Effects of Very Thin Carbon Seedlayer on Formation of hcp Phase for CoCrPtB/$Co_{60}Cr_{40}$ Perpendicular Magnetic Recording Media

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***Abstract*—This paper reports on significant improvement of magnetic properties for CoCrPtB/$Co_{60}Cr_{40}$ perpendicular recording media by utilizing very thin C seedlayer even with the thickness of less than 1 nm. This is caused by the following microstructural characteristic: 1) the C seedlayer, heated to higher than 200 °C, reacts with CoCr intermediate layer, and results in the formation of nanocrystalline layer with the thickness of about 6 nm; 2) Cr-deprived hcp grains with Cr segregation structure grow on the nanocrystalline layer without forming σ-phase grains in the intermediate layer; 3) CoCrPtB magnetic layer epitaxially grows on the intermediate layer without forming initial layer, which behaves as soft ferromagnetic layer and degrades magnetic properties of the media.**

***Index Terms*—σ-phase, $Co_{60}Cr_{40}$ intermediate layer, epitaxial growth, very thin C seedlayer.**

I. Introduction

For CoCr-based perpendicular recording media, it has been pointed out that media with low perpendicular loop squareness (S) show large media noise due to the formation of reversal domains [1]. As an attempt to increase S, elimination of initial growth layer in CoCr-based recording layer by using epitaxial growth on Cr-rich CoCr-based intermediate layer has been reported [2]–[5]. However, few papers discussed the relationship between the improvement of the magnetic properties and the structure of CoCr intermediate layer. In this paper, we show that magnetic properties for CoCrPtB/CoCr media are significantly improved by utilizing a very thin C seedlayer, and we clarify the effect of the C seedlayer on the growth of CoCr intermediate layer from the view point of phase formation.

II. Experimental Procedure

CoCrPtB perpendicular thin film media were fabricated by dc magnetron sputtering method on glass disk substrates of 65 mm in diameter, using the so-called ultraclean sputtering system [6]. Underlayers of 25-nm-thick Ti or Ta were deposited on the substrate at room temperature. The disks were then heated by quartz lamp and their temperatures were checked by radiation thermometer calibrated by infrared (IR) radiation of 25 nm-thick Ti film. The sputtering was made under Ar pressure of 6.7×10^{-1} Pa. The composition of the magnetic layer and the intermediate layer was fixed at $Co_{69}Cr_{19}Pt_8B_4$ and $Co_{60}Cr_{40}$, respectively. The thickness of the magnetic layer and carbon protective layer was 30 and 7 nm, respectively. To control the growth of the CoCr intermediate layer, seedlayer of C or $Ni_{60}Nb_{40}$ is sputtered between the underlayer and the intermediate layer.

For structural analysis, the X-ray diffraction (XRD) profiles were examined by conventional method (XRD; $2\theta - \omega$ scan) and Grazing incident angle method (in-plane XRD; $2\theta_\chi$ scan) using Cu-$K\alpha$ radiation. In the case of in-plane XRD, the incident angle was 0.4°, which corresponds to about 20-nm-thick penetration of X-ray from the incident surface. The microstructure was examined by cross-sectional transmission electron microscopy (TEM). The magnetization curve, saturation magnetization, and perpendicular magnetic anisotropy were evaluated by polar Kerr equipment, vibrating sample magnetometer (VSM), and torque magnetometer, respectively.

III. Results and Discussion

A. Effect of Seedlayer on Magnetic Properties for CoCrPtB/CoCr Media

Amorphous material is considered to be a promising candidate for a seedlayer due to its relatively low surface energy than that of CoCr intermediate layer and Ti underlayer [7]. Therefore, we chose amorphous C and $Ni_{60}Nb_{40}$ as seedlayer materials. Fig. 1(a) shows the magnetic properties for CoCrPtB/CoCr media deposited on Ti underlayer without and with C or NiNb seedlayer (1 nm) as a function of substrate temperature, $T_{\rm sub.}$. For the media without seedlayer, perpendicular coercivity, H_c and loop squareness S show the values of nearly zero at $T_{\rm sub.}$ = R.T.. With increasing $T_{\rm sub.}$, H_c and S show two-step increase at around $T_{\rm sub.} = 150$ °C and 250 °C. The two-step increase of magnetic properties against $T_{\rm sub.}$ was also observed for the media with NiNb seedlayer at around $T_{\rm sub.} = 200$ °C and 300 °C. For these media, high H_c and high S ($H_c \geq 2.5$ kOe and $S \geq 0.85$, for instance) are not realized consistently. On the other hand, for the media with C seedlayer, H_c and S show one-step increase against $T_{\rm sub.}$ and take significantly high values of 3.5 kOe and 0.88 at $T_{\rm sub.} = 250$ °C, respectively. Fig. 1(b) shows the magnetic properties for CoCrPtB/CoCr media on Ta underlayer with and without C seedlayer as a function of $T_{\rm sub.}$. As is also the case

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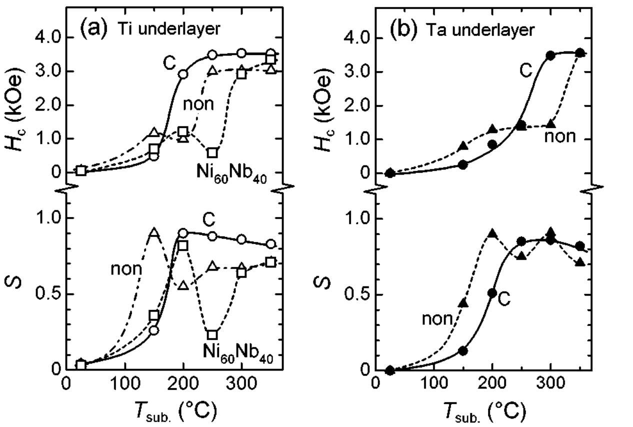

Fig. 1. Magnetic properties as a function of substrate temperature for CoCrPtB/CoCr media fabricated on (a) Ti underlayer and (b) Ta underlayer. The thickness of C or NiNb seedlayer was fixed at 1 nm.

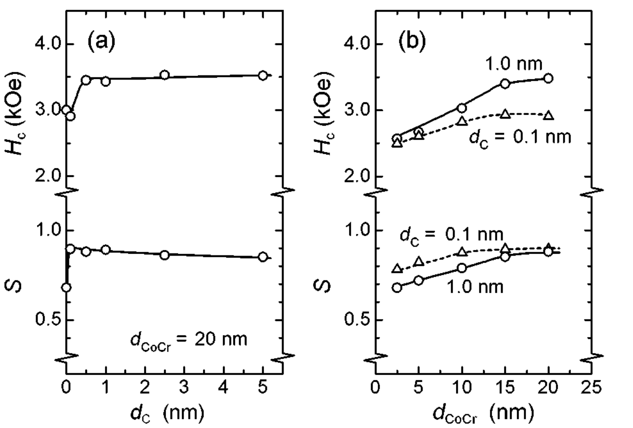

Fig. 2. Dependence of magnetic properties on (a) C seedlayer thickness and (b) CoCr intermediate layer thickness is shown for CoCrPtB/CoCr media fabricated at 250 °C.

with Ti underlayer, H_c and S show two-step increase against $T_{sub.}$ for the media without seedlayer, while for the media with C seedlayer, they show one-step increase against $T_{sub.}$ and take high values of 3.5 kOe and 0.85, respectively. Note that the conversion of the emissivity to temperature for various kinds of thin underlayers is very difficult, therefore, it is hard to compare the absolute values of $T_{sub.}$.

Fig. 2(a) shows H_c and S as a function of C seedlayer thickness for the media with CoCr intermediate layer (20 nm) on Ti underlayer fabricated at $T_{sub.} = 250$ °C. For the media without C seedlayer, H_c and S show the values of 3.0 kOe and 0.68, respectively. However, utilization of C seedlayer with the thickness of 0.5 nm or more improves both H_c and S up to high values of about 3.5 kOe and 0.85–0.90, respectively. Fig. 2(b) shows H_c and S as a function of thickness of CoCr intermediate layer for the media with C seedlayer (0.1 nm or 1.0 nm) deposited on Ti underlayer fabricated at $T_{sub.} = 250$ °C. With increasing intermediate layer thickness, H_c and S increase monotonously and reach to their maximum values at $d_{CoCr} = 10$ nm for the media with $d_C = 0.1$ nm and at $d_{CoCr} = 15$ nm for the media with $d_C = 1.0$ nm.

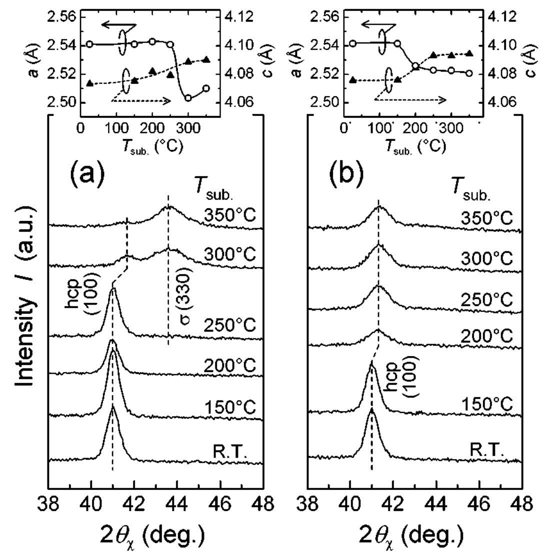

Fig. 3. In-plane XRD profiles for CoCr(20 nm) thin films (a) without and (b) with C(1 nm) seedlayer on Ti underlayer fabricated at various substrate temperatures. The insets show the $T_{sub.}$ dependence of lattice constant a and c of hcp grains in CoCr films.

B. Effect of C Seedlayer on Phase Formation in CoCr Layer

Fig. 3 shows the in-plane XRD profiles for CoCr(20 nm) film on Ti underlayer [Fig. 3(a)] without and [Fig. 3(b)] with C(1 nm) seedlayer fabricated at various $T_{sub.}$. The insets in Fig. 3(a) and (b) show the $T_{sub.}$ dependence of lattice constant a and c of hcp grains in CoCr films evaluated from in-plane diffraction of (100) plane and $2\theta - \omega$ diffraction of (002) plane, respectively. For the CoCr film without C seedlayer, as seen in Fig. 3(a), a diffracted line from hcp(100) plane at around $2\theta_\chi = 41.0°$ is observed in the $T_{sub.}$ range from R.T. to 250 °C. However, for the film fabricated at $T_{sub.} = 300$ °C, this diffracted line shifts toward $2\theta_\chi = 41.7°$ and another diffracted line from $\sigma(330)$ plane becomes observed at $2\theta_\chi = 43.6°$. Note that σ phase is known for an intermetallic compound with Cr composition from 54 to 66 at.% and with the space group of $P4_2/mnm$ [8]. Lattice constants a and c of the hcp phase drastically change in the $T_{sub.}$ range from 250 to 300 °C. Therefore, it is suggested that in CoCr films without C seedlayer fabricated at $T_{sub.}$ from R.T. to 250 °C, c-plane oriented hcp grains with Cr-rich composition are formed, while for the films fabricated at $T_{sub.}$ higher than 300 °C, σ grains are precipitated and residual hcp matrix consists of Cr-deprived grains. The coexistence of the σ and the hcp grains is also confirmed by TEM method [9].

On the other hand for the CoCr films with C(1 nm) seedlayer as seen in Fig. 3(b), a diffracted line from hcp(100) plane at around $2\theta_\chi = 41.0°$ is observed in the $T_{sub.}$ range from R.T. to 150 °C. For the film fabricated at $T_{sub.}$ over 200 °C, this diffracted line shifts to $2\theta_\chi = 41.3°$ without formation of the σ phase. Lattice constants a and c of the hcp grains drastically change in the $T_{sub.}$ range from 150 °C to 200 °C. These data suggest that in CoCr film with C(1 nm)-seedlayer, the Cr-rich hcp grains was formed at $T_{sub.}$ lower than 150 °C, and at $T_{sub.}$ more than 200 °C, hcp grains with less-Cr are formed due to the Cr segregation.

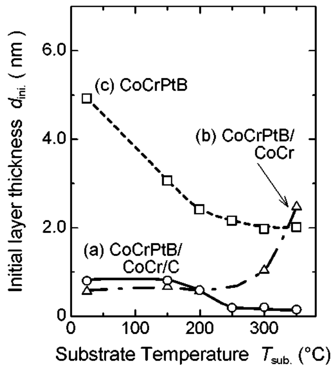

Fig. 4. Dependence of initial layer thickness in magnetic layer on substrate temperature for: (a) CoCrPtB/CoCr(20 nm)/C(1 nm) media; (b) CoCrPtB/CoCr(20 nm) media; and (c) CoCrPtB media on Ti underlayer.

C. *Epitaxial Growth of CoCrPtB/CoCr Media With C Seedlayer*

Fig. 4 shows dependence of the initial layer thickness in magnetic layer, $d_{\rm ini.}$, on $T_{\rm sub.}$ for [Fig. 4(a)] CoCrPtB/CoCr(20 nm)/C(1 nm) media, [Fig. 4(b)] CoCrPtB/CoCr(20 nm) media and [Fig. 4(c)] CoCrPtB media fabricated on Ti underlayer. The value of $d_{\rm ini.}$ was determined from the perpendicular magnetic anisotropy analysis, $K_{\rm u\perp}^{\rm exp.} \times d_{\rm mag.}$ vs. $d_{\rm mag.}$ plot [10]. For the media [Fig. 4(c)], at least 2 nm-thick initial layer is formed in the magnetic layer. For the media [Fig. 4(a)] and [Fig. 4(b)] with CoCr intermediate layer, the initial layer is thinner than 0.9 nm for $T_{\rm sub.} \leq 200$ °C. In the range $T_{\rm sub.} \geq 200$ °C, for the media [Fig. 4(b)], $d_{\rm ini.}$ becomes thicker with increasing $T_{\rm sub.}$, while for the media [Fig. 4(a)], $d_{\rm ini.}$ shows an extremely thin value of about 0.1 nm. Therefore, from the perpendicular magnetic anisotropy analysis, the initial layer is considered to be almost eliminated in the magnetic layer for the CoCrPtB/CoCr media with C seedlayer.

Fig. 5 shows bright and dark field images and electron diffraction patterns for the media with CoCr(20 nm)/C(1 nm) intermediate layer on Ti underlayer fabricated at $T_{\rm sub.} = 250$ °C. The dark field image was obtained from the diffraction of (002) plane with the hcp structure. The spot pattern of electron diffraction images obtained from the columnar structure of [Fig. 5(b)] and [Fig. 5(c)] reveal that preferred orientation of columnar structure is c-plane. As seen in the bright and dark field images, the columnar structures grow from the intermediate layer to the magnetic layer continuously, which means the epitaxial-growth of CoCrPtB on hcp grains of the CoCr intermediate layer. Note that a layer with light gray contrast in the bright field image with the thickness of about 6 nm can be seen in the initial region of the CoCr layer. Judging from the ring pattern of the electron diffraction image of a), this layer consist of nanocrystal grains whose crystal axes are randomly oriented in three-dimensional space. Therefore, it was suggested that very thin C seedlayer

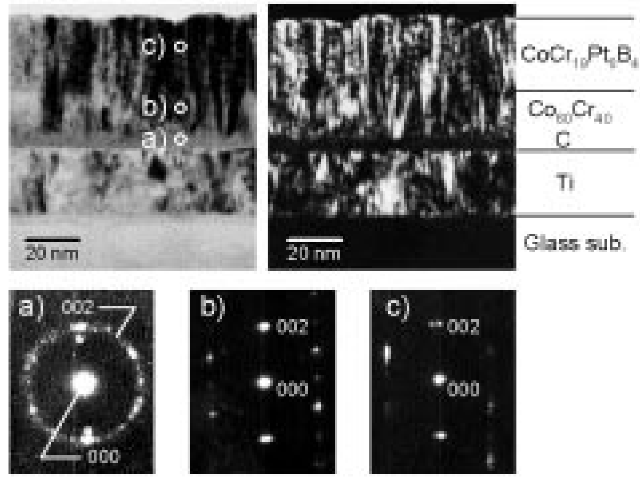

Fig. 5. Bright field image (top-left), dark field image (top-right), and electron diffraction patterns (bottom) obtained by cross-sectional TEM for the CoCrPtB media with CoCr(20 nm)/C(1 nm) intermediate layer on Ti underlayer fabricated at $T_{\rm sub.} = 250$ °C.

heated to higher than 200 °C reacts with CoCr film, and results in the formation of nanocrystalline grains in the initial growth stage of intermediate layer.

Consequently, for the CoCrPtB/CoCr/C media, it is found that C seedlayer promotes the formation of Cr-deprived hcp grains with Cr segregation structure in the CoCr intermediate layer, although nanocrystalline layer is formed in the initial growth stage of the CoCr intermediate layer. Furthermore, the Cr-deprived hcp grains in the intermediate layer prevent the formation of initial layer in magnetic layer due to epitaxial growth, which is the main reason for the remarkable improvement of the magnetic properties from the structural point of view.

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