

# Development of Perpendicular Magnetic Recording Media

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## 1. Introduction

Hard disk drives (HDDs), first used in practical applications in 1956, have recently been undergoing rapid increases in their areal densities at annual rates of 60 to 100 %, and the rate of increase is expected to continue at an annual rate of approximately 30 % in the future. As a result of such remarkable growth, the longitudinal magnetic record method, which has been used so far, is approaching its areal density limit due to the tradeoff between low noise performance and thermal stability. Thermal instability is a phenomenon in which the thermal energy at room temperature causes prerecorded magnetic bits to invert, and thus signal stability cannot be maintained. With the longitudinal magnetic record method, thermal instability increases as areal density is increased.

The method of perpendicular magnetic recording method was proposed in 1975 by Iwasaki<sup>(1)</sup> et al. Having characteristics that are opposite those of the longitudinal magnetic record method, perpendicular magnetic recording becomes more resistant to thermal instability as the areal density increases. Because the principles of perpendicular magnetic recording are well suited to higher areal density, many trials relating to magnetic recording media and magnetic recording heads have been conducted, and in the Spring of 2005 an HDD that uses perpendicular magnetic recording method was finally introduced to the market.

Having begun developing perpendicular magnetic recording media in 1999, Fuji Electric has focused on

practical application of a magnetic recording layer that successfully overcomes the technical challenge of simultaneously realizing low-noise, high thermal stability and good overwrite performance, and on practical application of the soft magnetic underlayer for which improved manufacturability is needed. Figure 1 shows a schematic image of the perpendicular magnetic recording media developed by Fuji Electric. The use of a Co-based amorphous alloy film as the soft underlayer (SUL) and CoPtCr-SiO<sub>2</sub> as a granular type magnetic recording layer provides the perpendicular magnetic recording media with good performance, and the film thickness of each layer of the perpendicular magnetic recording media is relatively thin.

Fuji Electric is aiming to begin mass production of its first perpendicular magnetic recording media, and is making preparations for mass production.

This paper describes the development status of perpendicular magnetic recording media at Fuji Electric, including the effect of a texturing process on the soft underlayer, optimization of the soft underlayer, structural control of perpendicular magnetic recording media having a granular structure, and the like.

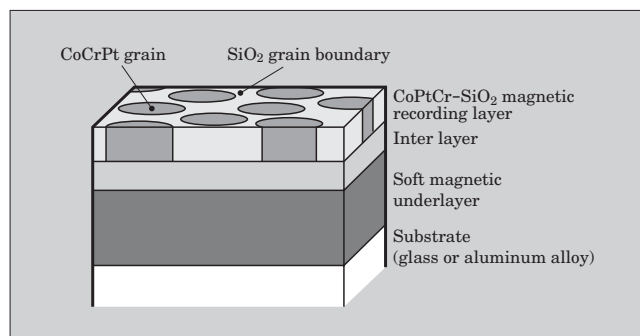
## 2. Development of the Soft Underlayer (SUL)

The SUL is a characteristic feature of perpendicular magnetic recording media. The existence of the SUL enables the head recording field to be set to approximately 1.5 times that of the longitudinal magnetic recording method, and this is very advantageous. However, spike noise, which is generated at magnetic domains of the SUL is a significant problem and must be suppressed. In consideration of manufacturability, the SUL should be made as thin as possible, and with the recent debut of shielded pole type heads, there is no need for SUL film to be as thick as in the past, and the reduction of SUL film thickness is a challenge of extreme importance for manufacturability.

### 2.1 Effect of texturing

In longitudinal magnetic recording media that uses aluminum alloy substrates, texturing is currently being performed to enhance the magnetic properties and

Fig.1 Schematic image of perpendicular media



HDI (head-disk interface) properties. In perpendicular magnetic recording media, as long as the magnetic recording head design does not change significantly from that of a conventional design, some sort of surface treatment is thought to be necessary for the HDI. Therefore, using aluminum substrates textured with various modified conditions, perpendicular magnetic recording media sputtered with those same conditions were evaluated, and the results are presented below.

Spike noise and recording performance were evaluated using a spin-stand tester and a shielded pole type head. Spike noise was evaluated for output signals after DC erasing, by computing the number of signals that exceed a threshold value of 1.2 times of the white noise level. Figure 2 shows the incidence of spike noise corresponding to the surface roughness ( $R_a$ ) of the aluminum substrates used. In cases where  $R_a$  is approximately 0.2 nm or less, the spike noise incidence is shown to remain at a low value of less than 100 spikes, but when  $R_a$  increases from 0.2 nm, the spike noise incidence is seen to increase suddenly.

Next, to verify the effect of texturing on the R/W (Read/Write) performance, a signal is written with areal density of 150 kfc (fci: flux change per inch), and then an OTP (off-track profile: track profile of a signal which is measured by shifting the magnetic head from side to side centering around the signal writing point with 10 nm pitch.) measurement is taken, and the output voltage at a distance of 230 nm from the center of the signal is computed and is defined as the height at the edge of the OTP. The relationship between the OTP edge height and  $R_a$  is shown in Fig. 3. The figure shows examples of OTPs of media having large and small edge heights. Similar to the case of spike noise, if  $R_a$  is smaller than 0.2 nm, the edge height remains at a low voltage of approximately 0.01 mV. However, if  $R_a$  becomes greater than 0.2 nm, the edge height increases rapidly and the OTP has a step-like shape at its left and right sides, and the signal spreads out horizontally.

To investigate these causes, the magnetic anisotropy of each media's SUL was examined. The results

showed that when  $R_a$  increases, the orientation of SUL magnetic anisotropy changes from the radial direction required for perpendicular magnetic recording media to the circumferential direction along a textured groove. Accordingly, from the perspective of the control of SUL anisotropy, the  $R_a$  of the substrate is preferably small. However, even when  $R_a$  is small, some substrates exhibited poor performance, and conversely, when  $R_a$  is large, some substrates exhibited good performance, and therefore, rather than sole dependence on  $R_a$ , the density, profile and direction of texturing are surmised to also exert influence on these performance.

On the other hand, an improved polishing technique enables  $R_a$  to be controlled and surface defects to be reduced in perpendicular magnetic recording media having a glass substrate, without the use of a texturing process. The first generation of perpendicular magnetic recording media to be mass-produced will be made without a texturing process.

Using an aluminum substrate as an example, the effect of texture shape on magnetic characteristics and R/W performance was studied, and the results are presented below. Previously, it has been reported that the increase in c-axis distribution of CoPtCr grains that accompanies an increase in  $R_a$  caused a decrease in coercivity  $H_c$ . However, according to the results of this study, the value of  $H_c$  is approximately constant relative to  $R_a$ . Additionally, the signal-to-noise ratio (SNR), which is one of the R/W performance evaluated, also exhibits an approximately constant value relative to  $R_a$ . We surmise that these tendencies are caused by a value of  $R_a$  that was smaller in this study than in prior reports, and by the selection of processing conditions that made it difficult for the effect of texturing to become noticeable in the SUL.

The dependency of the byte error rate (ByER), an important parameter for HDD performance, on  $R_a$  is shown in Fig. 4. The value of  $\log(\text{ByER})$  remains approximately constant at  $-2.5$  while  $R_a$  is greater than approximately 0.15 nm. However, for values of  $R_a$  less than 0.15 nm, ByER is observed to increase

Fig.2 Spike noise dependency on surface roughness ( $R_a$ )

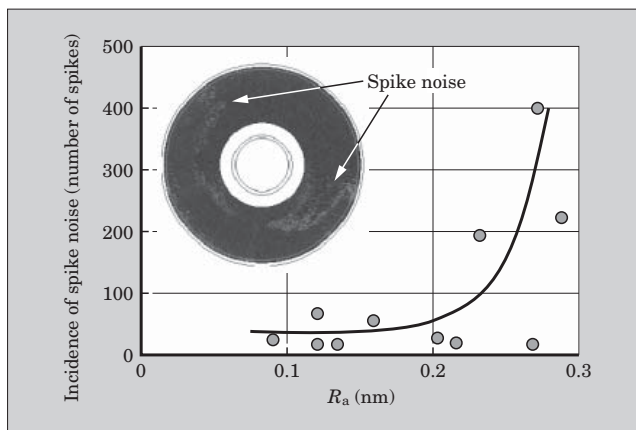


Fig.3 OTP edge height dependency on surface roughness ( $R_a$ )

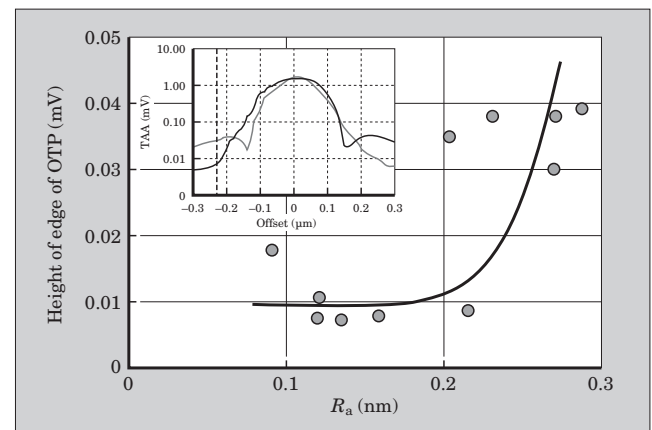
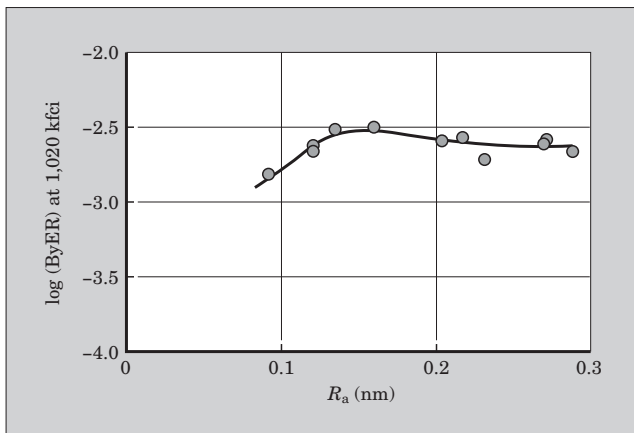


Fig.4 ByER dependency on surface roughness ( $R_a$ )



monotonously. Since  $H_c$  and the SNR exhibit approximately constant values relative to  $R_a$ , it is thought that modification of the  $R_a$  value of a magnetic recording layer will not result in any structural or other changes. Thus, the cause of the increase in ByER for values of  $R_a$  less than 0.15 nm is, as described above, surmised to be due to the decrease in spike noise that accompanies a reduction in the  $R_a$  value.

Accordingly, in perpendicular magnetic recording media, because the shape of the substrate surface has a large impact on the media performance, development of the surface shape required for perpendicular magnetic recording media is being advanced with a comprehensive perspective that includes consideration of the HDI performance.

## 2.2 Thinner SUL

When the media is used in combination with a conventional single pole (or mono pole) head, the SUL must have a thickness of more than 100 nm. Presently, however, with the advent of the shielded pole type head, which is the main type of head used with perpendicular magnetic recording media, a thick SUL is no longer necessary. This effect is believed to be attributed to the action of the effective recording field at a tilted angle to the easy axis of the recording layer when a shielded pole head is used. For example, as has been reported<sup>(2)</sup> in a simulation-based study, in the case of a magnetic recording layer thickness of 15 nm and a flying height of 10 nm, an optimally efficient recording magnetic field angle of 45 degrees can be obtained when the interlayer thickness is 10 nm. However, the ability to perform highly efficient writing also means that simultaneous erasing is also easy to implement. Thus, we investigated changes in R/W performance and changes in adjacent track erasures (ATE) to study the possibility for making the SUL thinner.

Figure 5 shows the SUL thickness dependency of the SNR measured at 510 kfcf and of overwriting (O/W) a 68 kfcf signal on a 510 kfcf signal. By reducing the SUL thickness from 70 nm to 40 nm, the O/W performance decreases from -41 dB to -38.5 dB. How-

Fig.5 SNR and O/W dependency on SUL film thickness

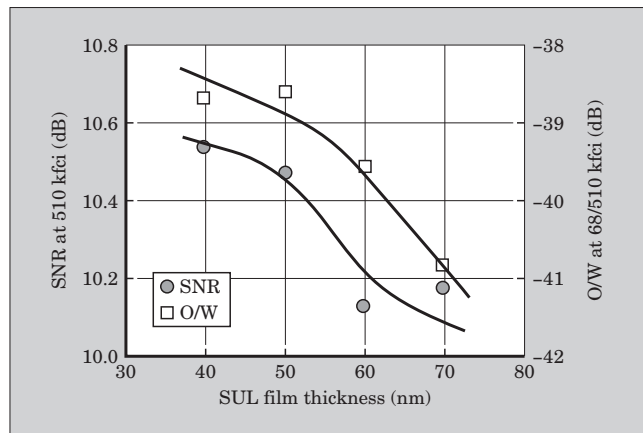
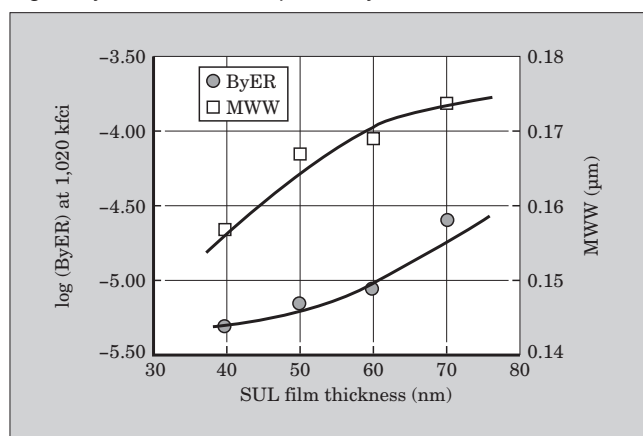


Fig.6 ByER and MWW dependency on SUL film thickness



ever, the amount of decrease is at most approximately 2.5 dB, and even with an SUL thickness of 40 nm, O/W that significantly exceeds -30 dB can be obtained, and therefore, it is thought that sufficient overwrite performance can be obtained in this SUL thickness range. Next, we consider the SNR, and although some variance does exist, it is understood that the SNR improves as the SUL thickness is reduced. Since the magnetic characteristics of the recording magnetic layer remain nearly constant regardless of the SUL thickness, the difference in SNR is presumed to be caused by the SUL.

Figure 6 shows the SUL thickness dependency of the ByER at 1,020 kfcf and of the MWW (magnetic write width). From the figure, it can be understood that the thinner the SUL, the more ByER improves and MWW becomes smaller. This result means that a thinner SUL results in a simultaneous improvement in both the bpi (bits per inch) and tpi (tracks per inch). Reduction of the noise originating in the SUL is thought to be one important factor for achieving higher densities.

Next, we studied the ATE, which is an important item for evaluation because of the existence of the SUL in the perpendicular magnetic recording media. In the ATE evaluation, a low-frequency signal was written to

multiple tracks on left and right sides of a central location, and then the level of signal output with a magnetic head was measured. Then, a high-frequency signal is written multiple times (1,000 to 10,000 times) to the central location, and again the level of signal output with a magnetic head was measured. The amount of attenuation of the signal output, before and after writing the high-frequency signal to the central location, is computed and this is the ATE value. Figure 7 shows the ATE measurement results for media with varying SUL thicknesses. As an example, the actual output waveform obtained is also shown in the same figure. Because SUL anisotropy is uncontrolled, a large drop of approximately 17 % in the ATE value is observed. In the perpendicular magnetic recording media used, the anisotropy and surface shape of the SUL are controlled, and therefore even at an SUL thickness of 60 nm, the ATE value is suppressed to a low value of approximately 7 %. As the SUL becomes thinner, the ATE decreases monotonously, and at a 40 nm SUL thickness, the ATE value is a low value of approximately 5 %. Therefore, from the perspective of ATE as well, with the sufficient O/W value, a thinner SUL is preferable.

With the head and media combination described herein, the O/W value still has some degree of leeway, and an SUL of 40 nm or less can be realized. Also, if recording is performed with a tilted writing field while using a shielded pole head, there is optimum thickness of the magnetic recording layer and interlayer for efficient recording. With these points in mind, Fuji Electric is committed to developing even higher densities media.

As has been described, Fuji Electric's perpendicular magnetic recording media is made with a thin SUL and is optimized so that even an SUL film thickness of about 50 nm will provide good performance in an HDD. This good performance results from Fuji Electric's use of a thinner non-magnetic interlayer and optimized magnetic recording layer that enable the media overall to be easily written to with a magnetic head, even if the

SUL film is thin. As a result of these efforts, and in order to improve manufacturability and lower production costs, Fuji Electric is aiming to begin mass-production.

### 3. Microstructure and Crystalline Orientation of CoPtCr-SiO<sub>2</sub> Perpendicular Media

Ahead of other companies, Fuji Electric has actively reported<sup>(3)(4)</sup> that the use of CoPtCr with an SiO<sub>2</sub> additive as the recording layer material makes it possible to realize perpendicular magnetic recording media having large uniaxial anisotropy and a well-segregated grain structure, and that the performance of the media exhibits low noise and good thermal stability. Figure 8 shows in-plane and cross-sectional lattice images of the perpendicular magnetic recording media obtained by using transmission electron microscopy (TEM). The average grain size in the CoPtCr layer is 4.5 nm, and the average grain boundary width is 2.4 nm. Also, the interlayer is known to have a crystalline grain size of 7.4 nm, and sum of the CoPtCr crystalline grain size and the grain boundary width approximately matches the crystalline grain size of the interlayer. From the cross-sectional TEM image, it can be seen that the interlayer and the CoPtCr layer grow in a 1:1 ratio, that the c-plane lattice structure is continuous from the interlayer to the CoPtCr layer, and that the CoPtCr grains are well-segregated by amorphous grain boundaries from the initial layer of the recording layer. Furthermore, the results of X-ray diffraction show that the c-axis distribution  $\Delta\theta_{50}$  is 2.5 degrees in both the interlayer and the CoPtCr layer, and that c-axis distribution is less than in conventional media.

The grain size of the perpendicular magnetic recording media shown in Fig. 8 is reduced to approximately 65 % that of conventional media. However, if the grain boundary width is included, the size compared to conventional media is reduced to only ap-

Fig.7 ATE dependency on SUL film thickness

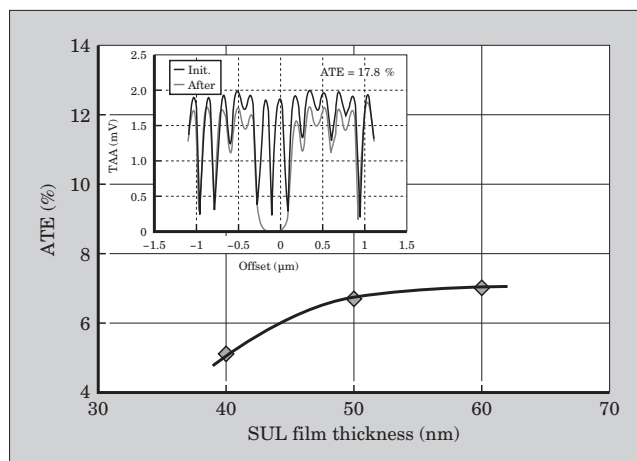
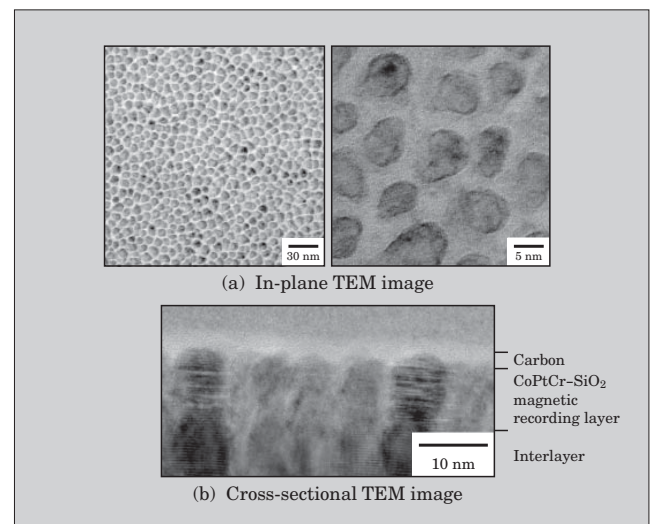


Fig.8 TEM images of CoPtCr-SiO<sub>2</sub> perpendicular magnetic recording media



proximately 80 %. The reduction in crystalline grain size results in an actual decrease in media noise, but the technique of expanding the grain boundary width and reducing the grain size is limited when considering the trend toward higher bpi. In the future, in order to maintain the number of crystalline grains in the bpi direction at a certain level per bit, it is desirable to reduce the grain size while increasing the packing density. For this purpose, reduction of the grain size in the interlayer and optimization of the amount of SiO<sub>2</sub> additive in the CoPtCr layer are thought to be necessary.

#### 4. Conclusion

In recent years, HDD usage has been expanding over a wide range of applications, and with higher recording densities enabled by the utilization of perpendicular magnetic recording, the range of applications is expected to expand further and the usage is expected to increase.

Fuji Electric has been developing perpendicular magnetic recording media since 1999 and began mass-production in the Spring of 2006. Fuji Electric intends to continue to develop and investigate technology for realizing more advanced mass-production technology and higher recording densities.

#### References

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