Magnetic Technology for Perpendicular Magnetic Recording Media

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ABSTRACT

This paper describes three technologies for the recording layer, intermediate layer and soft magnetic underlayer, developed to increase the recording density of perpendicular magnetic recording media. The design and development of an optimal structure for a new multilayer magnetic recording layer constructed from four functionally-separated layers has enabled an increase in track density. A new material of an intermediate layer was developed. The magnetic grain sizes of the magnetic recording layer on the intermediate layer and the distribution of the grain sizes were reduced. The crystalline orientation was also improved. Materials having a high saturation magnetic flux density have been newly developed for the soft magnetic underlayer. The application of these materials has resulted in improved electromagnetic conversion characteristics.

1. Introduction

The recording density of magnetic recording media continues to increase by approximately 40% per year. At present, recording densities of up to approximately 500 Gbits/in^2 have been commercialized. Recording densities of 1 Tbits/in^2 are expected to be achieved at the research level during 2010. Further, it is thought that a new recording method will be needed for recording densities higher than about 1 Tbits/in^2. Fuji Electric has set a goal of achieving 1 Tbits/in^2 with the current method, and is advancing the technical development of magnetic recording media.

Fig. 1 shows the structure of a hard disk drive (HDD) and magnetic recording media. The magnetic recording media is fabricated by sequentially depositing an alloy film, a carbon overcoat layer and a lubricative layer, each having a film thickness ranging from several to several tens of nanometers, onto a substrate having a thickness of approximately 1.0 mm. The alloy film in a multilayer structure contains a magnetic recording layer consisting of magnetic material for retaining information. The alloy film used in recent magnetic recording media consists of about 10 layers, and has become complicated. Magnetic technology is the general term for the technology used in designing the alloy film layer structure in order to increase the areal density.

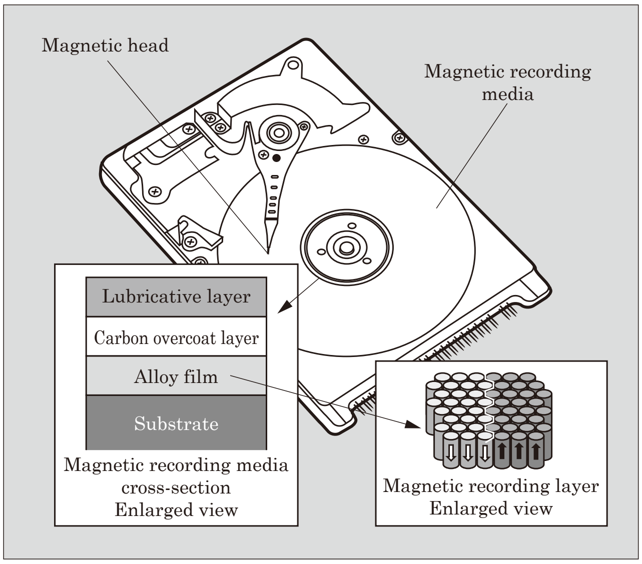

Fig.1 HDD and magnetic recording media structure

This paper describes the technical challenges for realizing higher recording densities (section 2) and topical improvements that have been made to overcome those challenges (section 3).

2. Technical Challenges for Higher Density

To increase the recording density, the performance of the recording layer that forms the recording bits must be improved. Specifically, the magnetic crystalline grains arranged in a columnar structure and dispersed throughout the recording layer should have a small uniform size of several nanometers and their crystalline orientation should be improved to enhance resistance to thermal energy. As a result, large capacity and long-term data retention will be possible. However, if such a method is used to control the recording layer characteristics, typically, the coercivity H_c increases and a large magnetic field is required for magnetization reversal. The recording of “1” and “0” digital signals requires that the direction of magnetization be reversed by 180 degrees, and therefore a magnetic head that generates a field greater than the coercive

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force must be used for the recording. Because there is a limit to the magnetic field that can be generated by a magnetic head, a design simply based on the aforementioned guidelines would not be successful. To overcome this technical challenge, Fuji Electric is actively researching[1] a multilayer recording structure known as the ECC (Exchange-Coupled Composite) structure[2] and is applying this technology as a solution.

On the other hand, the formation process for recording bits is significantly affected by the distribution of the recording magnetic field of the magnetic head. The head's magnetic field that is incident on the recording layer is ideally perpendicular with respect to the film surface. As a result, a sharp recording transition (border with adjacent bits) is formed and good signal quality can be ensured. For this purpose, the distribution of the head's magnetic field incident upon adjacent recording tracks that are formed in concentric circles in an HDD must be suppressed. If the magnetic field component in the cross-track direction is large, the signal strength of pre-recorded adjacent tracks will leak, and the magnetic field will be attenuated. Thus, the track density cannot be increased, and as a result, the areal density does not increase. The magnetic field distribution is largely determined by the magnetic head structure, but the media structure can be devised for optimized control.

In general, the easy axis of magnetization is the direction in which magnetization is stable, and depends on the crystalline structure of the magnetic material. With perpendicular magnetic recording media, the easy axis of magnetization is perpendicular to the film surface. Magnetic film that is magnetized in the direction of the easy axis exhibits the property whereby coercivity H_c decreases as the applied magnetic field tilts with respect to the easy axis of magnetization. Therefore, since magnetization reversal occurs more easily for an oblique magnetic field, not only must the distribution of the head's magnetic field be controlled, but resistance to the oblique component of the recording layer itself must be increased.

The aforementioned technical challenges for magnetic recording media can be summarized as follows.

(a) Improvement of the basic performance of the recording layer (crystalline orientation, refinement and uniformity of grain size)
(b) Ensuring write capability (optimization of ECC structure, etc.)
(c) Formation of a sharp recording transition (control of distribution of magnetic field of head)
(d) Less signal strength attenuation at adjacent recording tracks (improved resistance to oblique magnetic field components)

3. Magnetic Technology Development Statuses

3.1 Design of multilayer magnetic recording layer

As shown in Fig. 2(a), the typical media layer structure consists of three layers: a recording layer, an intermediate layer and a soft magnetic underlayer. Additionally, the recording layer consists of multiple layers separated by function. In a conventional recording layer, a three-layer ECC structure consisting of a hard layer (hard magnetic layer), a coupling force control layer and a semi-hard layer (semi-hard magnetic layer) is used. A method for optimizing the magnetic coupling force between the hard layer and the semi-hard layer is used with the ECC structure.

The hard layer is provided for the purpose of increasing the recording density described above. The hard layer has a high H_c value and the magnetic head cannot write to the hard layer as a single layer. With an ECC structure, a semi-hard layer having a low H_c value is also provided, and a coupling force control layer is positioned between the hard layer and the semi-hard layer to implement control by weakening the magnetic coupling force. The applied magnetic field

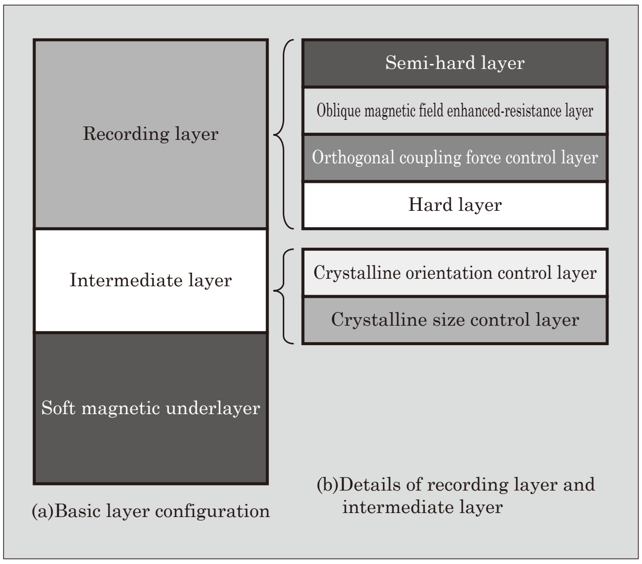

Fig.2 Basic layer configuration and details of media

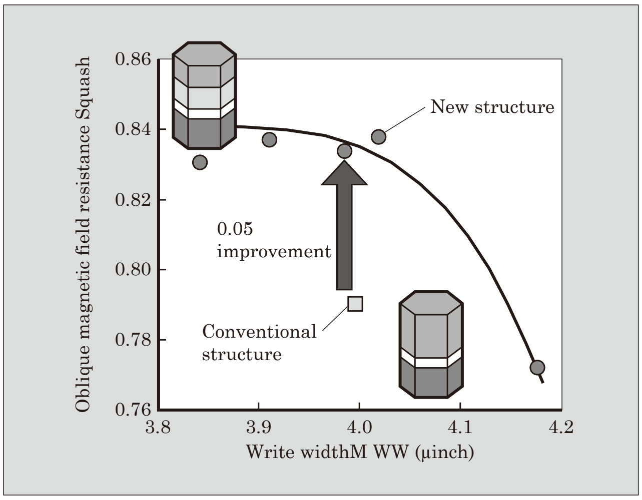

Fig.3 Improvement in oblique magnetic field resistance resulting from use of new structure

Table 1 Comparison of properties of the recording layer (hard layer) micro-structure according to intermediate layer (crystalline grain size control layer) material devices

Intermediate layer material	Avg. grain size (nm)	Average grain boundary width (nm)	Grain size variation (%)	orientation distribution $\Delta\theta_{50}$ (degrees)
Conventional	5.9	1.4	23	2.7
New	5.7	1.8	19	2.5

induces magnetization reversal in the hard layer and the semi-hard layer semi-independently. As a result, the overall H_c value decreases and writing capability increases. By using this type of ECC structure, the requirements of "(b) Ensuring write capability" described above in section 2 have been satisfied.

Meanwhile, in some cases the width of the magnetic field distribution in the cross-track direction due to the magnetic head is large, and measures for "(d) Less signal strength attenuation at adjacent recording tracks" as described in section 2 must be strengthened. Therefore, the new oblique magnetic field enhanced-resistant layer shown in Fig. 2(b) was introduced. The effect of this new layer is shown in Fig. 3. A read/write (R/W) evaluation was performed using a standard tester. After writing several times to both sides of the recording track, the output from the recorded track was measured, and the output value, normalized with respect to the initial output, is shown as the oblique magnetic field resistance (Squash characteristic) on the vertical axis of figure. The horizontal axis of the figure indicates the write width. In general, as the write width becomes narrower, the crosstalk decreases and the Squash characteristic increases. When compared with the same write width, a large improvement (0.05 increase) in the Squash characteristic from 0.79 to 0.84 was realized when a recording layer with the new structure was used.

Measured simultaneously, the overwrite (OW) characteristic and signal-to-noise ratio (SNR) were the same, thereby indicating that the Squash characteristic was improved without degrading the write capability or the signal quality. Because the track density could be increased while maintaining the performance (linear recording density) in the down-track direction, the areal density can be increased. Presently, aiming for further improvement, the material and composition of various magnetic layers, especially the oblique magnetic field enhanced-resistant layer, are being optimized.

3.2 Microstructural control enabled by the intermediate layer

The overall performance of a recording layer is determined not only on the design of the multilayer structure, but also largely by the composition of the magnetic layers included therein and the processes used. Additionally, the grain size and the crystalline orientation depend significantly on the microstructure of the layer immediately below[3]. As discussed above,

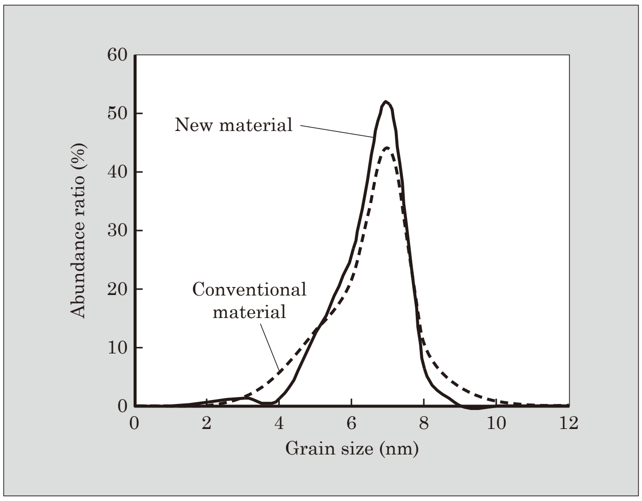

Fig.4 Change of grain size distribution in recording layer according to intermediate layer material

the resistance to thermal energy must be increased by making the grains finer and uniform in size, and improving their crystalline orientation. A tradeoff relation generally exists between making the grains finer and improving the crystalline orientation. However, both of these factors must be improved simultaneously. The intermediate layer plays an important role in improving this tradeoff relation. The reason for calling this layer the intermediate layer is because it acts as a non-magnetic layer that divides the magnetic coupling between the soft magnetic underlayer and the recording layer. Actually, its function as an underlayer for the recording layer, as described above, is extremely important. As in the case of the recording layer, the intermediate layer is presently divided according to function and basically has a two-layer structure consisting of a layer for grain control and a layer for control of the crystalline orientation (see Fig. 2).

An example of the use of new material in the crystalline grain control layer to realize an improved microstructure of the recording layer (hard layer) is presented below. The grain size and the like were analyzed using a transmission electron microscope (TEM) and the crystalline orient was analyzed using an X-ray diffraction apparatus. Table 1 compares properties relating to the recording layer microstructure when conventional and new materials are used. By using the new material, the average grain size decreased from 5.9 nm to 5.7 nm, the average grain boundary width increased from 1.4 nm to 1.8 nm, and the variation in grain size decreased from 23% to 19%. The orientation

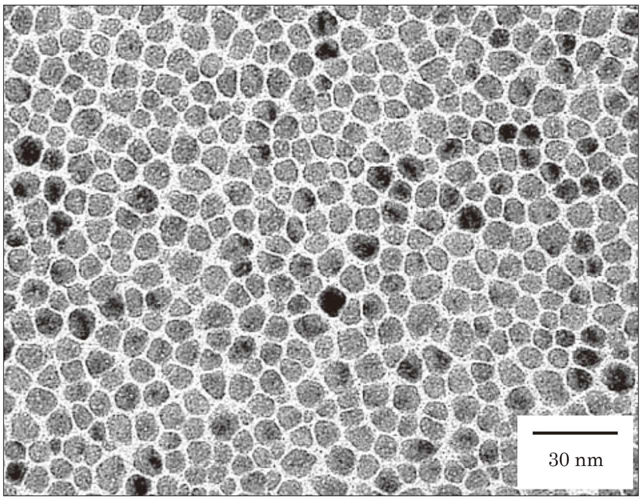

Fig.5 Plan-view TEM image of recording layer using new material

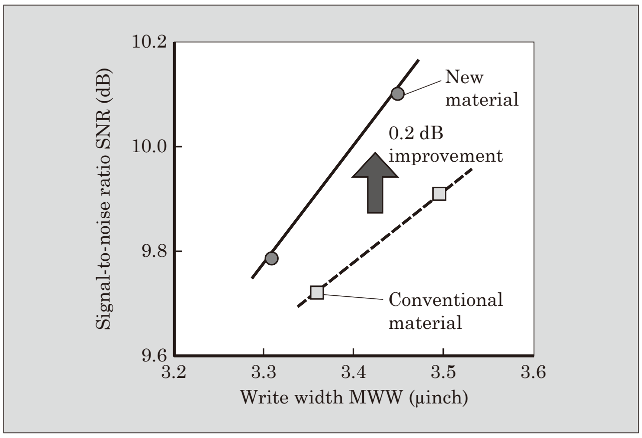

Fig.6 Change in SNR according to soft magnetic underlayer material

distribution $\Delta\theta_{50}$ decreased from 2.7 to 2.5 degrees, and the crystalline orientation also improved at the same time. Particularly noteworthy in this result is that the variation in grain size improved by 4 percentage points. Fig. 4 shows the change in grain size distribution in the recording layer for each intermediate layer material. Previously, many micro-grains of about 4 nm in size and large grains of about 9 nm in size coexisted, but with the change to the new material, the distribution width is found to have narrowed. Fig. 5 shows a plan-view TEM image of a recording layer that uses the new material. Fuji Electric has been actively developing this recording layer material based on (Co-Pt-Cr)-SiO_2.

The uniform distribution of grain size can be considered to be a significant effect of the new material. That is, this example achieves "(a) Improvement of the basic performance of the recording layer" described in section 2.

3.3 Improvement of recording performance with soft magnetic underlayer

For controlling the distribution of the magnetic field, the thickness of each layer and the properties of the materials used in the soft magnetic underlayer are important factors in the design of the media. While limiting the distribution of the magnetic field generated from the magnetic pole of the magnetic head, the magnetic field must be drawn-in sharply toward the soft magnetic underlayer and returned to the return yoke. By shortening the distance between the magnetic head and the soft magnetic underlayer, the magnetic field gradient increases. Considering that this distance affects the performance during playback[4] and that the thickness of the intermediate layer and the recording layer affect the magnetic properties (such as H_c, for example) of the recording layer, the actual design range of film thickness is limited.

Meanwhile, the soft magnetic underlayer is required to exhibit the properties of excellent flatness, high saturation flux density B_s and high permeability. Flatness affects the crystalline orientation of the intermediate layer and the recording layer that are formed above the soft magnetic underlayer. A large surface roughness is directly related to the deterioration of the crystalline orientation. By realizing the magnetic properties of a high B_s value and high permeability, as discussed above, the magnetic field distribution can be controlled. This paper introduces an example of a new material that realizes both a relatively high B_s value and good flatness.

Fig. 6 compares the SNR versus write width for soft magnetic underlayers that use the conventional material and new material. For the same recording width, the new material shows a 0.2 dB improvement in SNR. In this case, the OW characteristic, the Squash characteristic and other characteristics exhibit the same or improved performance. The new material shows the same flatness and an approximate 15% improvement in the B_s value compared to the conventional material, and this effect is thought to be reflected in the R/W characteristics. Of the technical challenges described in section 2, the above results are thought to be particularly applicable to the improvement of "(c) Formation of a sharp recording transition" and also to contribute to improvement of items (b) and (d).

4. Postscript

Design guidelines for the recording layer, intermediate layer and soft magnetic underlayer have been described and examples of improvements have been presented. To meet the challenges for achieving higher density, improvements must be implemented appropriately for the magnetic head of each successive generation of technology. Meanwhile, one anticipated method that may replace the conventional recording method is the "shingled-write recording" method. This method is said to have the potential to attain a 10 Tbits/in^2 recording density[5]. Fuji Electric has also begun to design recording layer structures that use this method. Fuji Electric will continue to develop new materials and process technologies in an attempt to reach the recording density limit.

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