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CoPtCr–SiO_2 Perpendicular Media for High Density Recording With a High Order Magnetic Anisotropy Energy Term

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The first and second order energy terms of uniaxial magnetic anisotropy, K_{u1} and K_{u2}, of CoPtCr–SiO_2 perpendicular recording media were studied as a function of film composition and film structure. Moreover, the fabrication of CoPtCr–SiO_2 media having adequate values of K_{u1} and K_{u2} for high recording density was preliminarily studied. An analysis of CoPtCr films with various kinds of seed layer materials revealed that the values of K_{u1} and K_{u2} varied significantly with the seed layer material used, probably due to epitaxial growth of CoPtCr on the seed layers. K_{u2} increased, accompanied by a reduction in K_{u1} as the c/a ratio of the hcp–CoPtCr lattice increased. Moreover, experimental results suggest that a high stacking-fault density enhances the K_{u2} values, especially in the high Pt content region. The addition of SiO_2 reduces the total anisotropy, $K_{u1} + K_{u2}$, but no significant change in the ratio of K_{u2}/K_{u1} was observed. The fabrication of CoPtCr–SiO_2 media with adequate values of K_{u1} and K_{u2} was successfully demonstrated, although more intensive efforts to enhance grain isolation are required to confirm the advantages conferred by the K_{u2} term.

***Index Terms*—CoPtCr–SiO_2, high order energy term, lattice deformation, magnetic anisotropy, perpendicular recording media, thermal stability.**

I. INTRODUCTION

IT IS theoretically predicted that the high order energy term of uniaxial magnetic anisotropy, K_{u2}, enhances the energy barrier for the remanent state, without a notable change in the switching field [1]–[4]. CoPtCr–SiO_2 perpendicular media deposited on Ru seed layers show negligibly small K_{u2} values, although the first order energy terms of uniaxial magnetic anisotropy, K_{u1}, of these media are exceedingly large, reaching 1×10^7 erg/cm^3 [5], [6]. However, the values of K_{u1} and K_{u2} for CoPtCr media vary significantly with the seed layer materials used, probably due to epitaxial growth of CoPtCr on the seed layers, and the use of certain seed layers leads to an appearance of K_{u2} [5], [6]. In this study, the magnetic anisotropy of CoPtCr-SiO_2 perpendicular recording media, including the K_{u2} term is examined as a function of film composition and film structure. Moreover, the fabrication of CoPtCr–SiO_2 media with adequate values of K_{u1} and K_{u2} for high density recording is preliminarily studied.

II. EXPERIMENTAL PROCEDURE

CoPtCr–SiO_2 media were deposited on 2.5-in glass disks by the co-sputtering method with Co, Pt, Cr, and SiO_2 targets using an UHV-magnetron sputtering system. The film composition was varied by controlling the deposition rates. The standard film thickness of the CoPtCr layer was 10 nm. Various kinds of materials were used as seed layers (10–20 nm in thickness), with Pt/Ta or Ta pre-seed layers underneath. The substrates were not heated during the deposition process. The Ar pressure during deposition of the CoPtCr films was either 0.3 or 0.5 Pa. However, the Ar pressure during the seed layer deposition was 1.5 or 2 Pa when CoPtCr–SiO_2 media were fabricated. The values of K_{u1} and K_{u2} were evaluated by the GST method [7]. The recording performance was studied for double-layered media with CoZrNb (200 nm) soft under layers using a SPT flying head for the recording (track width 180 nm) and a GMR head for the read back (shield gap length 55 nm and track width 140 nm).

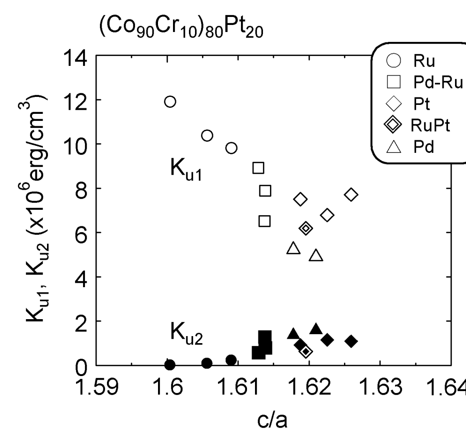

Fig. 1. Values of K_{u1} (open symbols) and K_{u2} (solid symbols) for $(Co_{90}Cr_{10})_{80}Pt_{20}$ films deposited on various kinds of seed layer materials, as a function of the c/a values.

III. RESULTS AND DISCUSSION

Fig. 1 shows the values of K_{u1} and K_{u2} for $(Co_{90}Cr_{10})_{80}Pt_{20}$ films without SiO_2 deposited on various kinds of seed layer materials, as a function of the c/a values of the hcp-CoPtCr

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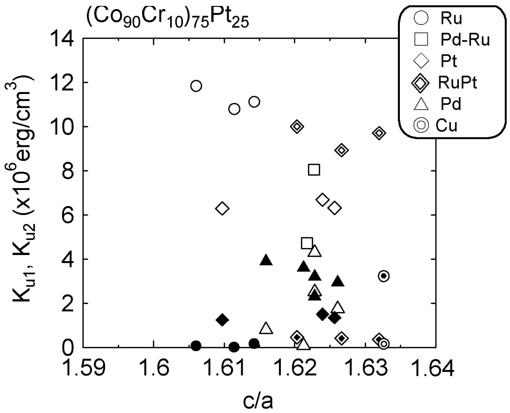

Fig. 2. Values of K_{u1} (open symbols) and K_{u2} (solid symbols) for $(Co_{90}Cr_{10})_{75}Pt_{25}$ films deposited on various seed layer materials, as a function of the c/a values.

TABLE I
RATIO OF X-RAY DIFFRACTION INTENSITY OBTAINED USING SYNCHROTRON RADIATION

Seed materials used	Ru	Pt	Pd
Normalized intensity ratio fcc(111)/hcp(101) for $(Co_{90}Cr_{10})_{80}Pt_{20}$ films	1	2.3	4.2
K_{u1} (x10^6 erg/cm^3)	11.9	7.7	5.2
K_{u2} (x10^6 erg/cm^3)	<0.01	1.1	1.4
K_{u2} /K_{u1}	<0.01	0.14	0.26

lattices. X-ray diffraction (XRD) and transmission electron microscopy (TEM) analyses revealed that all CoPtCr films had a hcp structure with the (002) plane parallel to the film plane. The c-axis distribution, $\Delta\theta_{50}$, of hcp-CoPtCr grains ranges from 3 to 8°, depending on the seed layer materials used, however the difference in $\Delta\theta_{50}$ values due to the seed layer materials was negligible for the following discussion. The CoPtCr films deposited on Ru seed layers showed large K_{u1} values of up to 1.2 $\times 10^7$ erg/cm ^{3}, but with negligibly small K_{u2}. The increase in c/a values with the use of adequate seed layer materials led to the appearance of K_{u2}. However, K_{u1} decreased as the c/a increased, resulting in a reduction of total anisotropy, $K_{u1} (= K_{u1} + K_{u2})$. This correlation between c/a and (K_{u1}, K_{u2}) is qualitatively in good agreement with theoretical predictions [8], [9].

Fig. 2 shows the values of K_{u1} and K_{u2} for $(Co_{90}Cr_{10})_{75}Pt_{25}$ films as a function of the c/a values. The values of K_{u1} and K_{u2} have a greater dependence on the seed layer material used compared to the media with 20at%Pt, and some CoPtCr films show large K_{u2} of 3–4 $\times$ 10^6 erg/cm^3 with $K_{u1} = \sim 0$ (Cone state of magnetization). It should be noted that the relationship between c/a and (K_{u1}, K_{u2}) is unclear, compared to the CoPtCr films with 20 at%Pt composition.

Grazing incidence XRD analysis using Synchrotron radiation showed that very weak fcc-lattice diffractions could be observed in the CoPtCr films, although no fcc-lattice diffraction lines were observed in XRD patterns measured by a conventional XRD analysis using Cu-Kα radiation. Table I shows the ratio of the diffraction intensity of fcc(111) to that of hcp(101) for $(Co_{90}Cr_{10})_{80}Pt_{20}$ films deposited on Ru, Pt and Pd seed layers. The values of the intensity ratio were normalized to that of the film deposited on the Ru seed layer. The K_{u1} and K_{u2}

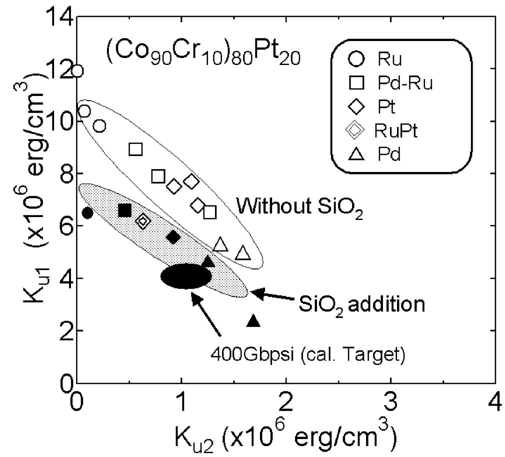

Fig. 3. Relationship between the values of K_{u1} and K_{u2} of CoPtCr films and CoPtCr-SiO_2 media (shaded area).

values of these films are also shown in the table. This result shows that the value of K_{u2}/K_{u1} increases as the diffraction intensity of the fcc-lattice increases. It is likely that the increase in the diffraction intensity of the fcc-lattice is caused by an increase in the density of stacking-faults in the hcp-lattice. Kubo, *et al.* revealed [10] that the CoPtCr(-SiO_2) films show a very high stacking-fault density in the Pt content region higher than 20 at%Pt. It is assumed that the appearance of K_{u2} is related to an increase in the density of stacking-faults in the hcp-lattice in addition to the lattice deformation, especially in the Pt content region higher than 20 at%Pt, which results in the unclear relationship between c/a and (K_{u1}, K_{u2}) shown in Fig. 2.

Fig. 3 shows the relationship between the values of K_{u1} and K_{u2} for the $(Co_{90}Cr_{10})_{80}Pt_{20}$ films deposited on various kinds of seed layer materials. K_{u1} decreases almost linearly as K_{u2} increases. This almost linear relationship was also observed for $(Co_{90}Cr_{10})_{75}Pt_{25}$ films [5]. The addition of SiO_2 reduces the total anisotropy as indicated by the shaded area, but no significant change in the values of K_{u2}/K_{u1} was observed on the addition of SiO_2 [5], [6]. Theoretical calculations for media designs for 400 Gb/in^2 revealed [5] that the values of K_{u1} and K_{u2} are required to be 4.3 $\times 10^6$ erg/cm^3 and 0.9–1.5 $\times$ 10^6 erg/cm^3, respectively (the saturation magnetization, M_s, is 500–600 emu/cm^3), to enhance the energy barrier for the remanent state without a notable change in the switching field. The experimental results shown in Fig. 3 indicate that the required values of K_{u1} and K_{u2} are achievable by controlling the lattice deformation. The most important point is control of the microstructure to enhance grain isolation whilst simultaneously achieving adequate magnitudes of K_{u1} and K_{u2}.

We did some studies of ways to enhance the grain isolation, and Fig. 4 shows the magnetization curve of a prototype CoPtCr-SiO_2 medium. The values of K_{u1}, K_{u2}, M_s, and the grain size, including the grain boundary thickness, D_{grain}, are shown in Table II. The values required for 400 Gb/in ^{2} [5] are also shown for comparison. The values of K_{u1}, K_{u2}, and D_{grain} satisfy the required values, although M_s is still too large. The values of remanence coercivity measured at $\sim$10 Oe/s, H_r, and $\sim$ 10^8 Oe/s, H_r^P, were 3.9 and 4.5 kOe, respectively. The values of H_0 and $K_u V_{\text{act}}/kT$ were obtained

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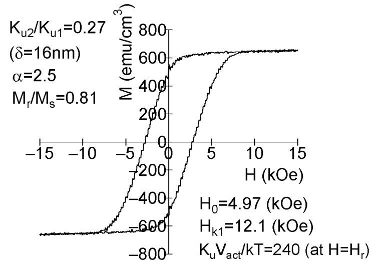

Fig. 4. Magnetization loop of the prototype K_{u2}-medium.

TABLE II
MAGNETIC ANISOTROPY FOR THE K_{u2} MEDIA PRELIMINARY FABRICATED

	CoPtCr-SiO_2 /Pd	Required values (400 Gbits/inch^2)
K_{u1} (x10^6 erg/cm^3)	4.6	4.3
K_{u2} (x10^6 erg/cm^3)	1.3	0.9-1.5
K_{u2}/K_{u1}	0.27	0.2-0.35
M_s (emu/cm^3)	700	500-600
D_{grain} (nm)	~7	< 8.4

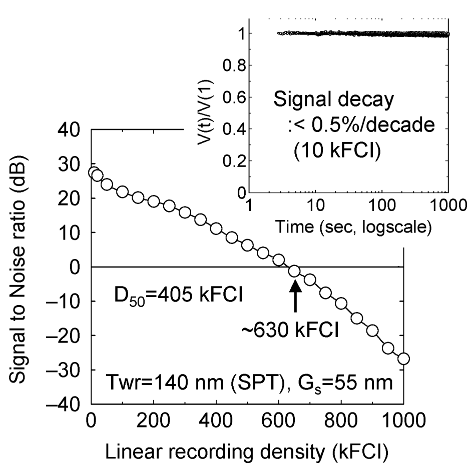

Fig. 5. Recording performance of the prototype K_{u2}-medium with SUL.

by fitting the values of H_r and H_r^P to Sharrock's equation [11], taking account of the influence of K_{u2} on the Sharrock's equation [12]. (V_{act} is the activation volume, k the Boltzmann constant, and T the absolute temperature). H_0 corresponds to the "intrinsic" remanence coercivity obtained by subtracting the effect of the thermal agitation of magnetization. The value of H_0 was $\sim$ 5.0 kOe, which was about 40% of the anisotropy field determined from K_{u1} term, H_{k1}, indicating that a possibly further grain isolation is required. However, the medium shows relatively good recording performance as seen in Fig. 5; the value of signal to medium noise ratio crosses the zero line at $\sim$ 630 kFCI, and the recording resolution (the linear recording density where the readout signal becomes half that at low density), D_{50}, is $\sim$ 405 kFCI. The value of K_uV_{act}/kT of this medium was 240. The value of $\Delta EV_{\mathrm{act}}/kT(\Delta E$ is the stabilizing energy barrier) in the saturation remanent magnetization state, calculated from the K_uV_{act}/kT value, was about 140, and no significant time decay of readout signal was observed at low recording density. It is likely that a further enhancement of grain isolation and a reduction of the saturation magnetization will lead to increases in H_c and M_r/M_s, resulting in an improvement of the recording performance whilst maintaining sufficient thermal stability.

IV. CONCLUSION

The values of K_{u1} and K_{u2} of CoPtCr-SiO_2 media are related to the deformation of the hcp–CoPtCr lattice, moreover, a high stacking-fault density is likely to enhance the K_{u2} values, especially in the high Pt content region. The fabrication of CoPtCr–SiO_2 media having adequate values of K_{u1} and K_{u2} was successfully demonstrated, although a more intensive effort is required to confirm advantages of the K_{u2} term.

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