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著者	齊藤　伸
journal or publication title	Journal of applied physics
volume	91
number	10
page range	8028-8030
year	2002
URL	http://hdl.handle.net/10097/35353

doi: 10.1063/1.1452270

Evaluation of thickness of initial growth layer in CoCr-based perpendicular media by perpendicular torquemetry

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Quantitative evaluation of the initial growth layer thickness was performed by using perpendicular torquemetry. It was clarified that: (1) The thickness of the initial growth layer becomes thicker by the increment of the content of Cr, Ta, or B additional element for CoCrPt(B, Ta) media. In the case of $CoCr_{16}Pt_8B_x$ media, with increasing x from 0 to 8 at. %, the initial growth layer thickness was increased from 1.5 to 2.2 nm. In the case of $CoCr_{16}Pt_8Ta_y$ media, with increasing y from 0 to 4 at. %, the initial growth layer thickness was increased from 1.5 to 4.8 nm. In the case of $CoCr_zPt_8B_4$ media, with increasing z from 16 to 24 at. %, the initial growth layer thickness was increased from 1.6 to 2.6 nm; (2) In the CoCrPtB medium, the initial growth region is relatively thin, and c-plane oriented fine grains with homogeneous columnar structure are realized. On the other hand for the CoCrPtTa medium, the initial growth region is relatively thick, and the grain size distribution and surface roughness is large due to selective grain growth; (3) The CoCrPtB magnetic film grew epitaxially on the CoCr/C/Ti underlayer. The perpendicular squareness of CoCrPtB/CoCr/C/Ti epitaxial medium was improved up to 0.88 and was maintained even for the $d_{mag}=30$ nm. [DOI: 10.1063/1.1452270]

I. INTRODUCTION

For CoCr-based perpendicular recording media, it has been pointed out that an initial growth region in a recording layer formed on top of an underlayer should be removed, since it behaves as a soft magnetic layer, resulting in the decreases of perpendicular coercivity and squareness of the medium.[1,2] However, quantitative evaluation of the dependence of the thickness of the initial growth layer on magnetic layer and underlayer materials has not been done yet. Here, we study the effect of the magnetic layer and underlayer materials on the thickness of the initial growth layer and on the film microstructure in CoCrPt(B, Ta) perpendicular thin film media.

II. EXPERIMENTAL PROCEDURE AND ANALYSIS

CoCrPtB and CoCrPtTa perpendicular thin film media were fabricated by dc magnetron sputtering method on 65 mm diam glass substrates using the so-called ultraclean sputtering system.[3] The substrate was heated by quartz lamp and the temperature was in the range from 200 to 300 °C. The sputtering was made under Ar pressure of 6.7×10^{-1} Pa. The film thickness of the media is varied from 5 to 50 nm. The underlayer and the protective layer were Ta with the thickness of 25 nm, and C with the thickness of 7 nm, respectively. The film thicknesses were controlled by sputtering times. The microstructure was examined by the transmission electron microscope (TEM) method. The saturation magnetization and perpendicular magnetic anisotropy were evaluated by vibrating sample magnetometer and high sensitive torque magnetometer, respectively. The torque curves measured in various fields up to 20 kOe were Fourier analyzed. The saturated torque coefficient of the two-fold component, $L_{2\theta}^{sat}$, was obtained by extrapolating the two-fold coefficient versus $1/H$ curve to $H\rightarrow\infty$. By taking account of the self-energy caused by demagnetizing field, the experimentally obtained total perpendicular magnetic anisotropy of the whole film, $K_{u\perp}^{exp}$, can be expressed as

$$K_{u\perp}^{exp}=L_{2\theta}^{sat}+2\pi M_s^2. \quad (1)$$

For perpendicular media composed of the initial layer and the columnar structure, the following equation can be satisfied:[4,5]

$$K_{u\perp}^{exp}\times d_{mag}=K_u^{grain}\times(d_{mag}-d_{ini}), \quad (2)$$

where d_{mag} and d_{ini} are the thicknesses of the magnetic layer and the initial layer, respectively. According to Eq. (2), with using a linear portion of $K_{u\perp}^{exp}\times d_{mag}$ vs d_{mag} curve, K_u^{grain} can

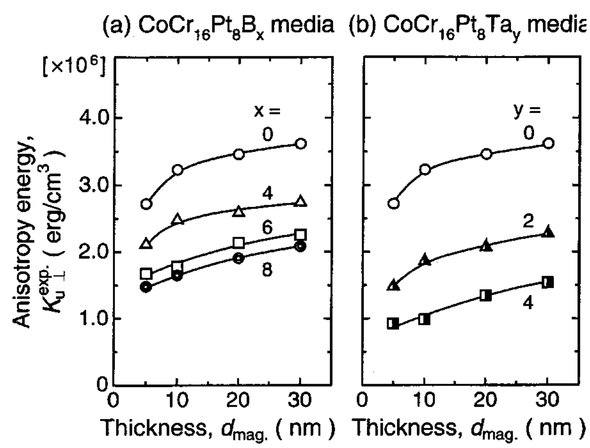

FIG. 1. Experimentally obtained perpendicular magnetic anisotropy, $K_{u\perp}^{exp}$, as a function of magnetic film thickness, d_{mag}, for (a) $CoCr_{16}Pt_8B_x$ media and (b) $CoCr_{16}Pt_8Ta_y$ media deposited on a Ta underlayer.

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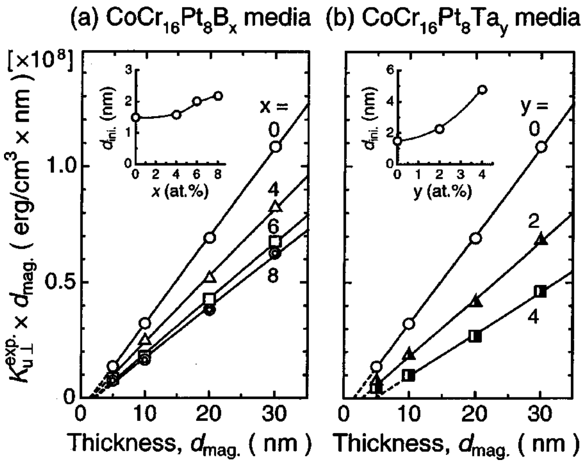

FIG. 2. $K_{u\perp}^{\rm exp}\times d_{\rm mag}$ vs $d_{\rm mag}$ plot for (a) $CoCr_{16}Pt_8B_x$ media and (b) $CoCr_{16}Pt_8Ta_y$ media deposited on a Ta underlayer. The insets to Figs. 2(a) and 2(b) show the thickness of the initial growth layer plotted against the content of x or y.

be uniquely determined from the gradient, and $d_{\rm ini}$ can be also determined from the intersection of the extended line with the $d_{\rm mag}$ axis.[4,5]

III. RESULTS AND DISCUSSION

Figures 1(a) and 1(b) show the experimentally obtained perpendicular magnetic anisotropy, $K_{u\perp}^{\rm exp}$, as a function of magnetic film thickness, $d_{\rm mag}$ for CoCrPtB and CoCrPtTa media on a Ta underlayer, respectively. For every medium, $K_{u\perp}^{\rm exp}$ gradually decreases with decreasing $d_{\rm mag}$. This fact indicates that nanocrystalline ferromagnetic grains, whose c axes are three-dimensional randomly oriented and perpendicular magnetic anisotropy is fairly low, are formed in the initial growth region of the magnetic layer. Therefore, in order to clarify the dependence of perpendicular anisotropy on film thickness, the data in Figs. 1(a) and 1(b) were replotted with a $K_{u\perp}^{\rm exp}\times d_{\rm mag}$ vs $d_{\rm mag}$ graph.

Figures 2(a) and 2(b) show the product of the experimentally obtained perpendicular magnetic anisotropy to the magnetic film thickness plotted against the magnetic film thickness ($K_{u\perp}^{\rm exp}\times d_{\rm mag}$ vs $d_{\rm mag}$) for $CoCr_{16}Pt_8B_x$ and $CoCr_{16}Pt_8Ta_y$ media on a Ta underlayer, respectively. The insets of Figs. 2(a) and 2(b) show the thickness of the initial growth layer plotted against the content of x or y. $K_{u\perp}^{\rm exp}\times d_{\rm mag}$ shows a linear correlation with $d_{\rm mag}$ for various media, except for Ta additional media with $d_{\rm mag}=5$ nm. The evaluated $d_{\rm ini}$ for various media were summarized in Table I. The media A, B, C, and D corresponded to the media with the B content x of 0, 4, 6 and 8 at. %, respectively, and the media A, G, and H corresponded to the media with the Ta content y of 0, 2, and 4 at. %, respectively. In the case of the media with B addition [Fig. 2(a)], $d_{\rm ini}$ increases from 1.5 to 2.2 nm with increasing x from 0 to 8 at. %. In the case of media with Ta addition [Fig. 2(b)], $d_{\rm ini}$ also increases from 1.5 to 4.8 nm with increasing y from 0 to 4 at. %. It is well known that B or Ta addition is effective to realize magnetic isolated structure by segregation of a Cr-rich phase in the grain boundary.[6] However, it was found out that these elements tended to enhance the formation of initial growth layer in these media. Comparing CoCrPtB with CoCrPtTa media, with the same additional content of B or Ta, it was found that the CoCrPtB media has the thinner initial growth layer thickness. We also investigated the initial growth layer thickness for the $CoCr_zPt_8B_4$ media with various Cr content, z. As shown in Table I, the media B, E, and F corresponded to the media with the Cr content z of 16, 19, and 24 at. %, respectively. It was found that with increasing the Cr content z from 16 to 24 at. %, $d_{\rm ini}$ increased from 1.6 to 2.6 nm.

To further investigate the initial growth structure dependence on the additional elements, microstructure observation by the TEM method for the CoCrPtB and CoCrPtTa media were carried out. In Figs. 3(a) and 3(b), bright-field images of plane view and cross-sectional view are shown for the media $Co_{72}Cr_{16}Pt_8B_4$ and $Co_{68}Cr_{20}Pt_8Ta_4$ with the $d_{\rm mag}$ of 50 nm, respectively. As seen in the plane view for the CoCrPtB medium in Fig. 3(a), magnetic grains enclosed by the Cr-rich phase can be clearly observed. In the cross-sectional view, there exists an interface layer with light gray contrast between the magnetic film and Ta underlayer, and a columnar layer with striped contrast just on the interface layer. The light gray contrast layer is considered to be the initial growth layer. On the other hand for the CoCrPtTa medium in Fig. 3(b), relatively larger grains are found in the plane view. In addition for the cross-sectional view, it can be easily found that a relatively thick initial growth layer is formed. Furthermore, some grains grew with an inverted corn shape with

TABLE I. $d_{\rm ini}$, $K_u^{\rm grain}$, and M_s for various CoCrPtB ad CoCrPtTa media. Perpendicular magnetic properties, H_c and $S(d_{\rm mag}=50\ {\rm nm})$ are also summarized.

	Media composition and layer structure	$d_{\rm ini}$ (nm)	$K_u^{\rm grain}$ (erg/cm^3)	M_s (emu/cm^3)	H_c (kOe) (50 nm)	S (50 nm)
A	$Co_{76}Cr_{16}Pt_8$/Ta (25 nm)	1.5	3.78×10^6	630	4.27	0.92
B	$Co_{72}Cr_{16}Pt_8B_4$/Ta (25 nm)	1.6	2.88×10^6	570	3.20	0.65
C	$Co_{70}Cr_{16}Pt_8B_6$/Ta (25 nm)	2.0	2.40×10^6	504	3.37	0.57
D	$Co_{68}Cr_{16}Pt_8B_8$/Ta (25 nm)	2.2	2.22×10^6	467	3.35	0.60
E	$Co_{69}Cr_{19}Pt_8B_4$/Ta (25 nm)	2.0	2.11×10^6	442	3.18	0.66
F	$Co_{64}Cr_{24}Pt_8B_4$/Ta (25 nm)	2.6	1.45×10^6	330	1.78	0.50
G	$Co_{74}Cr_{16}Pt_8Ta_2$/Ta (25 nm)	2.3	2.43×10^6	470	3.09	0.88
H	$Co_{72}Cr_{16}Pt_8Ta_4$/Ta (25 nm)	4.8	1.82×10^6	366	2.21	0.70
I	$Co_{69}Cr_{19}Pt_8B_4$/$Co_{60}Cr_{40}$ (20 nm) /C (1 nm)/Ti (25 nm)	0	2.76×10^6	477	3.48 *(30 nm)	0.88 *(30 nm)

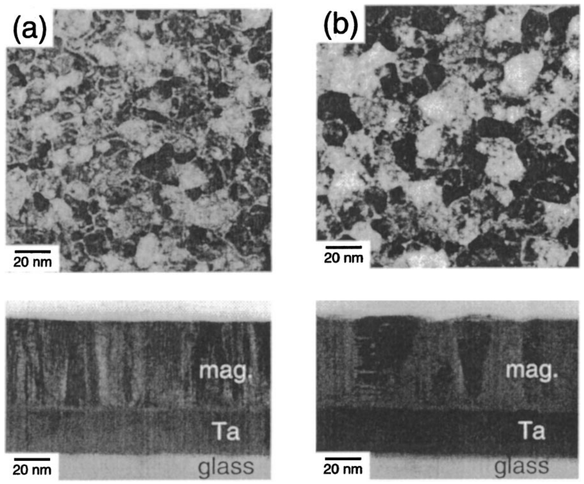

FIG. 3. Bright-field images of plane view and cross-sectional view for the (a) CoCrPtB medium and for the (b) CoCrPtTa medium with the thickness of 50 nm deposited on a Ta underlayer.

increasing d_{mag}, while the surrounding grains growth was suppressed. This fact is considered to be due to the different speed of grain growth, originated from the disordered crystal orientation of initial grains. Comparing the surface roughness of the media, a very smooth surface is realized for the CoCrPtB medium, on the contrary for the CoCrPtTa medium, roughness with the period of the grain diameter caused by the grain growth is formed. Therefore, it was clarified that in the CoCrPtB medium, the initial growth region is relatively thin, and the *c*-plane oriented fine grains with homogeneous columnar structure are realized. On the other hand for the CoCrPtTa medium, the initial growth region is relatively thick, and the grain size distribution and surface roughness is large due to selective grain growth.

Finally, to reduce the initial growth layer perfectly, we tried to prepare an epitaxial medium utilizing the CoCrPtB material. The construction of the underlayer was $Co_{60}Cr_{40}$ (20 nm)/C (1 nm)/Ti (25 nm). $Co_{69}Cr_{19}Pt_8B_4$ magnetic film was deposited on the CoCr layer with hexagonal close packed structure. In Figs. 4(a) $M_s^{exp}\times d_{mag}$ and 4(b) $K_{u\perp}^{exp}\times d_{mag}$ for the CoCrPtB/CoCr/C/Ti media are plotted against d_{mag}. Where M_s^{exp} means the total saturation magnetization of the whole medium divided by the volume of magnetic film. $M_s^{exp}\times d_{mag}$ decreases linearly with decreasing d_{mag} and the extended broken line intersects with the $M_s^{exp}\times d_{mag}$ axis at 1.2×10^3 emu/cm$^3\times$nm. This appearance of magnetization at $d_{mag}=0$ is due to the magnetization of the CoCr underlayer with the saturation magnetization of about 100 emu/cm^3. The saturation magnetization, M_s, of the CoCrPtB film on the CoCr layer was determined as 477 emu/cm^3 from the gradient of the $M_s^{exp}\times d_{mag}$ vs d_{mag} plot. It is clarified that the $K_{u\perp}^{exp}\times d_{mag}$ curve is proportional to the d_{mag} crosses zero, which means no initial growth layer with low perpendicular anisotropy is formed in the medium. Therefore, it suggests that the CoCrPtB magnetic film grows epitaxially on the CoCr underlayer. The validity of this expectation is supported by the cross-sectional image of high resolutional TEM analysis. It was found that the perpendicular squareness of the CoCrPtB/CoCr/C/Ti epitaxial medium was improved up to 0.88 and was maintained even for the $d_{mag}=30$ nm as shown in Table I.

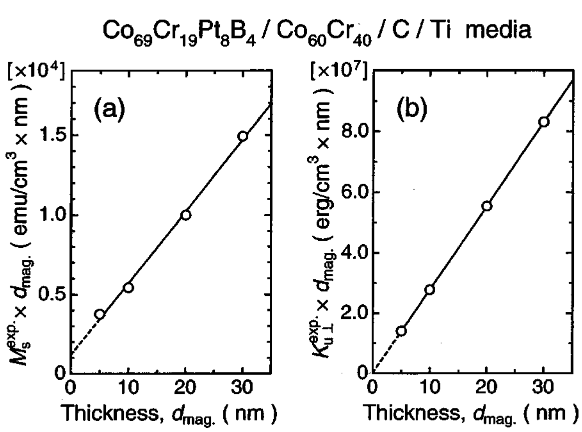

FIG. 4. (a) $M_s^{exp}\times d_{mag}$ vs d_{mag} plot and (b) $K_{u\perp}^{exp}\times d_{mag}$ vs d_{mag} plot for $Co_{69}Cr_{19}Pt_8B_4/Co_{60}Cr_{40}$/C/Ti epitaxial media.

IV. CONCLUSION

Quantitative evaluation of the initial growth layer thickness was performed by using perpendicular torquemetry. It was clarified that: (1) The thickness of the initial growth layer becomes thicker by the increment of the content of Cr, Ta, or B additional element for CoCrPt(B, Ta) media. In the case of $CoCr_{16}Pt_8B_x$ media, with increasing x from 0 to 8 at. %, the initial growth layer thickness was increased from 1.5 to 2.2 nm. In the case of $CoCr_{16}Pt_8Ta_y$ media, with increasing y from 0 to 4 at. %, the initial growth layer thickness was increased from 1.5 to 4.8 nm. In the case of $CoCr_zPt_8B_4$ media, with increasing z from 16 to 24 at. %, the initial growth layer thickness was increased from 1.6 to 2.6 nm; (2) In the CoCrPtB medium, the initial growth region is relatively thin, and *c*-plane oriented fine grains with homogeneous columnar structure are realized. On the other hand for the CoCrPtTa medium, the initial growth region is relatively thick, and the grain size distribution and surface roughness is large due to selective grain growth; (3) The CoCrPtB magnetic film grew epitaxially on a CoCr/C/Ti underlayer. The perpendicular squareness of the CoCrPtB/CoCr/C/Ti epitaxial medium was improved up to 0.88 and was maintained even for the $d_{mag}=30$ nm.

ACKNOWLEDGMENTS

The authors gratefully acknowledge N. Goto from OHARA Inc. for contributing all the substrates used in this experiment. The authors would also like to thank Storage Research Consortium for support of this research.

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