

# Structural Control Method for Perpendicular Magnetic Recording Film

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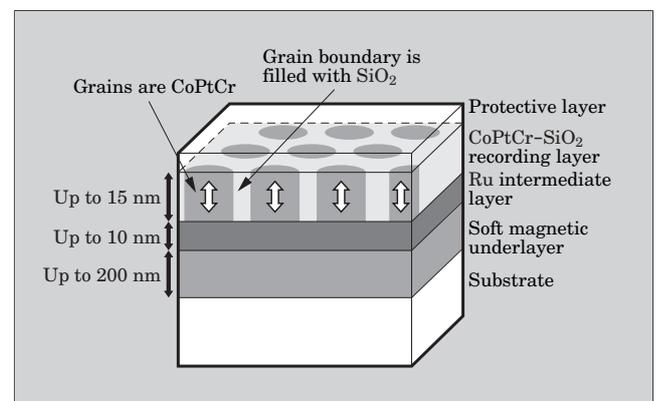
## 1. Introduction

The recording density for HDDs (hard disk drives) has rapidly increased at a rate of 60 to 100 % per year since 1997. The rate of increase is slowing down nowadays, but is still expected to continue at about 30 to 60 % per year in the future. As a result of this significant advancement, the method of longitudinal recording is approaching its application limits due to the phenomenon of “thermal fluctuation” in which recorded bits become unable to retain their stability. With the longitudinal recording method, as higher recording density increases, thermal fluctuation becomes larger. As a consequence, the perpendicular recording method, which has opposite characteristics to those of the longitudinal recording method, i.e. its recorded bits become more stable at higher recording densities, has been developed actively.

There have been many studies of the perpendicular recording method since it was first proposed by Iwasaki et al. in 1975<sup>(1)</sup>. Even though the perpendicular recording method had obvious advantages in principle, only recently has a perpendicular medium demonstrating higher performance than a longitudinal medium been obtained. The application of CoPtCrO<sup>(2)</sup> or CoPtCr-SiO<sub>2</sub> to a recording layer provided the necessary breakthrough. These types of media realize enhanced grain segregation due to oxide materials that easily precipitate at the grain boundary. We have previously reported that good read-write performance and high thermal stability resulting from relatively large uniaxial anisotropy constants and a well-isolated microstructure can be obtained by using CoPtCr-SiO<sub>2</sub> as the recording layer instead of a conventional CoCr-based alloy, alluding to the great potential for high-density recording in the future<sup>(3)</sup>. Figure 1 shows a schematic diagram of Fuji Electric perpendicular recording medium in which CoPtCr-SiO<sub>2</sub> and Ru are typically utilized as a recording layer and an intermediate layer, respectively.

Generally speaking, magnetically separated, uniform and fine grains for a recording layer must be made in order to obtain an excellent performance medium. To realize the above conditions, in addition

Fig.1 Schematic diagram of Fuji Electric's perpendicular recording medium



to controlling the material and deposition conditions of the recording layer, the structural control of intermediate layers is also known to be an important factor. Structural and magnetic characteristics of CoPtCr-SiO<sub>2</sub> recording layers are also strongly affected by the grain size and the surface structure of intermediate layers.

In this paper, we report on the characteristics of CoPtCr-SiO<sub>2</sub> media, and in particular, focus on the effect of the grain size and surface structure of Ru intermediate layers on the size and magnetic separation of grains in recording layers.

## 2. Control of the Grain Size in a Recording Layer

A finer grain of the recording layer does not necessarily contribute to further improvement of the read-write performance of media. Especially for granular magnetic layers with added SiO<sub>2</sub>, grains tend to become too fine, which leads to the degradation of thermal stability, and in the worst case, to loss of magnetism at room temperature. Therefore, control of the grain size of Ru intermediate layers is important, as this determines the microstructure of the recording layer. An example is described below.

Figure 2 shows planar TEM (transmission electron microscopy) images of CoPtCr-SiO<sub>2</sub> magnetic layers for which the average grain sizes of Ru intermediate

Fig.2 Planar TEM images of the CoPtCr-SiO<sub>2</sub> magnetic layers. Ru grain sizes are (a) 9.9 nm and (b) 12.4 nm

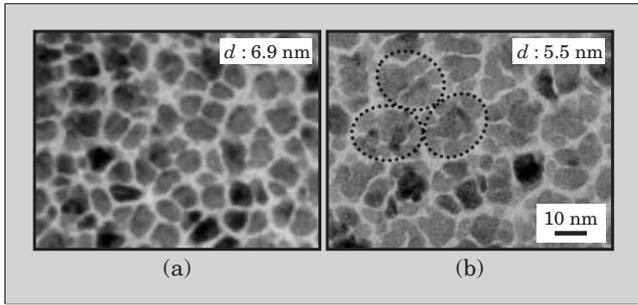


Table 1 Magnetic characteristics and read-write performance of samples (a) and (b)

Media	$H_c$ (kOe)	R/W performance at 370 kfcf		Decay at 30 kfcf (%/decade)
		Normalized media noise	SN <sub>mR</sub> (dB)	
(a)	6.39	52.9	12.4	1.5
(b)	4.98	90.8	8.98	0.5

layers are (a) 9.9 nm and (b) 12.4 nm, respectively. For the samples shown in Fig. 2, average CoPtCr grain sizes are (a) 6.9 nm and (b) 5.5 nm, respectively. It is interesting to note that the CoPtCr grain size of sample (b) is smaller than that of sample (a) despite its larger Ru grain size. We believe this is because grains in granular magnetic layers with added SiO<sub>2</sub> have a tendency to become too fine, and if the size of Ru grains exceed a particular threshold, multiple CoPtCr grains will grow on a single Ru grain. Dotted lines representing the size of Ru grains are shown in Fig. 2. It can be seen that multiple CoPtCr grains exist in each region surrounded by a dotted line. In contrast, CoPtCr grain growth achieves a one-to-one correspondence with Ru grains in sample (a). Table 1 shows the magnetic characteristics and read-write performance of samples (a) and (b). As shown in the table, sample (b) has poorer coercivity ( $H_c$ ), medium noise and SNR (signal-to-noise ratio) than sample (a), regardless of the fact that the CoPtCr grain size of sample (b) is smaller than that of sample (a). However, the decay (degradation rate of output signal) of sample (b) is smaller than that of sample (a), i.e. sample (b) is thermally more stable than sample (a). Judging from these results, it is believed that the magnetic reversal unit of sample (b) is larger than that of sample (a), i.e. grains of sample (b) are more strongly coupled than those of sample (a), despite the smaller CoPtCr grain size of sample (b). On the other hand, sample (a) has looser intergranular magnetic interaction despite its larger CoPtCr grain size.

As described above, control of the Ru grain size is important for realizing a one-to-one correspondence in the growth of Ru and CoPtCr grains, which leads to the control of CoPtCr grain size and reduction of intergranular magnetic interaction.

### 3. Control of Magnetic Cluster Size

#### 3.1 Magnetic cluster size

It is known that magnetization reversal of a recording medium occurs in units of magnetically coupled grains rather than on a per-grain basis. Intergranular magnetic interaction is thought to generate such granular units, which are called magnetic clusters. Magnetic cluster size ( $D_{cluster}$ ) can be measured using magnetic force microscopy (MFM), and it is also known that  $D_{cluster}$  calculated from a MFM image is useful to analyze the origin of media noise<sup>(4)</sup>. For example, it has been reported that media noise in longitudinal media increases with increasing saturation magnetization of the recording layer even in the absence of exchange coupling because the increase of  $D_{cluster}$  due to the magnetostatic interaction enhances the zigzag transition<sup>(5)</sup>. Transition noise is also reported to be the dominant source of noise in perpendicular media<sup>(6)</sup>. Accordingly, it is necessary for both longitudinal media and perpendicular media to reduce the zigzag transition, i.e. reduce  $D_{cluster}$ , in order to reduce media noise.

#### 3.2 Evaluation of $D_{cluster}$

As stated above, MFM and image processing techniques are often used for the evaluation of  $D_{cluster}$ . We also have previously used that method and obtained the result that reducing  $D_{cluster}$  is an effective means to increase both bit and track densities<sup>(7)</sup>. Here we are concerned with another evaluation method in which  $D_{cluster}$  is estimated using the  $M-H$  loop slope parameter  $\alpha$  ( $=dM/dH|_{H=H_c}$ )<sup>(8)</sup>. For a perpendicular magnetic film, it is known that when perpendicular magnetic columns with no exchange interaction rotate coherently,  $\alpha$  can be computed from the demagnetization factor (using cgs units) as:

$$\alpha = 4\pi / (N_z^f - N_z) \dots\dots\dots (1)$$

where  $N_z^f$  is the perpendicular-to-film directional demagnetization factor of the film, and  $N_z$  is that of the magnetization reversal unit. The demagnetization factor is a constant and is only dependent on the shape of the magnet. For example, the demagnetization factor equals 0 if the shape of the magnet is an infinitely long fine wire in the magnetization direction, and equals  $4\pi$  if the shape of the magnet is an infinitely large thin sheet. For the recording layer of perpendicular media,  $N_z^f$  of equation (1) can be considered to be  $4\pi$  because the film thickness is very thin compared to the dimensions of the film surface. Then,  $N_z$  can be obtained by determining  $\alpha$ , and  $D_{cluster}$  can be calculated according to the film thickness and  $N_z$  assuming that the magnetic clusters have cylindrical shapes of which demagnetization factors have been experimentally obtained as a function of the major-to-minor axis ratio. Based on that same assumption, an  $\alpha$ -film thickness curve can be calculated to give a

Fig.3 Planar TEM images of samples using processes A and B for the deposition of Ru intermediate layers

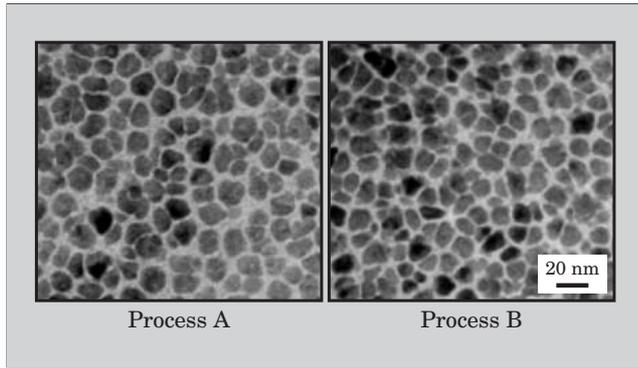


Table 2 Magnetic properties and read-write performance for process A and B media

Process	$K_u$ (erg/cm <sup>3</sup> )	$H_c$ (kOe)	R/W performance at 300 kfci	
			Normalized media noise	SN <sub>m</sub> R (dB)
A	$3.55 \times 10^6$	2.09	47.5	12.6
B	$3.21 \times 10^6$	2.04	29.6	17.3

certain  $D_{cluster}$  value.

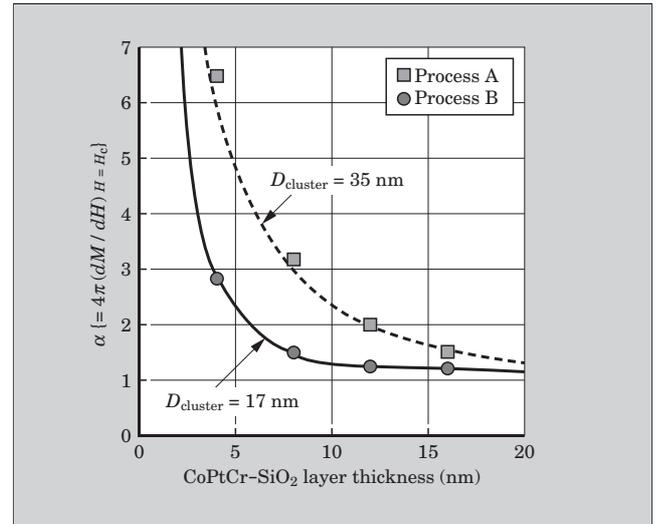
In the experiments,  $\alpha$ -film thickness curves calculated from certain  $D_{cluster}$  values were fitted to measured  $\alpha$  values of different recording layer thicknesses, and  $D_{cluster}$  was determined from the most suitable curve.

### 3.3 Influence of the Ru deposition process

Planar TEM images of the samples using processes A and B for the deposition of Ru intermediate layers are shown in Fig. 3. Moreover, magnetic properties and read-write performance at the linear density of 300 kfci are given in Table 2. The recording layer thickness of these samples is 8 nm. Although not shown in detail, the surface structure of Ru was varied when using process A or B. There is no marked difference in appearance such as grain size or segregation state (see Fig. 3), nor in magnetic properties such as  $K_u$  or  $H_c$  (see Table 2). However, in comparing the read-write performance shown in Table 2, the process B media has 40 % less media noise and 4.7 dB higher SNR than the process A media. In this case, the read-write performance differs substantially for each sample but the reason for this cannot be ascribed to the microstructure or magnetic properties. Therefore,  $D_{cluster}$  was evaluated to examine the cause of differences in the read-write performance.

Figure 4 shows the recording layer thickness dependence of  $\alpha$ , in which circles and squares indicate experimental values. The solid and dotted lines in Fig. 4 are lines that have been fitted to experimental data using the previously described method. These lines fit closely to the experimental data, and  $D_{cluster}$  values of process A and B media are estimated to be 35

Fig.4 Recording layer thickness dependence of  $\alpha$



and 17nm, respectively. Furthermore, although the results are not shown in this paper, the  $D_{cluster}$  of process A media is found to be larger in the initial layer where the effect of the surface of the Ru intermediate layer on the recording layer is especially large.

As described above, it is found that the surface structure of the Ru intermediate layer is reflected in  $D_{cluster}$  and read-write performance. Further optimization of the depositing conditions of Ru is considered to be an effective means for decreasing  $D_{cluster}$  and improving media performance.

## 4. Conclusion

A method for controlling the structure of CoPtCr-SiO<sub>2</sub> recording film was reported, focusing on the effect of the grain size and surface structure of Ru intermediate layers. Especially in the case of a larger  $D_{cluster}$  in the initial growth region of CoPtCr-SiO<sub>2</sub> that results in poorer read-write performance, it is pointed out that in addition to TEM or commonly used magnetometer based methods, a more detailed analytical method such as  $D_{cluster}$  analysis is needed to identify the cause. In perpendicular recording media, recording layer properties are affected by many factors such as surface roughness of the substrate and soft magnetic underlayer, and deposition conditions of the recording layer itself. We plan to optimize those conditions to realize perpendicular recording at high densities above 200 Gbits/in<sup>2</sup> and also to reduce costs for commercial application at the earliest feasible time.

In the near future, we expect perpendicular recording systems to be employed not only in computers, but also in audio-visual applications, which require compact size and large capacity.

## References

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