

Perpendicular Magnetic Recording Media with Aluminum Substrate

Shinji Takei †
Naoki Hara †

1. Introduction

Hard disk drives (HDDs) have been used in practical applications since 1956. Their areal densities have been increased rapidly in recent years. This trend is expected to continue at an annual rate of increase approximately 40%. As a result of this sort of remarkable increase of areal density, the method of longitudinal magnetic recording has reached its areal density limit due to a trade-off between low noise performance and thermal stability, and the perpendicular magnetic recording method, first proposed by Iwasaki et al.⁽¹⁾ in 1975, has emerged as an alternative to longitudinal magnetic recording. Perpendicular magnetic recording is characteristically dissimilar to longitudinal magnetic recording, namely, its thermal stability increases as areal density increases and is therefore well suited, in principle, for high areal densities. In the Spring of 2005, HDDs that utilized perpendicular magnetic recording technology were released commercially, and in 2006, Fuji Electric began mass-producing perpendicular magnetic recording media.

Fuji Electric has been working to develop perpendicular magnetic recording media since 1999. By concentrating on the development of perpendicular magnetic recording media that simultaneously realize low noise performance, and good thermal stability and writability, which had presented significant challenges

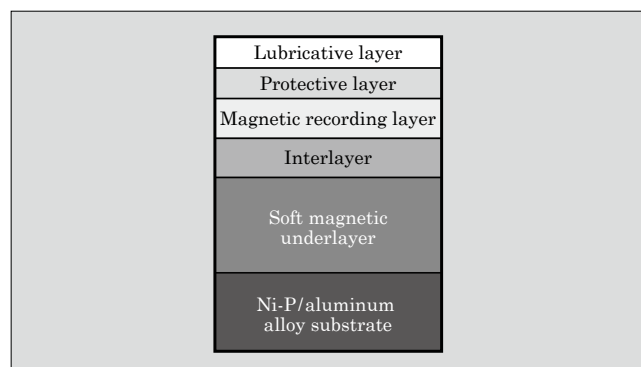
for commercialization, has attained commercial viability. Figure 1 shows an example of the layer structure of perpendicular magnetic recording media. A SUL (soft underlayer), inter-layer, magnetic recording layer and protective layer are deposited sequentially on an aluminum substrate, and then the protective layer is coated with a lubricative layer. These layers are typically formed from several thin films.

This paper describes the required substrate performance for use with perpendicular magnetic recording media, the development of sputtering techniques for the SUL, inter-layer, magnetic recording layer and protective layer of perpendicular magnetic recording media, which use completely different materials and layer structure from that of longitudinal magnetic recording media, and the status of development of aluminum perpendicular magnetic recording media at Fuji Electric.

2. Substrate for Perpendicular Magnetic Recording Media

Substrates used for aluminum perpendicular magnetic recording media, as in the case of substrates for conventional longitudinal magnetic recording media, are polished after a Ni-P film is been plated on an aluminum alloy, but differ from substrates for longitudinal magnetic recording media in terms of surface roughness. With longitudinal magnetic recording media, in order to improve the electromagnetic transfer characteristics, the magnetic moment must be oriented in the circumferential direction of a substrate, and a texturing process to provide a certain degree of controlled roughness is applied in the circumferential direction. On the other hand, with perpendicular magnetic recording media, if the easy axis of the SUL is oriented in the circumferential direction, leakage flux from adjacent tracks during recording may possibly cause erasure, and therefore a circumferential orientation is not desirable. Moreover, the texturing process in the circumferential direction is also undesirable since there is increased likelihood that the easy axis of the SUL, which needs to be oriented in the radial direction, will also become aligned in the circumferen-

Fig.1 Layer structure of perpendicular media



† Fuji Electric Device Technology Co., Ltd.

tial direction. Additionally, in order to realize higher areal densities of magnetic recording media, the spacing between the magnetic layer and the magnetic head for recording and playback must be reduced to achieve a lower flying height of the head, and a smoother substrate surface is sought. To reduce the surface roughness, Fuji Electric uses a circumferential texturing process which is easy to implement, and also adopts a texturing process that is controlled to achieve a roughness below a certain level.

With magnetic recording media, long-term reliability is sought, but there is a potential risk of micro corrosion due to particles adhered to the substrate surface. For this reason, in addition to a substrate surface smoothing process, a cleaning process is also extremely important.

Fuji Electric is also developing and producing aluminum substrates, and the ability to implement a continuous series of processes from substrate manufacturing to polishing, cleaning, sputtering and finally to evaluation is a tremendous advantage for developing aluminum perpendicular magnetic recording media.

3. Sputtering Technology

3.1 SUL

One major difference between perpendicular recording media and longitudinal recording media is that perpendicular recording media has a SUL. The existence of the SUL provides significant advantages including the ability to establish a magnetic field for the head that is 1.5 times the magnitude as that of the longitudinal recording method. Consequently, however, the required thickness of the SUL exceeds one-half of the total film thickness of the perpendicular magnetic recording media. In consideration of the ease of manufacture and cost, the SUL is preferably made as thin as possible. To realize a thinner SUL, the design of the inter-layer and the magnetic recording layer play important roles, but the most effective method is to increase the saturation magnetic flux density B_s of the SUL. The first generation of perpendicular magnetic recording media typically used Co-based alloy amorphous films such as CoZrNb and CoZrTa. Co-based alloy thin films were used because they have relatively high levels of B_s and corrosion resistivity, and could easily provide the necessary amorphous structure for the SUL. However, the B_s of CoZrNb and CoZrTa ranges from approximately 1.1 to 1.3 T, and is not as large as the maximum value of 2.3 T for a magnetic material.

The B_s of the SUL can be increased by adding Fe ($B_s = 2.1$ T), but corrosion resistivity decreases as the amount of Fe additive increases. Adding paramagnetic materials such as Cr, Ta and Nb to increase the corrosion resistivity will cause the B_s level to drop, thereby making it pointless to add Fe in the first place.

Fuji Electric conducted an investigation of SUL

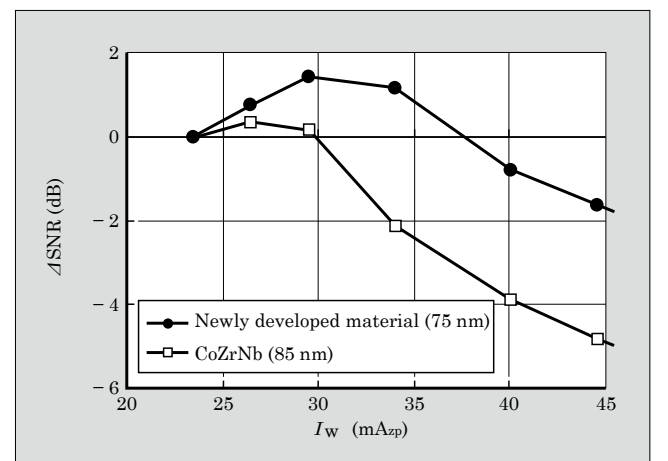
materials based on theoretical considerations, and succeeded in developing a structure having a high B_s level while maintaining high corrosion resistivity and an amorphous structure. Table 1 shows a comparison of the characteristics of the newly developed material versus those of CoZrNb, which has typically been used in the past. The B_s level was raised to 1.5 T, an increase to approximately 1.4 times the 1.1 T B_s of CoZrNb. As magnetic recording media, this newly developed material showed good corrosion resistivity, with less Co corrosion than CoZrNb. Additionally, cross-sectional images obtained by X-ray diffraction (XRD) and transmission electron microscopy (TEM) were analyzed, and the results exhibited a good amorphous structure.

Figure 2 shows the write current dependency of the standard value of signal-to-noise ratio (SNR), which is an indicator of the read/write (R/W) performance. SNR values for both SUL materials are shown normalized with reference to the SNR when the write current is 23 mA. In the case of CoZrNb, the SNR rapidly deteriorates as the write current increases. However, with the newly developed material, the deterioration in SNR is minimized, despite having a thinner film thickness as compared to CoZrNb. This behavior is believed to be attributable to the B_s level of CoZrNb, which is not so high when the write current is large, and as a result, the magnetic flux generated from the magnetic head causes the SUL magnetization to saturate completely. Therefore, the SUL made of CoZrNb is unable to fulfill its role as a magnetic circuit, and magnetic leakage flux that does not pass through the SUL causes recorded signals to be erased. On the other hand, with the newly developed SUL material, since the B_s level is high, magnetic flux generated from the

Table 1 Comparison of SUL materials

	B_s (T)	Co corrosion (ng/cm ²)	Crystal structure
Newly developed material	1.5	0.006	Amorphous
CoZrNb	1.1	0.018	Amorphous

Fig.2 Write current dependency of normalized SNR



magnetic head returns to the magnetic head without saturating the magnetization of the SUL and without erasing any signals.

Use of the newly developed material enabled a successful reduction in SUL film thickness to approximately 70% the conventional thickness and a significant boost in manufacturing ease. Additionally, the corrosion resistivity improved dramatically and the reliability of perpendicular magnetic recording media also improved.

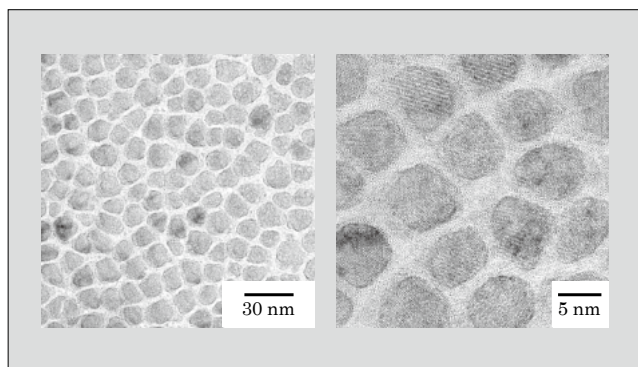
In addition to increasing the B_s level of the SUL, appropriately control of the soft magnetic performance and magnetic anisotropy is crucial for improving the performance of perpendicular magnetic recording media, and therefore, Fuji Electric is actively advancing the development of such control.

3.2 Inter-layer

The inter-layer is used to enhance the crystalline orientation and segregation of the magnetic recording layer. Ideally, individual grains in the magnetic recording layer are grown epitaxially with a 1:1 correspondence on top of the grains in the inter-layer. Accordingly, in order to increase the density of the magnetic recording media, the grain size of the magnetic recording layer must be reduced. Although the grain size of the inter-layer must be reduced, refining the grain size makes the orientation and segregation become susceptible to deterioration. Therefore, Fuji Electric uses a multilayer inter-layer method to refine the grain size while improving orientation and segregation. This method separates the functionality by forming separate layers for refining grain size, for improving crystalline orientation and for improving segregation. For this purpose, the necessary material design is carried out and the sputtering process is optimized with high precision.

Figure 3 shows an in-plane TEM image of perpendicular magnetic recording media being developed by Fuji Electric. At the start of mass-production of magnetic recording media (corresponding to an areal density of 120 Gbits/in²), the grain size was approximately 7 nm, but the material presently being developed has a grain size of less than 6 nm, a successful refinement in

Fig.3 In-plane TEM image



size of approximately 20%. Additionally, the TEM image shows good segregation characteristics. From the results of analysis using XRD, the c-axis distribution $\Delta\theta_{50}$ was verified to be rather good at approximately 2.5 degrees.

Moreover, the capability to maintain the above-mentioned characteristics while making the inter-layer as thin as possible is the key to improving the write performance and manufacturing ease of the magnetic recording media. Fuji Electric has successfully realized the world's thinnest inter-layer film and is able to mass-produce perpendicular magnetic recording media that is highly competitive.

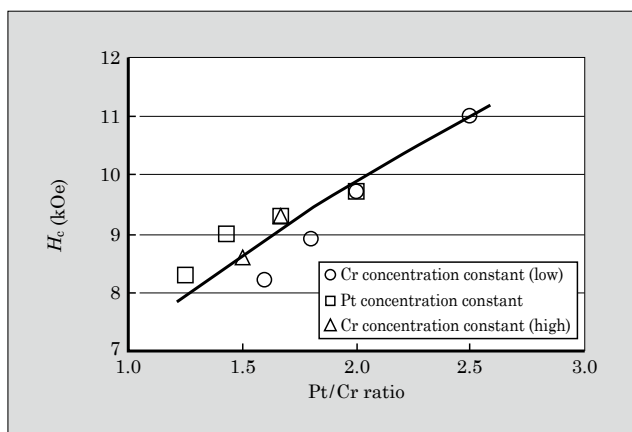
3.3 Magnetic recording layer

Fuji Electric pioneered the use of CoPtCr (granular magnetic material) with an SiO₂ additive as magnetic layer material and has actively issued announcements^{(2), (3)} describing such achievements as the realization of perpendicular magnetic recording media having a large uniaxial magnetic anisotropy constant K_u and a favorably segregated structure, and the good recording and playback characteristics and high thermal stability that are exhibited.

In the granular magnetic layer structure, individual grains of CoPtCr are surrounded by non-magnetic amorphous SiO₂ and results in reduced magnetic interactions between CoPtCr grains and lower noise. In order to fabricate a thin film having a favorably segregated structure, the amount of SiO₂ additive is an important factor, but the sputtering process which includes doping with additional gas and the concentration thereof, control of the doping timing, and so on is extremely critical. Fuji Electric's ongoing development efforts are focusing on this sputtering process.

Moreover, as described above, in order to improve the performance of perpendicular magnetic recording media, the size of grains in the magnetic recording layer is refined as a result of the refinement of grain size in the inter-layer, but in doing so, thermal stability becomes a problem. As a consequence of the smaller size of crystalline grains, the volume V of each crystal

Fig.4 Pt/Cr ratio dependence of H_c



becomes smaller and the value of $K_u V/kT$ (where k : Boltzmann's constant, T : absolute temperature), which indicates thermal stability, decreases. One way to boost thermal stability would be to increase the thickness of the magnetic recording layer and increase V , but in consideration of the balance between the magnetic head and write performance, simply increasing the film thickness is not a good idea. Thus, the K_u of the magnetic recording layer must be increased. Figure 4 shows the change in coercivity H_c according to the ratio of Cr and Pt contained in the magnetic recording layer. Although H_c and K_u do not always have a 1:1 correspondence, K_u exhibits a similar trend as H_c and therefore the direction of change in K_u can be ascertained by observing the change in H_c . Increasing the percentage of Pt in the film causes H_c to increase nearly linearly, and this demonstrates that increasing the Pt percentage is also an effective means for increasing K_u . However, simply increasing the amount of Pt in the magnetic recording layer will lead to higher noise and poorer SNR characteristics. Therefore, the film composition must be designed in consideration of the balance with other elements such as Cr and SiO₂.

Furthermore, important factors for achieving good performance in the magnetic recording layer include, in addition to the layer composition, the layer structure and the above-mentioned sputtering process, and development of the magnetic recording layer must proceed with a comprehensive consideration of all of these factors. This is Fuji Electric's area of expertise.

3.4 Protective layer

The protective layer, as its name states, is formed to protect the magnetic recording media. Owing to the synergistic effect derived from the prevention of corrosion in the magnetic recording layer and the provision of a lubricative layer that is coated on top of the protective layer, the protective layer functions to protect the magnetic layer from abrasive wear from the head. Carbon film, sputtered by ordinary CVD (chemical vapor deposition), is suitable for use as the protective layer. Generally, a thinner protective layer leads to an improved SNR due to a small spacing between the magnetic layer and head. However, susceptibility to Co corrosion increases rapidly as the protective layer becomes thinner. Or in other words, corrosion resistivity deteriorates rapidly when the protective layer is made thinner. Thus a tradeoff relation exists between SNR and Co corrosion characteristics.

Consequently, there is a need for development of a high-density carbon film that enables a reduction in the thickness of the protective layer without increasing Co corrosion. In response to this need, equipment for manufacturing high-density carbon film has been developed, but as of the present point in time, has not yet been put into practical use.

Meanwhile, by using the conventional CVD method directly and modifying the sputtering process, Fuji

Fig.5 Protective layer thickness dependence of Co corrosion

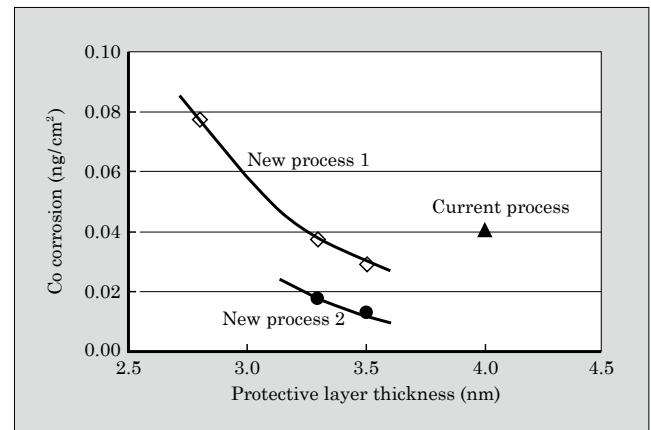
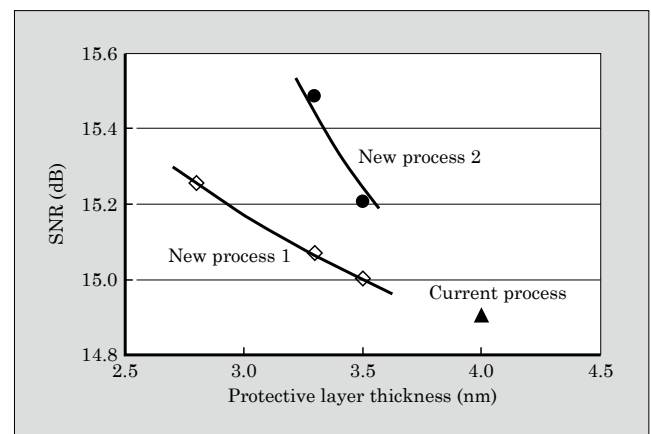


Fig.6 Protective layer dependence of SNR



Electric has succeeded in developing high-density carbon protective film. Figure 5 shows the relationship between Co corrosion and protective layer thickness in perpendicular magnetic recording media that has been manufactured by this newly developed process. Results obtained by using the current process are also shown on the same graph. The results show that by increasing the density of the protective layer, corrosion resistivity equivalent to that of the current process can be obtained even for film thicknesses on the order of 3 nm. Additionally, Fig. 6 shows the protective layer dependence of SNR in perpendicular magnetic recording media that has been manufactured using the newly developed process. Also shown on this graph is the SNR obtained when using the current process. Use of the new process improves not only the film density, but also improves the head flyability, i.e., enables lower flying heights, so as to realize an improved SNR for the same protective film thickness. Thus, the newly developed process for improving protective film density enables the manufacture of magnetic recording media that exhibits good corrosion resistivity and a favorable SNR even in thin film areas. Fuji Electric will continue to advance this development work in order to realize thinner films in the future, and simultaneously, is also working to develop new sputtering methods for

realizing even thinner films.

4. Postscript

Fuji Electric has been mass-producing perpendicular magnetic recording media since the Spring of 2006, and was the first company in the industry to advance a production line that supports perpendicular media, and then to transition production from longitudinal to perpendicular media. At present, perpendicular magnetic media accounts for more than 90% of Fuji's total production. In the future, Fuji Electric intends to continue to pursue highly productive processes in order to realize even higher density of perpendicular magnetic

media, and will actively continue to develop leading-edge technology.

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