High Perpendicular Magnetic Anisotropy of CoPtCr/Ru Films for Granular-Type Perpendicular Media

T. Shimatsu, H. Sato, T. Oikawa, Y. Inaba, O. Kitakami, S. Okamoto, H. Aoi, H. Muraoka, *Member, IEEE*, and Y. Nakamura, *Fellow, IEEE*

***Abstract*—The perpendicular magnetic anisotropy K_u of CoPtCr films deposited on Ru seed layers is discussed as a function of film composition. Moreover, the change in K_u by the addition of SiO_2 is examined in light of thermal stability of CoPtCr–SiO_2 media. The K_u of Co-10 at % Cr shows a high value of $\sim 5 \times 10^6$ erg/cm^3, which is much higher than that reported by Bolzoni *et al.* The addition of Pt to the Co-10 at % Cr film results in a further enhancement of K_u. A maximum K_u of nearly 10×10^6 erg/cm^3 is observed at $25 \sim 30$ at % Pt. All series of films with various Cr contents show maximum values of K_u at $25 \sim 30$ at % Pt. The maximum value for CoPt (Cr $=$ 0) films reaches $\sim 15 \times 10^6$ erg/cm^3. The value of magnetocrystalline anisotropy of grains K_u^g, calculated by taking account of the volume fraction of CoPtCr grains, decreases as the SiO_2 content increases. However, the K_u^g maintains a large value of more than 7×10^6 erg/cm^3, even at 10 at % SiO_2 in addition to $(Co_{90}Cr_{10})_{80}Pt_{20}$, which indicates a high potential of CoPtCr–SiO_2 media to resist thermal agitation of magnetization.**

***Index Terms*—CoPtCr films, CoPtCr–SiO_2 media, perpendicular magnetic anisotropy, Ru seed layer, thermal agitation of magnetization.**

I. Introduction

LOW MEDIA noise performance and high thermal stability are critical issues for perpendicular recording media to achieve high recording density beyond 200 Gbits/in^2. Enhancement of grain isolation is vital to improve media noise performance. Moreover, large perpendicular anisotropy is required to resist thermal agitation of magnetization. CoPtCr–SiO_2/Ru media having a large perpendicular anisotropy were shown to have excellent high density recording performance and good thermal stability [1]. In this study, the perpendicular magnetic anisotropy of CoPtCr/Ru films is discussed as a function of the film composition. Moreover, the change in magnetocrystalline anisotropy by the addition of SiO_2 is also discussed.

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T. Shimatsu, H. Sato, Y. Inaba, H. Aoi, H. Muraoka, and Y. Nakamura are with the Research Institute of Electrical Communication, Tohoku University, Sendai 980-8577, Japan (e-mail: shimatsu@riec.tohoku.ac.jp).

T. Oikawa is with the Fuji Electric Company, Ltd., Matsumoto 390-0821, Japan (e-mail: oikawa@kiroku.riec.tohoku.ac.jp).

O. Kitakami and S. Okamoto are with the Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai 980-8577, Japan (e-mail: kitakami@tagen.tohoku.ac.jp).

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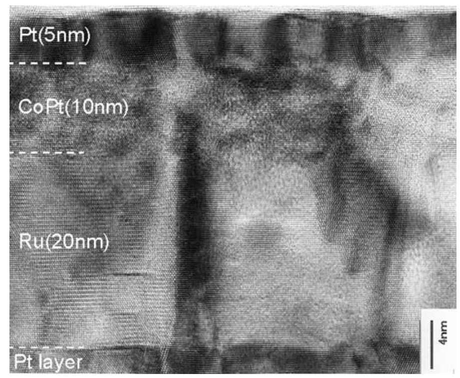

Fig. 1. High-resolution HR-TEM image of the cross section of $Co_{75}Pt_{25}$/Ru/Pt film.

II. Experimental Procedure

CoPtCr films were deposited on 2.5-in glass disks by the cosputtering method with Co, Pt, and Cr targets using a UHV-magnetron sputtering system. The thickness of the CoPtCr layer was fixed at 10 nm. Ru (20 nm) and Pt (10 nm) layers were employed as a seed and a pre-seed layers, respectively. Pt capping layers of 5 nm were deposited on the top of the CoPtCr layers. No substrate heating was carried out during the deposition process. Film deposition pressure of Ar for all layers was kept at 0.3 Pa for the fabrication of CoPtCr films. However, the Ar pressure for the Ru seed layer was 2 Pa when CoPtCr–SiO_2 media were fabricated, whereas the Ar pressure for the other layers was fixed at 0.3 Pa.

The value of perpendicular anisotropy K_u was obtained by subtracting the shape anisotropy $2\pi M_s^2$ from the value measured by torque magnetometry. The high-order magnetic anisotropy term K_{u_2} was evaluated by the GST method [2]. The anisotropy field H_k was calculated using the values of $K_u(= K_{u_1} + K_{u_2})$ and saturation magnetization $M_s(H_k = 2K_u/M_s)$.

III. Results and Discussion

A. CoPtCr/Ru Films

Fig. 1 shows a high-resolution transmission electron microscope (HR-TEM) image of the cross section of the $Co_{75}Pt_{25}$ film, i.e., hcp (002) lattice plane of the CoPt layer is continuously formed grown on Ru (002), indicating epitaxial growth of CoPt on Ru.

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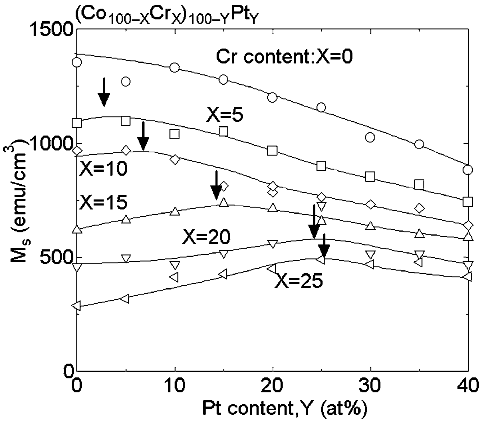

Fig. 2. Pt content dependence of M_s for $(\mathrm{Co}_{100\text{-}X}\mathrm{Cr}_X)_{100\text{-}Y}\mathrm{Pt}_Y$ films.

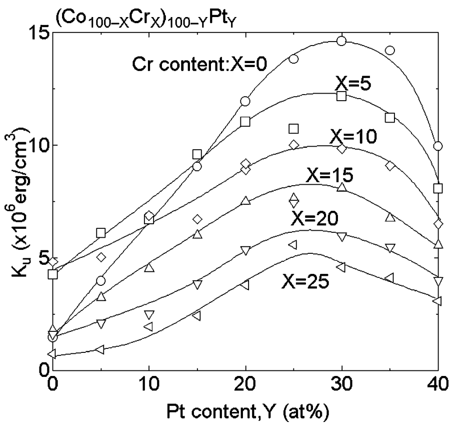

Fig. 3. Pt content dependence of K_u for $(\mathrm{Co}_{100\text{-}X}\mathrm{Cr}_X)_{100\text{-}Y}\mathrm{Pt}_Y$ films.

X-ray diffraction patterns indicate that all CoPtCr films show hcp structure with a (002) plane parallel to the film plane, except for a pure Co film, which has fcc structure with (111) preferred grain orientation. The rocking curve of the hcp (002) plane reveals that c-axis distribution $\Delta\theta_{50}$ of CoPtCr films are significantly small ($\sim 4^\circ$), independently of film composition. Moreover, no significant difference in $\Delta\theta_{50}$ was observed between the CoPtCr and Ru layers, probably due to the epitaxial growth of CoPtCr on Ru.

Fig. 2 shows Pt content dependence of saturation magnetization M_s for $(\mathrm{Co}_{100\text{-}X}\mathrm{Cr}_X)_{100\text{-}Y}\mathrm{Pt}_Y$ films. The value of M_s of CoPt films decreases as the Pt content increases. The addition of Cr to the series of CoPt films reduces the $_s$ values. The value of M_s shows a broad maximum at a Pt content in every series of $(\mathrm{Co}_{100\text{-}X}\mathrm{Cr}_X)_{100\text{-}Y}\mathrm{Pt}_Y$ films, and the peak position shifts to Pt rich region as the Cr content increases, which is probably due to the enhancement of phase separation by the Cr addition [3].

Fig. 3 shows the values of K_u of these films in a similar way. It should be noted that Co-10 at % Cr film shows a high K_u value of $\sim 5 \times 10^6$ erg/cm^3, which is much larger than that of bulk alloys reported by Bolzoni *et al.* [4]. Moreover, the higher-energy term of magnetocrystalline anisotropy K_{u_2} of the Co-10 at % Cr was nearly 0, which is significantly different from that previously reported [3]. The addition of Pt to the Co-10 at % Cr film results in a further enhancement of the magnitude of K_u, showing a large maximum of $\sim 10 \times 10^6$ erg/cm^3 at $25 \sim 30$ at % Pt. All series of the films with various Cr contents show maximum values of K_u at $25 \sim 30$ at % Pt. The maximum value for CoPt (Cr $= 0$) films reaches a high value of $\sim 15 \times 10^6$ erg/cm^3.

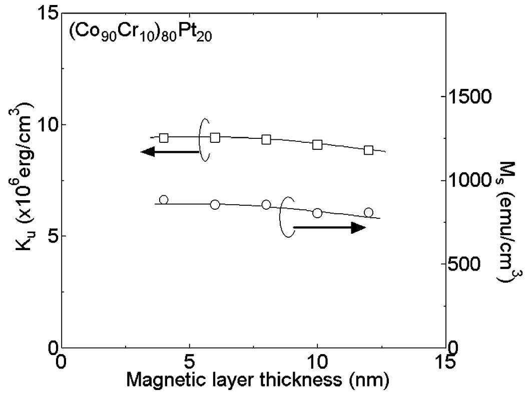

Fig. 4. Thickness dependence of K_u for $(\mathrm{Co}_{90}\mathrm{Cr}_{10})_{80}\mathrm{Pt}_{20}$ films.

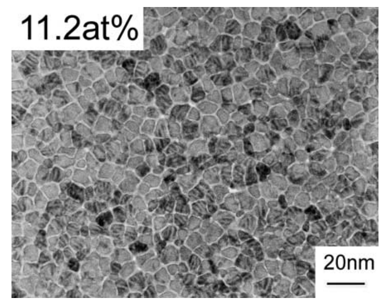

Fig. 5. TEM bright field image of $\{(\mathrm{Co}_{90}\mathrm{Cr}_{10})_{80}\mathrm{Pt}_{20}\}_{89}$–$(\mathrm{SiO}_2)_{11}$ media.

Fig. 4 shows thickness dependence of K_u and M_s for $(\mathrm{Co}_{90}\mathrm{Cr}_{10})_{80}\mathrm{Pt}_{20}$ composition. The K_u slightly increases as the thickness decreases; however no significant change in K_u was observed in the thickness range from 12 to 4 nm.

As mentioned above, CoCr, CoPt, and CoPtCr deposited on Ru underlayers exhibit very high K_u compared with the corresponding bulk alloys. One possible explanation for such high K_u would be growth-induced anisotropy, as commonly observed in CoPt alloy films [5]. However, our structural analyzes showed no clear evidence of chemical anisotropy responsible for the growth-induced anisotropy. Another possible explanation may be the lattice deformation of hcp-CoPtCr due to the lattice matching with Ru underlayers, although no obvious crystal distortion has been observed in XRD and SAD measurements. A more intensive effort is strongly required to clarify the origin of very high K_u in granular type CoPtCr(-SiO_2)/Ru media.

B. CoPtCr–SiO_2/Ru Media

The addition of SiO_2 to CoPtCr worked effectively to promote a well-isolated fine grain structure without disturbing the epitaxial growth of the CoPtCr grains on the Ru underlayer. Fig. 5 shows TEM bright field image of $\{(\mathrm{Co}_{90}\mathrm{Cr}_{10})_{90}\mathrm{Pt}_{10}\}_{89}$-$(\mathrm{SiO}_2)_{11}$ media. Grain diameter D_{grain}, including grain boundary thickness, is fine of $= 7.7$ nm.

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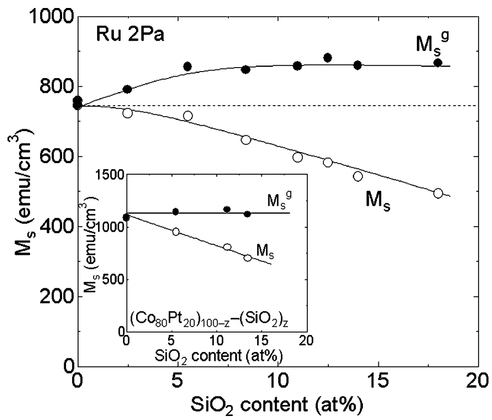

Fig. 6. Values of M_s and M_s^g for $\{(Co_{90}Cr_{10})_{80}Pt_{20}\}_{100\text{-}Z}$–$(SiO_2)_Z$ media as a function of SiO_2 content. In the figure, the results for $(Co_{80}Pt_{20})_{100\text{-}Z}$–$(SiO_2)_Z$ media are also shown for compasiton.

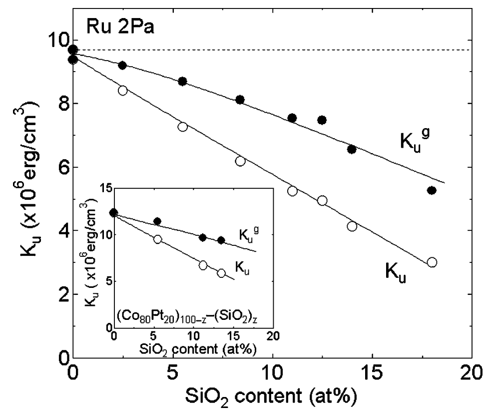

Fig. 7. Values of K_u and K_u^g for $\{(Co_{90}Cr_{10})_{80}Pt_{20}\}_{100\text{-}Z}$–$(SiO_2)_Z$ media as a function of SiO_2 content. In the figure, the results for $(Co_{80}Pt_{20})_{100\text{-}Z}$–$(SiO_2)_Z$ media are also shown for compasiton.

The X-ray analysis indicated that the c-axis distribution $\Delta\theta_{50}$ of the CoPtCr grains is relatively large (nearly 7–8°), but almost independently of SiO_2 content.

Fig. 6 shows the values of M_s for $\{(Co_{90}Cr_{10})_{80}Pt_{20}\}_{100\text{-}Z}$-$(SiO_2)_Z$ media as a function of SiO_2 content. In the figure, the values of saturation magnetization of grains M_s^g, which is calculated by taking account of the volume fraction of CoPtCr grains, are also shown. The value of M_s gradually decreases as the SiO_2 content increases. It should be noted that the value of M_s^g gradually increases as the SiO_2 content increases and tends to saturate at around 5 at % SiO_2. However, the value of M_s^g for $(Co_{80}Pt_{20})_{100\text{-}Z}$-$(SiO_2)_Z$ media does not increase by increasing SiO_2, as shown in the inset figure, maintaining the same value as that of $Co_{80}Pt_{20}$ media. This result suggests the reduction of Cr content in CoPtCr grains by the addition of SiO_2, probably due to strong chemical coupling between Cr and oxygen.

Fig. 7 shows the value of K_u for the same media. In the figure, the value of magnetocrystalline anisotropy of grains K_u^g, which is calculated by taking account of the volume fraction of CoPtCr grains, are also shown.

The values of K_u and K_u^g decrease as the SiO_2 content increases. The K_u^g decreases to the value of $\sim$ 80 % of the original value by the addition of 10 at % SiO_2 in both CoPtCr and CoPt media. The reduction of K_u^g cannot be explained by the reduction of Cr content in CoPtCr grains, indicating that a structural change of CoPtCr grains occurs by the SiO_2 addition, yielding the reduction of K_u^g. However, the K_u^g of the CoPtCr–SiO_2 media shows a large value of more than 7×10^6 erg/cm^3, even at 10 at % SiO_2 addition. This indicates a high potential of CoPtCr–SiO_2 media to resist thermal agitation of magnetization.

IV. Conclusion

It is revealed that CoPtCr/Ru films show large K_u values up to 1.5×10^7 erg/cm^3, although the mechanism of the appearance of the large K_u values is not clear. The addition of SiO_2 to CoPtCr films reduces the value of K_u^g. However, the K_u^g maintains a large value of more than 7×10^6 erg/cm^3, even at 10 at % SiO_2 in addition to $(Co_{90}Cr_{10})_{80}Pt_{20}$, for instance, indicating a high potential of CoPtCr–SiO_2 media to resist thermal agitation of magnetization.

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