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MICROSTRUCTURE AND NOISE CHARACTERISTICS IN Co-Cr BASED ALLOY THIN FILM MAGNETIC RECORDING MEDIA

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ABSTRACT- Reducing media noise is a key to realizing high areal recording density. However, perpendicularly oriented Co-Cr films, strong candidates for high density recording media, have received little attention in terms of recording noise. We studied the noise characteristics of Co-Cr based alloy films by varying the compositionally separated structure.

Co-Cr films with fine compositionally separated microstructure were observed to have low noise , which recording density dependence were negative or week. Studies on control of the microstructure and magnetic properties in combination with noise analysis are important to realize high density recording media.

I .INTRODUCTION

To achieve high density magnetic recording, thin film media with high output, high resolution, and low noise are needed. Many materials have been examined as candidates for such media. These candidates must have high coercivity and proper saturation magnetization. Furthermore, their magnetic characteristics, wear resistance, and surface flatness must be controllable.

The thin-film media first developed in 1982 were sputtered gamma ferrous oxide and plated Ni-Co-P films, which were applied to commercial 8-inch 400-MB packaged air-tight tiny (nicknamed PATTY)[1] disk storage. In these media the noise increased proportionally with the recording density, which was significantly different from particulate media.

Further studies aimed at developing low noise media made it clear that a magnetic structure consisting of small grains was needed[2] to reduce media noise. It was also revealed that noise can be reduced by decreasing magnetic interaction[3].

Co-Cr based recording media are believed to be ultimately capable of high density recording, but deeper study of the signal-to-noise ratio (SNR), reliability, and so on, is needed before a hard disk drive system can be constructed. Perpendicular recording media has received little study in terms of media noise.

Recent microstructure studies have revealed that compositional separation (CS)[4] into ferromagnetic and nonmagnetic components occurs within crystal grains of Co-Cr-based alloy films in both longitudinal and perpendicular recording media. If such features can be used as fundamental magnetic elements, media noise should be reduced.

In this paper, the noise characteristics of various Co-Cr based-film media are investigated by varying compositionally separated microstructure. A conventional NiCoP plated medium was used as a reference.

II .COMPOSITIONAL SEPARATION

Studies on CS were initiated by the discovery of a chrysanthemum-like pattern (CP) structure (Fig.1(a)) which was revealed by chemical etching of a Co-Cr film deposited at an elevated substrate temperature (Ts)[5]. In this structure the fine white stripes were thought to correspond to preferentially dissolved Co-enriched areas while the dark regions were thought to correspond to passivated Cr-enriched areas[6]. This stripe pattern suggested the existence of a regular compositional modulation within each grain having a periodicity of between 8 and 10 nm. Using a combination of thermo-magnetic analysis[7], nuclear magnetic resonance (NMR)[8], and atom probe field ion microscopy (APFIM)[9], it was subsequently confirmed that CS into distinct Co-enriched and Cr-enriched components did indeed occur in Co-Cr films deposited between 100 °C and 400 °C.

In particular, APFIM showed that in a Co-22at.%Cr film deposited at a Ts of 200 °C, the Cr content fluctuated periodically between 5-7 at.% Cr and 30-35 at.% Cr (bulk Co-Cr alloy becomes nonmagnetic at a Cr contents greater than 25 at.%) across a single grain with a repeat spacing of about 6-12 nm. Furthermore, a recent small angle neutron scattering (SANS) study[10] revealed the existence of a periodic fluctuation in the saturation magnetization with a repeat distance similar to that of the compositional variation. Since the compositional and magnetic periodicity detected using APFIM and SANS are both similar to the spacing of the (bright) Co-enriched stripes of the CP structure, it was predicted that CS structure could be used to develop a particulate-type magnetic microstructure having magnetically isolated regions with dimensions smaller than the grain diameter.

Although drastic CS has been observed to occur in various Co-Cr-based alloy thin film media used for both perpendicular and longitudinal recording[11-15], the role of CS in determining recording characteristics has still not been clarified. This relationship between CS structure and recording characteristics requires further investigation.

Ⅲ.SAMPLE PREPARATION

The grain size control may yield suitable CS structure and its dispersion state by selecting sputtering method and deposition conditions.

To prepare a wide variety of magnetic properties and CS structures, we used both conventional RF sputtering and electron cyclotron resonance (ECR) plasma sputtering.

ECR sputtering was recently developed by NTT. The advantage of this method is low gas pressure sputtering combined with low energy / large current ion assistance which enhances surface diffusion of sputtered atoms and stimulates surface reactions [16,17]. Recent studies on ECR sputtering have revealed that this method simultaneously improves the magnetic properties and refines the CS structure[18].

Table 1 lists the characteristics of the samples. Sample No.1 is the medium used in the GEMMY disk[19] which achieved 1250 TPI and 32 KBPI in 1986. To compare these media, the signal and noise of the trial manufactured media were evaluated. Sample No.2 is the longitudinally oriented Co83Cr12Ta5/Cr film ,which is similar to recent disk media.

Samples No.3 to No.5 have the same film composition but their magnetic characteristics and micro-structure were controlled by changing the sputtering conditions. The target was a Co-22 at.% Cr alloy. The nominal Ar gas pressure was $1x10^{-3}$ Torr for RF-sputtering and $6x10^{-4}$ Torr for ECR sputtering. The magnetic films were prepared on non-textured glass disk substrates, except for the plated NiCoP sample used as a reference for reading and writing.

To stabilize the read/write head operation, a layer of PFPE lubricant a few nanometers thick was applied by dipping and curing at 220°C. The magnetic characteristics were measured with a vibrating sample magnetometer (VSM) and NMR.

For sample No.3, a chromium under-layer was deposited before sputtering the magnetic Co-Cr film to obtain an in-plane orientation of the crystallographic c-axis. Sample No.4 shows good perpendicular orientation and has a large CS structure with a Cr-enriched cores in the grain. On the contrary, sample No.5 shows a very fine CS structure.

Figure 1 shows the surface morphology of an RF-sputtered perpendicular (a: No.4), an ECR-sputtered

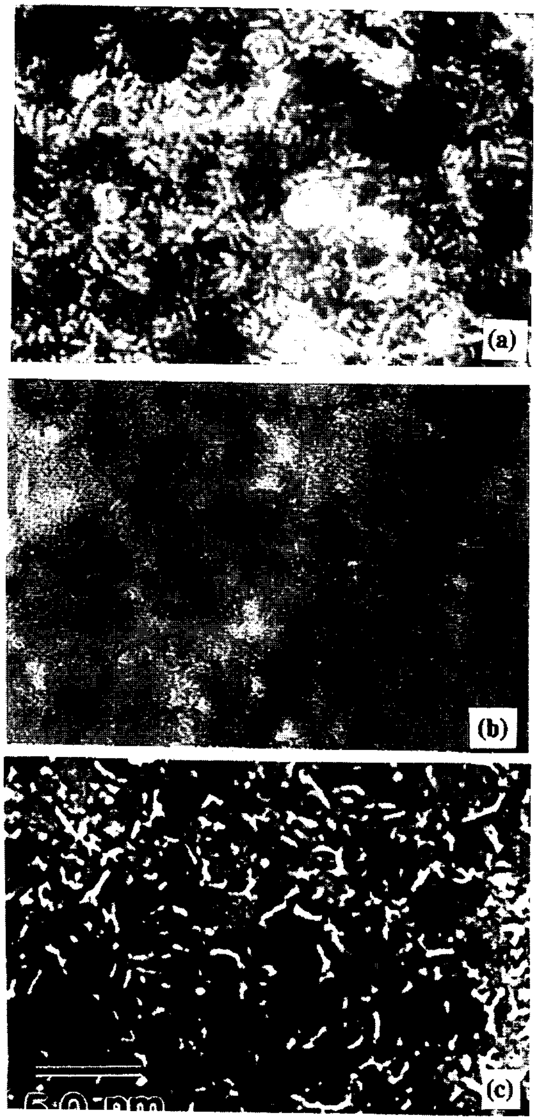

Fig. 1 Surface morphology of chemically etched microstructures on Co-Cr films .
(a)perpendicularly-oriented film deposited by RF sputtering (No.4)
(b)perpendicularly-oriented film deposited by ECR sputtering (No.5)
(c)Longitudinally-oriented film (No.3)

Table 1

Sample	Composition	Thickness	P/L	Hc(Oe)	Hk(kOe)	CS	Cr core
No. 1	NiCoP	60 nm	L	620			
No. 2	CoCrTa	60 nm	L	1080	--	Fine	No
No. 3	Co-Cr	60 nm	L	380	--	Fine	No
No. 4	Co-Cr	300 nm	P	1000	5.0	Large	Yes
No. 5	Co-Cr	50 nm	P	1090	4.5	Fine	No

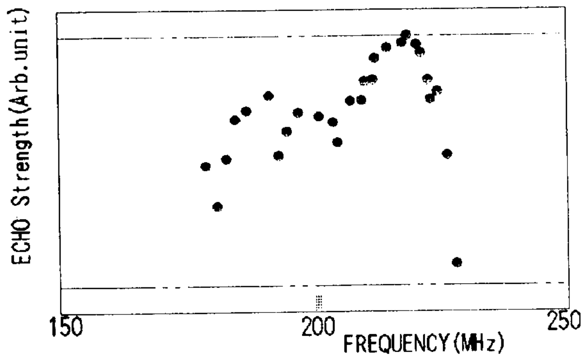

Fig. 2 NMR spectrum of longitudinal Co-Cr films (No.3).

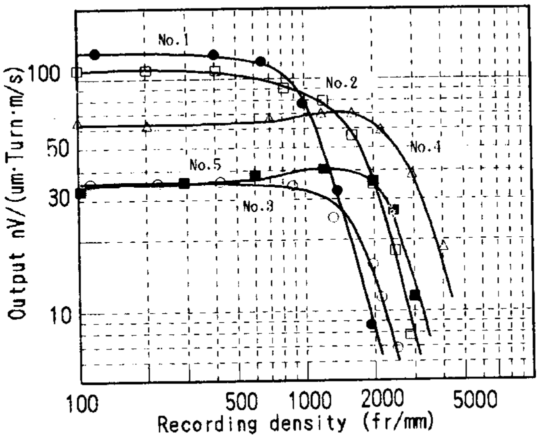

Fig. 3 Recording characteristics of samples

Fig. 4 Reproduced waveform of sampleNo.5

perpendicular (b: No.5), and an RF-sputtered longitudinal Co-Cr film(c: No.3) after selective etching. In these TEM photos, a fine CP structure is observed in every film. The ECR-sputtered perpendicular film have the finest microstructure.

Previous studies [20] indicates that the compositionally separated microstructures are influenced by the grain size. Even in the case of longitudinally-oriented Co-Cr films, the occurrence of CS was confirmed using NMR. As shown in Fig. 2 (sample No.3), main peak at 218 MHz indicates the existence of Co-enriched components (about 95 at.% Co) and suggests that strong CS occurred.

Ⅳ.RECORDING CHARACTERISTICS

In this study, we evaluated media noise by comparing actual disk media using a conventional ring-type flying head. To compare both longitudinal and perpendicular media with the same head, single-layer perpendicularly oriented films (No.4 and No.5) were prepared. The single-layer perpendicular media with ring head recording is not sufficient to evaluate perpendicular recording characteristics, but this arrangement is convenient for directly comparing media noise.

In the experiment, a metal-in-gap (MIG) type head with a 0.4 μm gap and a low noise preamplifier (0.5 $nV/Hz^{1/2}$) were used. The flying height of the head was set to about 0.07 μm. The recording current for each sample was controlled to obtain residual over-write noise of less than -30 dB.

Figure 3 shows the recording characteristics for the five samples. Sample No. 2, a high coercive force longitudinal thin medium, shows a relatively high maximum recording density and a slightly low output at low density. Sample No.3, a longitudinally oriented Co-Cr medium, also shows high recording density but output that is only 1/3 that of sample No. 1. The perpendicular media (No.4 and 5) can be recorded at high density, though their output at low density was low compared to sample No.1 (from 1/2 for the thicker sample No.4 to 1/3 for the thinner sample No.5). Samples No.4 and No.5 show a peculiar tendency in their recording density characteristics. There is a slight rise in their output during high density recording just before output drops sharply. As shown in Fig. 4, the isolated reproduced waveform of No.5 has a distinctive under-shoot, even though the film is very thin, which means that this medium is affected by a large perpendicular demagnetization field.

The waveform of a thin, low Hk medium with a similar micro-structure (made by conventional method), however, shows a relatively low recording density and a symmetrical waveform which looks like that of the longitudinal media (No.1,2 and 3). This suggests that both fine CS structure and high Hk are necessary in thin perpendicular recording films.

Ⅴ.NOISE CHARACTERISTICS

Total noise was calculated by integrating the frequency range corresponding to the recording density from 40 fr/mm to 4000 fr/mm. The media recording noise was calculated by automatically

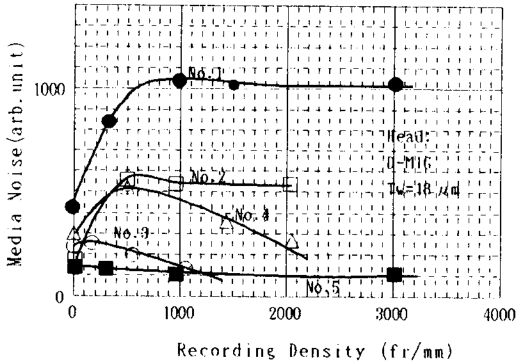

Fig. 5 Recording density dependency of media noise

interpolating the noise level after eliminating the signal components.

Figure 5 shows the recording density dependence of wide-band noise. Conventional longitudinal film media (No.1 and 2) show a proportional increase at low densities, while the longitudinally oriented Co-Cr/Cr medium (No.3) shows low noise and tends to have a negative recording density dependence. The perpendicularly oriented films (No.4 and 5) also show low noise which has a negative or weak dependence on the recording density.

Regarding the noise level, the thinner perpendicular medium (No.5) exhibits very low noise. The noise of sample No.5 at high density is only 1/16 that of the longitudinal medium (No.1) or 1/6 that of the CoCrTa longitudinal medium (No.2).

The output of sample No.5 is not high, but it might be enhanced by constructing a dual-layer medium by depositing this thin Co-Cr film as a magnetic layer on a soft magnetic layer.

Noise is not low in the thick perpendicular media (No. 4), though its output is twice that of the thinner one (No.5), and its recording density is the highest in this study. The dependence of noise on the recording density of sample No.4 is positive at low density, but becomes negative at high densities.

The noise of a thin, low Hk medium with a similar microstructure shows relatively high and slightly positive recording density dependence.

VI.DISCUSSION

The noise dependence on recording density is believed to be related to magnetic interaction[21]. If the interaction is negative and noise originates from magnetic defects in the film, the dependence of the noise on the recording density should be negative as is well known in particulate media.[22]

Media magnetic interaction can be evaluated from the delta M measurements by using a VSM. However, because of the demagnetization field, measuring delta M for perpendicularly oriented media is difficult in practice.

The delta M of the low-noise, longitudinal media (No.3) showed a clear negative component as shown in Fig. 6. This curve suggests that the film consisted of both negative and positive magnetic interaction parts. Based on our analysis of the noise source of a particulate media[22] and results from both the delta M and the NMR measurements, isolated areas consisting a Co -enriched component seems to ferromagnetic in the quasi-homogeneous film.

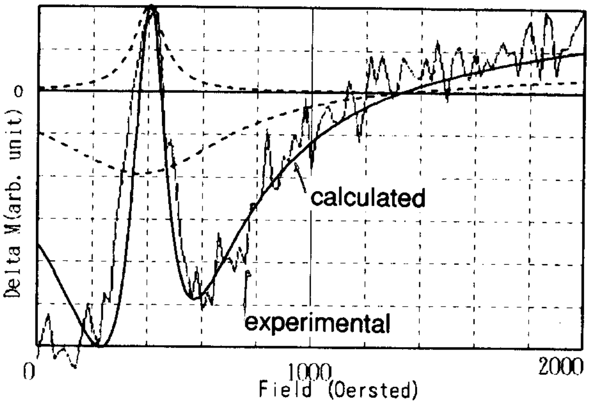

Fig. 6 Delta M characteristics No.3 and calculated curve using a mixture model.

We were not able to measure the delta M of the perpendicularly oriented media, but it should be similar for the longitudinally oriented media since the noise characteristics and CS structure are similar.

Sample No.4 shows a large CS microstructure with Cr-enriched cores as shown in Fig.1(a). This structure suggests that this sample consisted of large magnetic elements which generate a large amount of noise. Thicker Co-Cr films can be used to increase Hk, but this also enlarges the CS structure. These results indicate that thin, well-oriented perpendicular media are necessary for perpendicular recording.

From the view point of noise spectrum, specific length of the microstructure is too short. It is confirmed that the noise observed through read/write experiments represents the degree of the statistical fluctuation in the distribution of magnetic elements like as particles and grains. While noise evaluation through read/write experiments is troublesome in a research phase, measurement of demagnetized perpendicular films by magnetic force microscopy (MFM) can easily show micro-magnetic fluctuations[23].

To detect the residual magnetization of the sample, large bit areas can be recorded by the point-magneto-recording (PMR) technique[25]. Figure 7 shows an example of a measured sample. Since MFM measurement does not require a wide smooth lubricated surface, because of the limitation of spatial resolution, long-term fluctuations caused by magneto-static interaction are revealed as large modulations in the signal[24]. MFM measurements cannot reveal the exact micro-magnetic structure, but it can be used to

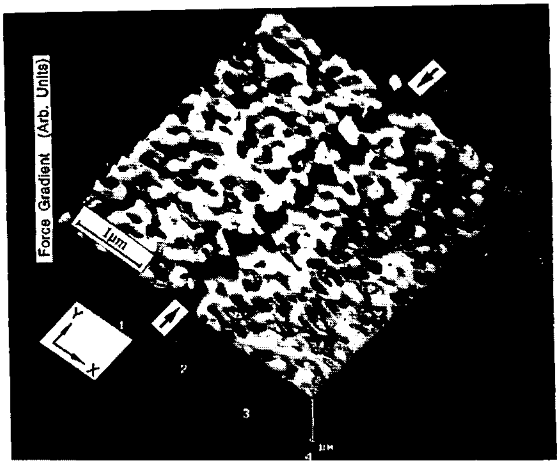

Fig. 7 Example of surface magnetic morphology near the PMR recorded bits

evaluate the magnitude of fluctuations by comparing the amplitudes. This new technique should advance the research on low noise media.

VII.CONCLUSIONS

To probe the way to achieve low noise media, the influence of CS micro-structure on recording noise was studied .

The experimental results show that the thin perpendicular medium (No.5) produces 1/3 the output, less than 1/15 the noise, and over three times the recording density of the longitudinal medium of sample No.1. As is well known, the media SNR corresponds to the square root of the track width, so this medium allows more than 25 times the track density. This evidence suggests that single layered perpendicular media have the potential to achieve forty times the areal density of a GEMMY disk. Greater output and recording density can be obtained with a dual layered perpendicular medium and a compatible perpendicular recording head. An optimistic estimate of the possible areal density attainable using a thin perpendicular medium such as a Co-Cr perpendicular media, is in the range of ten gigabits per square inch.

The Co-Cr thin-film recording media exhibit the compositional separation phenomenon, but the effect is not simple. Noise is not low in the thick perpendicular media (No. 4), even though drastic CS was observable. The dependence of noise on the recording density of the sample No.4 is positive at low density, but becomes negative at high densities. The CS structure in a longitudinal Co-Cr film (No.3) and a perpendicular film deposited by ECR-sputtering (No.5) is finer than that of perpendicular thick Co-Cr film (No.4). Even if the CS structure is confirmed, neither the noise level nor its recording density dependence is defined. For high density recording, both a fine CS structure and a high Hk are thought to be necessary.

In general, it is difficult to achieve good perpendicular magnetic orientation in thin films, and thicker films have a relatively rough surface morphology that prevents low head flying heights. Changing the sputtering conditions by using ECR-sputtering may achieve smaller and clearer CS structures that have lower noise and less recording-density-dependent noise characteristics. This may be because the highly compositionally separated Co-Cr film acts as a fine magnetic particulate media.

Other types of media, such as granular films and multi-layer films, should also be considered candidates for high density recording. Our approach, by establishing a method to control CS, means that fine CS films are also candidates.

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