Experimental Characterization of Intergranular Exchange Coupling in CoCrTaPt and CoNiCrPt Thin Film Media

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Abstract- Quantitative characterizations of magnetic anisotropy of grains and intergranular coupling were carried out in $(\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2)_{100-x}\text{Pt}_x$ ($x=1\sim 9$) and $(\text{Co}_{62.5}\text{Ni}_{30}\text{Cr}_{7.5})_{100-x}\text{Pt}_x$ ($x=0\sim 16$) thin film media, by magnetic torque and ΔM analyses. In both materials, magnetocrystalline anisotropy field of grains H_k^{grain} increases twice as large as those of $x=0$ with increasing x to about 9at%, which plays a main role in increasing H_c . However, H_c/H_k^{grain} decreases with increasing x in both media. In CoCrTaPt media, the decrement of H_c/H_k^{grain} is found to be mainly caused by the increment of intergranular exchange coupling. In CoNiCrPt media, it is suggested that the change of c-axes directions from in plane to normal mainly causes the decrement in H_c/H_k^{grain} . Furthermore, to examine the effect of intergranular coupling on magnetic properties by means of ΔM plot, it is clarified that the difference of H_k^{grain} should be taken into account.

1. INTRODUCTION

Intergranular coupling of magnetization degrades the appearance of high coercive force and also much influences media noise [1]. The knowledge for the degree of intergranular coupling of the media is indispensable to realize high density magnetic recording [2, 3]. In this study, quantitative characterizations of magnetic anisotropy of grains and intergranular coupling were carried out by both magnetic torque and ΔM plot analyses in $(\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2)_{100-x}\text{Pt}_x$ ($x=1\sim 8$) and $(\text{Co}_{62.5}\text{Ni}_{30}\text{Cr}_{7.5})_{100-x}\text{Pt}_x$ ($x=0\sim 16$) thin film media. Magnetic properties in these media were discussed in connection with the magnetic anisotropy of grains and the strength of intergranular coupling of magnetization. The comparison of characterized results concerning intergranular exchange coupling between by magnetic torque analysis and by ΔM plot was also made out.

2. EXPERIMENTAL PROCEDURE

$(\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2)_{100-x}\text{Pt}_x$ and $(\text{Co}_{62.5}\text{Ni}_{30}\text{Cr}_{7.5})_{100-x}\text{Pt}_x$ media were deposited by d.c. magnetron sputtering on non-textured glass substrates with the Cr underlayer of 2000Å. Thickness of the magnetic layer was fixed at 400Å. Concentration of Pt was controlled by the number of Pt plates on the alloy target of $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ or $\text{Co}_{62.5}\text{Ni}_{30}\text{Cr}_{7.5}$. The samples were deposited at the substrate temperatures of 150, 200 and 250°C. The other conditions for the film fabrication were fixed. The concentration of Pt was examined by E.P.M.A.

Magnetization and remanence curves were measured by V.S.M. Before measuring the isothermal remanence curve, all the samples were ac-demagnetized by decreasing the magnitude of applied magnetic field. Rotational hysteresis loss was measured by a high sensitive torque magnetometer.

Preferred grain orientation was analyzed by X-ray diffraction technique with Co-K α radiation.

3. RESULTS AND DISCUSSION

A. Coercive Force and Magnetic Anisotropy of Grains

In all media, magnetic anisotropy was not observed in hysteresis loops in the film plane. In Fig.1, coercive force H_c in both kinds of media are plotted against Pt content. In CoCrTaPt media deposited at 150 and 200°C, H_c increases monotonically from about 1 to about 1.7kOe with increasing Pt from 0 to about 9at%. However, remarkable increase in H_c is not observed in the media deposited at 250°C. Here, saturation magnetization M_s shows a constant value of about 620 emu/cc independent of Pt content.

Fig.1 Change in H_c against Pt content in CoCrTaPt and CoNiCrPt media.

Fig.2 Change in H_k^{grain} against Pt content in CoCrTaPt and CoNiCrPt media.

In CoNiCrPt media, H_c monotonically increases with increasing Pt to about 12at%. However, remarkable change in H_c is not found in the region beyond about 12at%Pt. Here, M_s in CoNiCrPt media decreases monotonically from about 850 to about 720 emu/cc as Pt increases from 0 to about 16at%.

On the other hand, the increase of intrinsic magnetocrystalline anisotropy of grains, due to the increase of soluted Pt into grains, is easily expected in both kinds of media. The increase of H_c with increasing Pt is assumed to be strongly correlated to the increment of the magnetocrystalline anisotropy of grains.

In Fig.2, the values of H_k^{grain} are shown against Pt content in the both kinds of media. Here, H_k^{grain} shows the value of magnetic anisotropy field of grains. This field was determined as the magnetic field where rotational hysteresis loss W_r vanishes by an extrapolation method [2-4].

In the media without Pt, H_k^{grain} shows about 4kOe in CoCrTa media and about 5kOe in CoNiCr media. In both kinds of media, H_k^{grain} gradually increases with increasing Pt and becomes twice as large as those without Pt at about 9at%Pt. This increment of H_k^{grain} in both kinds of media means the increment of magnetocrystalline anisotropy of grains. Therefore, it is obviously concluded that the increment of H_k^{grain} due to the addition of Pt plays a main role in increasing H_c in both kinds of media.

B. Intergranular Coupling of Magnetization

In Fig.3, the values of H_c normalized by H_k^{grain} are plotted against Pt content in the both kinds of media.

Fig.3 Change in H_c/H_k^{grain} against Pt content in CoCrTaPt and CoNiCrPt media.

In CoCrTaPt media deposited at 150 and 200°C, H_c/H_k^{grain} keep the values at around 0.26 in the Pt content region up to about 6at%Pt. With further increasing Pt to about 9at%, H_c/H_k^{grain} gradually decreases to about 0.2. However, in the media deposited at 250°C, H_c/H_k^{grain} monotonically decreases from about 0.31 to about 0.2 as Pt content increases from 0 to about 9at%.

On the other hand, in CoNiCrPt media, the values of H_c/H_k^{grain} are smaller than those in CoCrTaPt media at the whole Pt content region. With increasing Pt content from 0 to about 12at%, H_c/H_k^{grain} monotonically decreases from about 0.19 to about 0.13 at all substrate temperatures examined.

In order to analyze this dependence of H_c/H_k^{grain} on Pt content in the both kinds of media, two possible origins will be discussed. One is grain orientation effect, the other intergranular (magnetostatic or exchange) coupling of magnetization.

Fig.4 shows the X-ray diffraction patterns in CoNiCrPt media with different Pt content. With increasing Pt content, hcp-(100) and hcp-(002) peaks shift to lower 2θ values, which indicates the increments in lattice spacings of hcp-CoNiCrPt. For example, the hcp-(100) lattice spacing gradually increases to about 2% larger value by the addition of about 16at%Pt content. This increases in the lattice spacings of the hcp-CoNiCrPt indicate a monotonic increase of soluted Pt content into the CoNiCr grains. On the other hand, the ratio of the diffracted intensity from hcp-(100) plane to that from hcp-(002) plane $I_{(100)}/I_{(002)}$ gradually decreases with increasing Pt content, which indicates the change of the c-axes directions of CoNiCrPt grains

Fig.4 Dependence of X-ray diffraction patterns on Pt content in CoNiCrPt films.

from in plane to normal as Pt content increases. Here, $I_{(100)}/I_{(002)}$ was not dependent on the substrate temperature.

In CoCrTaPt media, the increase of lattice spacings of hcp-CoCrTaPt with increasing Pt content has been also observed in the similar way [4]. However, $I_{(100)}/I_{(002)}$ was independent of both the Pt content and the substrate temperature, and showed an almost constant value of about 0.8 [4]. This result means that remarkable difference of preferred grain orientation among those CoCrTaPt films does not exist and the c-axes directions of grains almost lie in the film plane.

On the other hand, in the case that the H_c value is mainly determined by the degree of magnetostatic coupling, H_c/H_k^{grain} should increase with decreasing $4\pi M_s/H_k^{\text{grain}}$. Here, the ratio of $4\pi M_s$ to H_k^{grain} indicates the intrinsic strength of magnetostatic coupling effect on the decreasing of coercive force [3-5].

In Fig.5, the values of $4\pi M_s/H_k^{\text{grain}}$ are plotted against Pt content in the both kinds of media. In the both kinds of media, $4\pi M_s/H_k^{\text{grain}}$ gradually decreases with increasing Pt content, however, H_c/H_k^{grain} also decreases as shown in Fig.3. Therefore, in the both kinds of media, the decrement of H_c/H_k^{grain} with increasing Pt content can not be simply explained by the change of the strength of intergranular magnetostatic coupling of magnetization.

In CoCrTaPt media presently examined, remarkable difference of preferred grain orientation is not found as has been mentioned above. Furthermore, the

Fig.5 Change in $4\pi M_s/H_k^{\text{grain}}$ against Pt content in CoCrTaPt and CoNiCrPt media.

decrement of H_c/H_k^{grain} with increasing Pt content can not be explained by the change of the strength of intergranular magnetostatic coupling of magnetization. Finally, the decrease of H_c/H_k^{grain} in CoCrTaPt media is concluded to be mainly caused by the increase of the strength of intergranular exchange coupling of magnetization.

On the other hand, in CoNiCrPt media, the c-axes directions of CoNiCrPt grains change from in plane to normal with increasing Pt content as shown in Fig.4. Decrement of in plane component of magnetocrystalline anisotropy decreases H_c in film plane. Therefore, it is not accurately known what is the main factor to decrease H_c/H_k^{grain} with increasing Pt, whether the decrement of in plane component of magnetocrystalline anisotropy or the increase of the strength of intergranular exchange coupling.

C. Intergranular Coupling Characterized by ΔM Plot

In order to develop the further examination concerning intergranular coupling, remanence curves measurement was carried out for all samples.

In Fig.6, the changes in ΔM against applied magnetic field were shown for both media. In each kind of medium, the results for the films with different amount of Pt content are shown.

In CoCrTaPt media, the maximum value ΔM^{max} gradually increases with increasing Pt content. It is considered [6,7] that the strength of intergranular exchange coupling is the main factor to determine the magnitude of ΔM^{max} . Therefore, the increment of

Fig.6 Dependence of ΔM on Pt content in CoCrTaPt and CoNiCrPt media.

$\Delta M^{\max}$ with increasing Pt suggests the increase of the strength of intergranular exchange coupling. On the contrary, in CoNiCrPt media, $\Delta M^{\max}$ drastically decreases with increasing Pt content. In this material case, grain orientation also changes as a function of Pt content. Strictly speaking, the effect of grain orientation on the $\Delta M^{\max}$ should be taken into account to discuss the correlation between the strength of intergranular coupling and $\Delta M^{\max}$ exactly. However, the decrease of $\Delta M^{\max}$ with increasing Pt indicates the possibility of the decrement of intergranular exchange coupling due to the increment of Pt content.

In Fig.7, the values of $\Delta M^{\max}$ of all media are plotted against the values of H_c . Furthermore, in Fig.8, $\Delta M^{\max}$ are plotted against H_c/H_k^{grain} .

As seen in Fig.7, no clear correlation between $\Delta M^{\max}$ and H_c is observed. While by taking account of the values of H_k^{grain} , as shown in Fig.8, the clear dependence of $\Delta M^{\max}$ on H_c/H_k^{grain} is found in both kinds of media.

In CoCrTaPt media, $\Delta M^{\max}$ gradually increases with decreasing H_c/H_k^{grain} . This result means that the decrease of H_c/H_k^{grain} is mainly caused by the increment of the strength of intergranular exchange coupling, which follows the result estimated by magnetic torque analysis mentioned above.

On the other hand, in the case that the change of grain orientation does not play a main role in determining H_c/H_k^{grain} value in CoNiCrPt media, the decrease of H_c/H_k^{grain} is mainly caused by the increment of the intergranular exchange coupling.

Fig.7 Correlation between H_c and $\Delta M^{\max}$ in CoCrTaPt and CoNiCrPt media.

Fig.8 Correlation between H_c/H_k^{grain} and $\Delta M^{\max}$ in CoCrTaPt and CoNiCrPt media.

Therefore, in this case, it is expected that $\Delta M^{\max}$ gradually increases with decreasing H_c/H_k^{grain} like as in the CoCrTaPt case. However, on the contrary, $\Delta M^{\max}$ gradually decreases with decreasing H_c/H_k^{grain} in CoNiCrPt media. Finally, this result suggests that the decrease of H_c/H_k^{grain} in CoNiCrPt media presently examined is mainly caused by the change of c-axes directions from in plane to normal with increasing Pt content.

Furthermore, as has been mentioned above, no clear correlation between $\Delta M^{\max}$ and H_c is observed. This result means that the correlation between intergranular exchange coupling and magnetic properties can not be quantitatively discussed through only the ΔM plot analysis. To examine the effect of

intergranular coupling on magnetic properties by means of ΔM plot, it is clarified that the difference of H_k^{grain} should be taken into account.

4. SUMMARY

- 1) In $(\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2)_{100-X}\text{Pt}_X$ and $(\text{Co}_{62.5}\text{Ni}_{30}\text{Cr}_{7.5})_{100-X}\text{Pt}_X$ media, magnetocrystalline anisotropy field of grains increases twice as large as those of $X=0$ with increasing X to about 9at%. This increment of H_k^{grain} plays a main role in increasing H_c in both kinds of media.
- 2) In CoCrTaPt media presently examined, the decrement of H_c/H_k^{grain} with increasing Pt content is concluded to be mainly caused by the increment of the strength of intergranular exchange coupling of magnetization.
- 3) In CoNiCrPt media presently examined, it is suggested that the decrease of in plane component of magnetocrystalline anisotropy of grains, due to the change of the c-axes directions from in plane to normal, plays a main role in decreasing H_c/H_k^{grain} with increasing Pt.

4) In order to examine the effect of intergranular coupling on magnetic properties by means of ΔM plot, it is clarified that the difference of H_k^{grain} should be taken into account.

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