasses.

Table Ⅳ. Average grain sizes(Å) of CoCr(Pt)Ta and Cr films.

substrates	Cr	CoCrTa(/Cr)	CoCrPtTa(/Cr)
glass	520	560	560
Al/glass	410	430	490

Fig.7 shows grain size distributions of CoCr(Pt)Ta films deposited on Cr/Al and Cr underlayers. The grains of CoCr(Pt)Ta films deposited on Cr/Al were more uniform than those of films on Cr.

Fig.8 shows coercivity variations of CoCr(Pt)Ta/Cr and CoCr(Pt)Ta/Cr/Al films with CoCr(Pt)Ta film thickness. The coercivities of both CoCrTa and CoCrPtTa films showed their maximum values at thicknesses of about 400Å and 500Å respectively irrespective of the existence of the Al layer. In our measurements, the grain size of CoCr(Pt)Ta increased with increasing thickness of the CoCr(Pt)Ta film. The refinement of CoCr(Pt)Ta grains also seems to contribute the increase of the coercivity in CoCrPtTa/Cr/Al films.

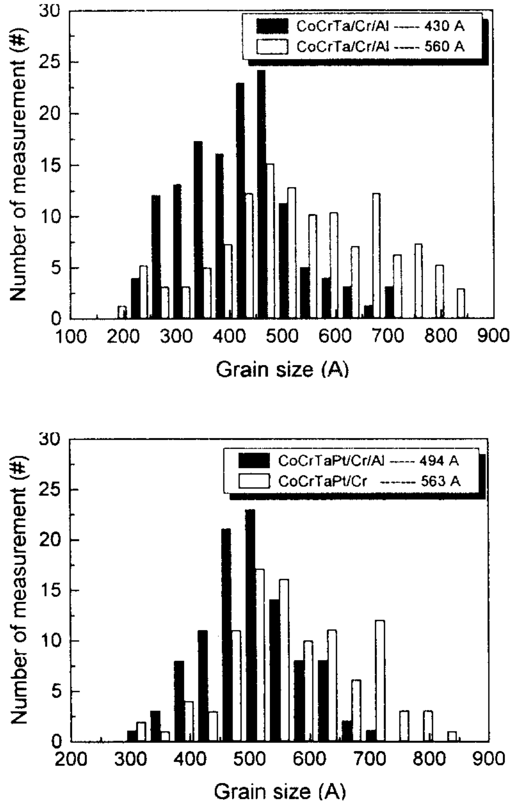

Fig. 7. Grain size distributions of CoCr(Pt)Ta films on different substrate conditions..

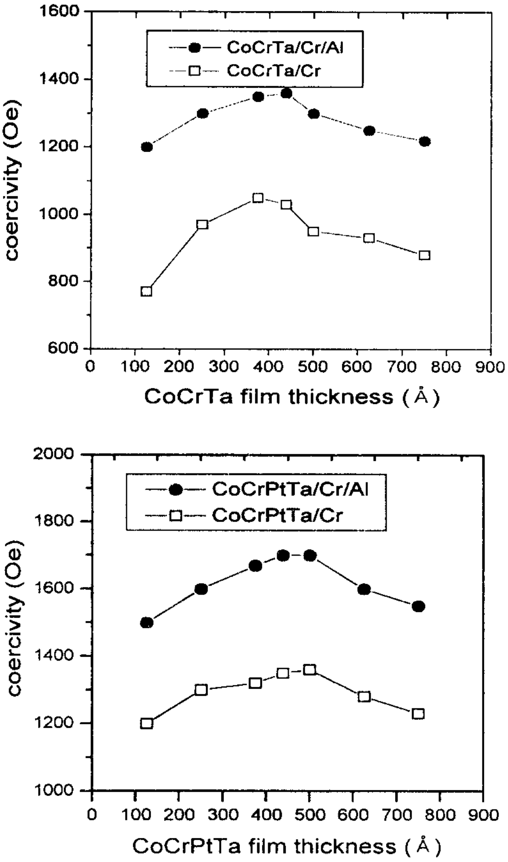

Fig. 8. Coercivity changes of CoCr(Pt)Ta/Cr and CoCr(Pt)Ta/Cr/Al films with CoCr(Pt)Ta film thickness.

IV. CONCLUSIONS

The magnetic properties of CoCr(Pt)Ta/Cr films are strongly affected by the incorporation of an Al layer either undercoated or overcoated. The increase of in-plane c-axis orientation and magnetic isolation of magnetic films with a small grain size led to the increase of coercivity. The magnetic isolation of CoCr(Pt)Ta grains due to an Al layer decreased the coercivity squareness of CoCr(Pt)Ta films.

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