CoCrTa/CoZrNb PERPENDICULAR MAGNETIC HARD DISK

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Abstract --- Low noise perpendicular magnetic recording hard disk using an amorphous soft magnetic CoZrNb underlayer, has been developed. Soft magnetic layer is prepared by the depositing materials on the disk substrates in the magnetic field directed radially by the magnets in a DC magnetron sputtering system. CoZrNb underlayer with magnetic easy axis uniform in the radial direction is more easily producible than a permalloy underlayer on the glass substrate. Perpendicular recording layer with high crystal orientation ($\Delta\theta 50 \leq 3^\circ$) is also obtained by sputtering CoCrTa on the fresh surface of the CoZrNb underlayer. On the glass substrate, remarkably lower medium noise and a higher SNR are achieved with the CoZrNb underlayer than with the permalloy underlayer. This noise reduction is mainly due to the uniformity of magnetic easy axis in the CoZrNb underlayer.

INTRODUCTION

In perpendicular magnetic recordings, high medium noise may be observed on the double layer medium which employs a soft magnetic underlayer [1-9]. One of the sources of the medium noise from the underlayer is considered to be domain wall caused by irregular easy axis directions [1]. And mechanical rubbing by the head was also reported to be responsible for the noise in case of a head-contact system for a tape medium [2]. On the other hand, concerning the perpendicular recording layer, noise is attributed to the dispersion of perpendicular magnetization direction which is caused by disorder of crystal orientation [3].

In this paper, reduction of the medium noise in the non-contact hard disk system is attempted by using amorphous CoZrNb for the underlayer instead of permalloy which has been generally used for underlayers. Because the CoZrNb film provides a good soft magnetic property permitting a small change of its composition or a variation of depositing condition, and also because underlayer is amorphous and double layer is composed of the same Co alloy, high crystal orientation of recording layer can be obtained [4].

EXPERIMENTS

Magnetic films were deposited on 3.5" size glass or textured NiP/Al substrates by DC magnetron sputtering process. An 8" size Co-Zr7-Nb5 atomic percent (at%) alloy target was used for the underlayer deposition and Cu-Mo-permalloy (Ni-Fe14-Mo4-Cu5 at%) was used for comparison with CoZrNb. Co-Cr15-Ta4 at% alloy was used for the perpendicular recording layer. Approximately 50 Oe of magnetic field was applied to the substrates radially by a magnetron during the sputtering. Carbon and lubricant layer were coated on the disk for measuring the R/W characteristics. Table 1 shows the sputtering conditions, where Ar pressure (PAr), the sputtering power and the substrate temperature (Tsub.) have been applied to obtain lower coercivity of the underlayer and higher coercivity of the recording layer.

Table 1. Sputtering conditions

	Underlayer	Recording layer
Target	Co-Zr7-Nb5 at% (Cu5-Mo4-Permalloy)	Co-Cr15-Ta4 at%
PAr	0.5 ~ 1.5 mTorr	
Power	1.9 W/cm ²	1.1 W/cm ²
Tsub.	R.T. ~ 200 °C	200 °C

Carbon overcoat 200 Å

Magnetic properties of the films were measured with a VSM and a B-H loop tracer. Permeability of the underlayer was measured by a vector impedance method at 1 MHz. Crystal orientation of the recording layer was evaluated as $\Delta\theta 50$ which was a half width of (002) rocking curve by an X-ray diffractometer. R/W characteristics was measured by a disk tester with a single pole head as seen in Table 2. Noise power was measured by a spectrum analyzer as a voltage within the band width of 16 MHz when a signal of 43 kFCI was recorded. Noise data were processed with the compensations for the head inductance and the circuit noise.

Table 2. Specifications of single pole head

Track width	7.7 μm
Pole thickness	0.42 μm
Coil	60 turns
Inductance	1.45 μH
Flying height	0.08 μm
Velocity	7.8 m/sec.

RESULTS AND DISCUSSIONS

Soft magnetic properties of underlayer

Table 3 shows the typical soft magnetic properties of CoZrNb films and permalloy films formed on the glass substrates. CoZrNb films have larger magnetic flux density (B) and smaller coersivity (Hc) than those of the permalloy films. And CoZrNb films have uniform magnetic anisotropy field (Hk) and permeability (μ), which values are about 15 Oe and 800 in circumferential direction respectively. But Hk and μ of permalloy films are not uniform in the circumferential direction (e.g. μ ranges from almost 0 to several thousand).

Table 3. Soft magnetic properties of underlayer

Substrate ; Glass
Thickness ; 0.5 μm
Direction ; Circumferential

Materials	B(Gauss)	Hc(Oe)	Hk(Oe)	μ (1MHz)
CoZrNb	13 000	0.12	15	800
PERMALLOY	5050	0.25	1~10	0~7000

Distribution of the easy axis direction and the Hk have been investigated. In Fig.1, the arrows indicate the easy axis directions and the Hk of underlayer. In the CoZrNb films on the NiP/Al substrates (a), the easy axes are inclined from the radial direction, and there are 2 positions (①, ②) where the inclination of the easy axis reverses. This result is considered due to the circumferential texturing of the substrates, and a small shift of the magnetic field from the radial direction during the deposition. But on the non textured glass substrates (b), the easy axes are strongly distributed radially and the magnitude of Hk is large. However, in the permalloy films (c), easy axis directions are not radial even when the radial magnetic field is applied to the non-textured glass substrates. One of the origins of the induced anisotropy of soft magnetic films is generally known as orientation of different magnetic atoms' pairs [10-12]. But this effect seems insufficient to support the result of our permalloy films.

At any rate, the easy axis of CoZrNb film is easily oriented to the radial direction which is normal to the head running direction, by the radial magnetic field applied by the magnet in the conventional magnetron sputtering system.

Fig. 1 Easy axis direction and Hk of underlayer.

- (a) CoZrNb on the NiP/Al substrate
- (b) CoZrNb on the glass substrate
- (c) Permalloy on the glass substrate

Crystal orientation of recording layer

Sputtering a perpendicular recording layer on the fresh CoZrNb underlayer is found to be very important to obtain high crystal orientation. Fig.2 shows the relationship between the $\Delta\theta_{50}$ and the interval time (T) for sputtering CoCrTa layer after the deposition of underlayer. In the permalloy underlayer, $\Delta\theta_{50}$ is as large as 7° independent of T. But on the CoZrNb underlayer, $\Delta\theta_{50}$ is not larger than 3° in the smaller T. And with larger T, $\Delta\theta_{50}$ becomes larger even on CoZrNb underlayer. This is because a contamination layer possibly formed on the CoZrNb surface.

Fig.3 shows a dependence of $\Delta\theta_{50}$ on CoCrTa thickness. Generally, $\Delta\theta_{50}$ of CoCr alloy increases rapidly at a smaller thickness on the permalloy underlayer. But the CoZrNb underlayer presents a small $\Delta\theta_{50}$ of less than 5° at the thickness of several hundred Å.

High crystal orientation is obtained by sputtering CoCrTa immediately after the CoZrNb deposition. This is considered that there exist many crystal sites where hcp crystallites of CoCrTa have easily grown up on the amorphous CoZrNb surface, and a strong combination is obtained between the CoZrNb and the CoCrTa as the same Co alloys of a double layer.

Fig. 2 Dependence of $\Delta\theta_{50}$ on interval time

Fig. 3 Dependence of $\Delta\theta_{50}$ on CoCrTa thickness

R/W and noise characteristics

Table 4 shows R/W characteristics of 4 disk samples with their underlayers (CoZrNb or permalloy) and substrates (glass or NiP/Al) varied respectively. Readback voltage of isolated pulse E_p mainly depends on the perpendicular coercivity $H_{c\perp}$ of CoCrTa. And a linear density D50 is almost same between these disks. D50 must be limited by the head to medium spacing and the pole thickness of the single pole head. On the other hand, on both the glass and the NiP/Al substrates, CoZrNb underlayer presents a remarkable SNR improvement by 7 dB over the SNRs of the permalloy underlayer. This improvement is resulted not by an increase of the signal voltage but by a reduction of noise.

Further examination tends to noise properties. Fig.4 shows noise spectra of Sample A (on the CoZrNb) and C (on the permalloy) at a 43 kFCI recording. These media noise levels were nearly equal to the DC erased noise levels. Noise of Sample A is lower than that of Sample C over the wide frequency range. Fig.5 shows DC erased noise envelopes in 1 revolution of each of the 4 disks. On the permalloy underlayer, many noises are observed throughout the readback on both the NiP/Al (D) and glass (C) substrates. But on the CoZrNb underlayer, the noise is almost as small as the background noise on the glass substrates (A), however on the NiP/Al substrate (B), large spike noises are observed at 2 positions (①, ②) per revolution. These spike noises are generated where the easy axis direction of the CoZrNb underlayer changes as seen in Fig.1. These noise envelopes are also observable on the disks having only an underlayer film. But in the noise spectra in the MHz range, no recording medium noise has been observed on these disks of only underlayers. These results are considered that the noise at a low frequency as seen in the envelope (Fig.5) is generated directly from the underlayer where large magnetic domains exist, and the noise at a higher frequency as seen in the spectra (Fig.4) is caused by an interaction between the underlayer and the recording layer in a small region [5].

Table 4. R/W characteristics of four disks

Disk sample	A	B	C	D
Underlayer(0.5 μ m)	CoZrNb		PERMALLOY	
Substrate	GLASS	NiP/Al	GLASS	NiP/Al
Recording layer	CoCrTa 0.075 μ m			
$H_{c\perp}$ (kOe)	2.2	1.8	2.3	1.9
$\Delta\theta_{50}$ (deg.)	2.7	3.3*	≥ 8	
S/N(dB)	37.0	34.1	29.9	26.6
E_p (nVpp/ μ m $\cdot$ t $\cdot$ m/s)	80	59	83	61
NOISE(μ Vrms)	0.62	0.67	1.70	1.54
D50(kFCI)	43	41	42	40

*circumferential value.

10° in the radial direction by texturing.

Fig. 4 Noise spectra of Sample A and C

A : CoCrTa / CoZrNb
C : CoCrTa / Permalloy

Fig. 5 DC erased noise envelopes of four disks

Examination extends further into the effect of crystal orientation of recording layer of noise and other R/W characteristics in the CoCrTa/CoZrNb disks. Fig. 6 shows a dependence of noise voltage and M.M.F. on $\Delta\theta_{50}$, where M.M.F. means a magneto motive force when the maximum SNR is obtained. $\Delta\theta_{50}$ changed as the function of the interval time T as mentioned before. With the higher crystal orientation, M.M.F. becomes low and recording sensitivity is improved. This indicates that the saturation recording is performed at a small magneto motive force because of a high perpendicular magnetic anisotropy caused by the high crystal orientation. And when the crystal orientation becomes disordered, higher noise voltage is observed. This high noise level can be reduced not by a DC erasure but by an AC erasure. And after the AC erasure, the noise voltage has not increased at all. It suggests that this noise of the disk with a large distribution of the crystal orientation causes the residual magnetization in the plane of the recording layer having a strong anisotropy in the direction of plane. However, noise voltage after the AC erasure is low enough

Fig. 6 Dependence of the recording sensitivity (M.M.F.) and noise voltage on the crystal orientation of CoCrTa ($\Delta\theta_{50}$)

independent of the $\Delta\theta_{50}$. Other R/W characteristics such as readback voltage, D50 and SNR are also independent of the $\Delta\theta_{50}$ after the AC erasure.

In R/W with a ring type head, high crystal orientation of recording layer is considered to be very significant [3,13]. But $\Delta\theta_{50}$ is less influential on R/W characteristics with a single pole head, except the recording sensitivity. Crystal orientation may be more effective for higher recording density.

After all, the highest SNR has been obtained on the CoCrTa/CoZrNb disk with a glass substrate of which the medium noise is mainly reduced by the radially uniform easy axis of CoZrNb underlayer, not by the high crystal orientation of CoCrTa recording layer.

CONCLUSIONS

We have studied CoCrTa/CoZrNb perpendicular magnetic recording hard disks. CoZrNb underlayer with a uniform magnetic easy axis in the radial direction is obtained by sputtering deposition on the glass substrate in the magnetic field oriented radially. And the CoCrTa recording layer with high crystal orientation ($\Delta\theta_{50} \leq 3^\circ$) is obtained by sputtering deposition on the fresh surface of CoZrNb underlayer. After all, remarkable noise reduction and a high SNR have been obtained with the CoZrNb underlayer on the glass substrate compared with the permalloy underlayer. This noise reduction is mainly due to the radially uniform magnetic easy axis of CoZrNb underlayer, not to the high crystal orientation of CoCrTa recording layer.

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