Magnetic Layers for Perpendicular Recording Media

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1. Introduction

Hard disk drives (HDDs) are recently being incorporated into video recorders, car navigation devices, family game machines, etc., as devices (AV-HDDs) to store digital AV (audio-visual) information such as movies and television programs. Because the AV-HDD has the features of large capacity, high speed and low cost, it is suitable for long-time recording, high-speed random access and multi-channel simultaneous recording and playback. The demand for AV-HDDs is anticipated to increase rapidly in the near future. In response to demands from this new market growing at a rate of 100 % per year, it is necessary to further increase the recording density, which is now at a level of 30 Gbits/in^2 in mass production.

Present HDDs utilize a longitudinal magnetic recording system in which the recorded magnetization is aligned in the film plane. If we increase the recording density of this system, the recorded magnetization becomes unstable due to the thermal energy at room temperature, thus creating the problem of thermal agitation of magnetization. Recently, a new recording system suitable for ultra-high density recording, i.e. a perpendicular magnetic recording system[(1)], has been attracting considerable attention, and this new system provides greater stability of the recorded magnetization as the recording density increases.

Figure 1 is a schematic drawing showing the general layer structures and recorded magnetization for perpendicular magnetic recording media. Successive layers are stacked on the substrate in the order of soft magnetic underlayer, non-magnetic interlayer and magnetic recording layer for the storage. Because the recorded magnetization is aligned vertically, as opposed to longitudinally, the film structure and magnetic properties are quite different from those of the longitudinal magnetic recording media. To realize perpendicular magnetic recording media, it is essential to redevelop and redesign the film structure, thin film material and processing techniques.

Of this group, the development of a high performance magnetic recording layer that retains the recorded magnetization is most important. Figure 2 shows several materials that may be used as the thin film material for magnetic recording layer such as CoCrPt alloy film, Co/X multilayer, amorphous film and FePt ordered lattice alloy film, depending on the applicable areal recording density. These materials each have their own characteristic microstructure, physical properties and, particularly, perpendicular magnetic anisotropy energy K_u. The material most suitable for the areal recoding density to be applied must be selected for the development of the magnetic recording layer.

From early on, Fuji Electric started the development of perpendicular magnetic recording media to realize the next generation ultra-high density recording media and also initiated active joint research with

Fig.1 Layer structures and schematic drawing of the recorded magnetization for perpendicular recording media

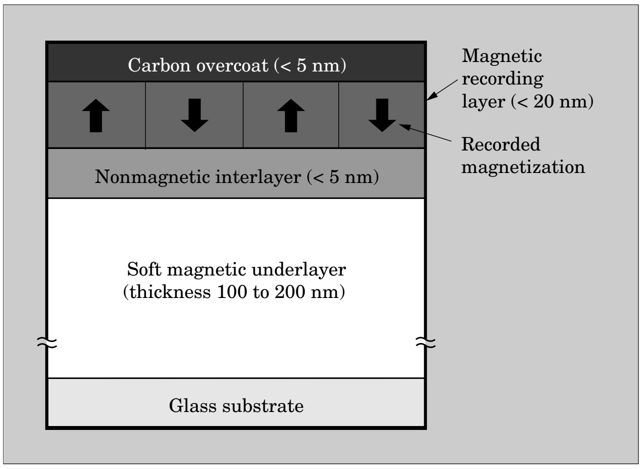
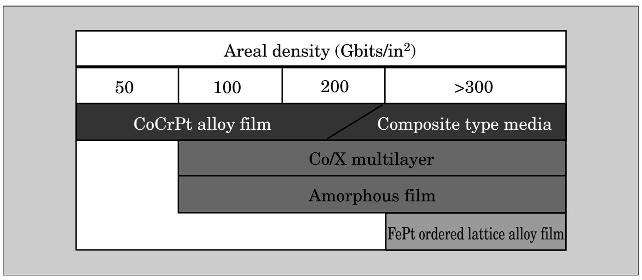


Fig.2 Materials for the perpendicular magnetic recording layer



the Research Institute of Electrical Communication of Tohoku University and the Science & Technical Research Laboratories of NHK.[2][3] In addition to the development of CoCrPt alloy thin film and Co/Pd multilayer with 100 to 200 Gbits/in^2, which are the immediate objectives, we are developing amorphous film which might be applicable to the ultra-high density recording media suitable for densities in excess of 300 Gbits/in^2.

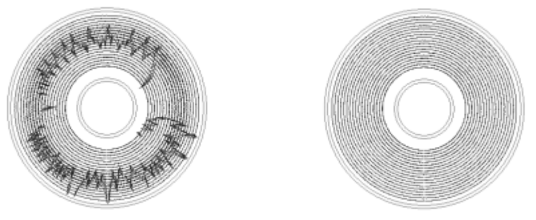
In this paper, we will introduce recent results of the research by Fuji Electric on high recording density technology, magnetic domain control of the soft magnetic underlayer and an evaluation technique for the media, which are essential technologies for the realization of perpendicular magnetic recording media.

2. Magnetic Domain Control of the Soft Magnetic Underlayer

The soft magnetic underlayer functions to raise the strength of the writing field of the recording head and the field gradient applied to the magnetic recording layer, and to improve the recording resolution[4]. However, the soft magnetic film is liable to have a complicated magnetic domain structure in which the direction of the magnetization is grouped in several magnetic domains. Because large stray fields will be generated from the boundaries (domain walls) of the magnetic domains, this will cause high spike noise during the read back of signal. Figure 3 (a) shows a typical observed result of the spike noise measured by a GMR head as generated from a CoZrNb alloy amorphous soft magnetic layer with a thickness of 100 nm sputtered on the glass substrate. Dark color areas correspond to the spike generating locations and such locations are distributed over the whole area of the disk.

Fuji Electric established a layer structure and related process technology so as to reduce the spike noise effectively through adopting magnetic domain control of the soft magnetic underlayer using an antiferromagnetic AF film. In this layer structure developed by Fuji Electric, AF film which consists of MnIr alloy is sputtered onto a seed layer, and then soft magnetic film which consists of CoZrNb is sputtered.

Fig.3 Typical observation results of the spike noise



(a) Without AF film (b) With AF film and magnetic annealing process

Ideally, the magnetization of the AF film will be aligned radially from the center of the disk and a radially biased magnetic field will be applied effectively to the soft magnetic underlayer, and thus formation of a magnetic domain can be prevented.

However, in actuality, the stray field from the target during the sputtering to align the magnetization of AF film is not always uniform, and the direction of the magnetization may change during sputtering of the magnetic recording layer due to heating of the substrate. Recognizing the antiferromagnetic characteristics of MnIr film vanish at temperatures above 280°C, we undertook the challenge of developing a magnetic annealing process to control the direction of magnetization of the AF film itself without degrading productivity. In this process, after sputtering of the magnetic recording layer, the temperature of the substrate will be raised up to about 300°C in the heating chamber of the sputtering machine and then will be cooled down to about 180°C in the cooling chamber where a uniform radial magnetic field will be applied. The magnetic field strength will be about 80 kA/m (1 kOe) and the media will be retained for about 15 seconds in the cooling chamber. Figure 3 (b) shows a typical observation result of the spike noise generated from media subject to the annealing process. The spike noise over the whole area was eliminated and we were able to reduce the spike noise effectively without degrading the productivity.

The layer structure and process described above are also applicable to any soft magnetic materials. We are developing new materials with higher saturation flux densities to realize higher density magnetic recording systems.

3. Technology for High Density Recording Layer

3.1 CoCrPt-SiO_2 granular media

To use CoCrPt alloy film as the magnetic recording layer of a perpendicular magnetic recording system, the following conditions must be realized.

① Media noise must be reduced by segregating Cr at the grain boundary of fine Co alloy grains in order to reduce the intergranular magnetic interactions between the grains.

② The c-axis orientation of the Co alloy grain normal to the film plane must be improved and a high K_u value must be induced.

Condition ① can be realized by increasing Cr content, as in the case of the longitudinal magnetic recording system. In addition, it is effective to add Ta or B, etc., however at the same time, the K_u value is liable to deteriorate. Condition ② can be realized by promoting epitaxial growth to optimize the non-magnetic interlayer, however it is known that this is liable to limit Cr segregation at the grain boundary.

Fuji Electric has been developing micro-structure control technology consisting of a CoCrPt alloy granular layer with SiO_2 additive for a longitudinal magnetic recording system. With these materials, a high K_u value can be realized, because SiO_2 can be easily precipitated to the grain boundary of the Co alloy grains and it is not necessary to increase Cr content or add elements for reducing the magnetic interactions between grains. Observing such features, we initiated an investigation of CoCrPt-SiO_2 granular media as the magnetic recording layer for a perpendicular magnetic recording system.

Figure 4 shows a TEM (transmission electron microscope) image of a CoCrPt-SiO_2 granular magnetic layer manufactured by an RF magnetron sputtering process using a CoCrPt/SiO_2 composite target on an Ru interlayer. A granular structure can be seen in which crystal grain boundaries (whitish areas in the image), composed mainly of the oxide, are formed surrounding 6 nm crystal grains. It was verified by X-ray diffraction analysis that the c-axis orientation of Co alloy grains was also excellent. These media have a very high K_u value of 4×10^5 J/m^3 which is more than twice the value of the CoCrPt magnetic recording layer and the loop squareness is almost 1.

Figure 5 shows MFM (magnetic force microscopy) images of magnetization bits recorded by a single pole type head on CoCrPt-SiO_2 granular media with a soft

Fig.4 TEM image of CoCrPt-SiO_2 granular magnetic layer

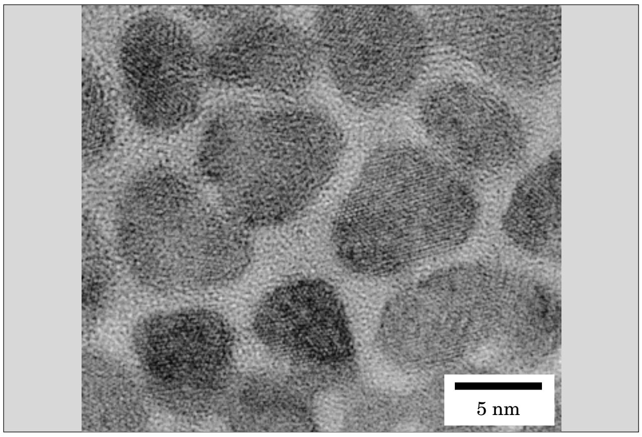
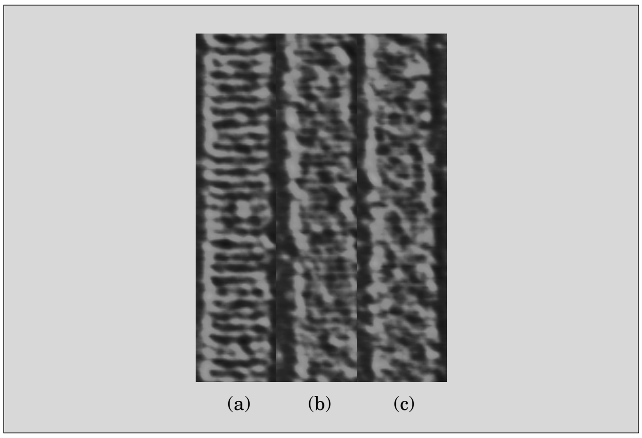


Fig.5 MFM images of CoCrPt-SiO_2 granular media



magnetic underlayer. In Fig. 5 (a), (b) and (c) are the bits recorded at linear recording densities of 20, 28 and 31 kfc/mm (500, 700 and 800 kFCI) respectively. Relatively clear magnetization switching is observed even at the linear recording density of (b) which corresponds to a recording density of 82 Gbits/in^2. These media have excellent thermal stability and the read back signal decay is almost zero at any recording density.

As mentioned above, the CoCrPt granular magnetic layer with SiO_2 additive is a promising material for magnetic recoding layers with recording densities of 100 to 200 Gbits/in^2. We are making further efforts to optimize the layer structure and composition of the material.

3.2 CoTb amorphous composite-type media

As mentioned before, amorphous film, consisting of a rare-earth metal such as Tb and a 3d transition metal such as Co or Fe, is a material that holds potential for realizing the high recording density beyond 300 Gbits/in^2. Because of the extremely strong exchange interaction in the film plane direction, the magnetization is widely coupled. Therefore, it is difficult to implement microscopic magnetization switching on the order of nanometers.

We investigated a process for realizing the microscopic magnetization switching of amorphous film and discovered that a composite type media layered with CoCrPtB film, for which the magnetization switching unit is small, is compatible with both thermal stability and media noise characteristics.

Fig.6 SNR and time decay of the read back signal as a function of CoTb layer thickness

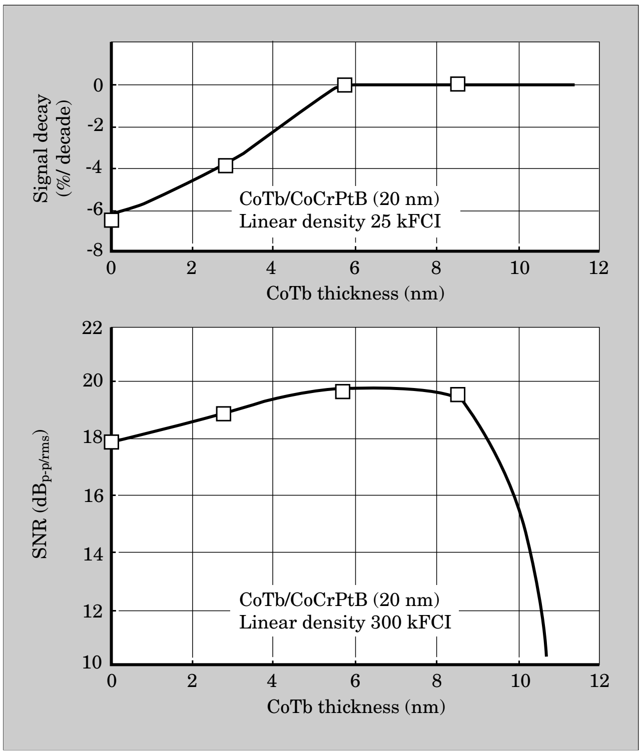


Figure 6 shows the signal-to-media-noise ratio (SNR) of the composite type media formed from CoTb amorphous film layered on a CoCrPtB alloy film, having a thickness of 20 nm at the linear recording density of 12 kfc/mm (300 kFCI), and the time decay of the read back signal measured at 1 kfc/mm (25 kFCI) for the evaluation of thermal stability, as a function of the CoTb layer thickness.

At a CoTb thickness of 6 nm, SNR is at its maximum value and SNR is improved by 2 dB compared with its value in the case without CoTb. With the increase of CoTb thickness, the time decay of the read back signal is improved. The time decay is almost zero when CoTb thickness is greater than 6 nm. Excellent SNR and thermal stability characteristics were obtained from composite type media having a layer structure of CoTb (6 nm) and CoCyPtB (20 nm).

By observation using an MFM, it was verified that 70 Gbits/in^2 could be realized with this media. We hope to be able to achieve even higher recording densities through combination with granular media.

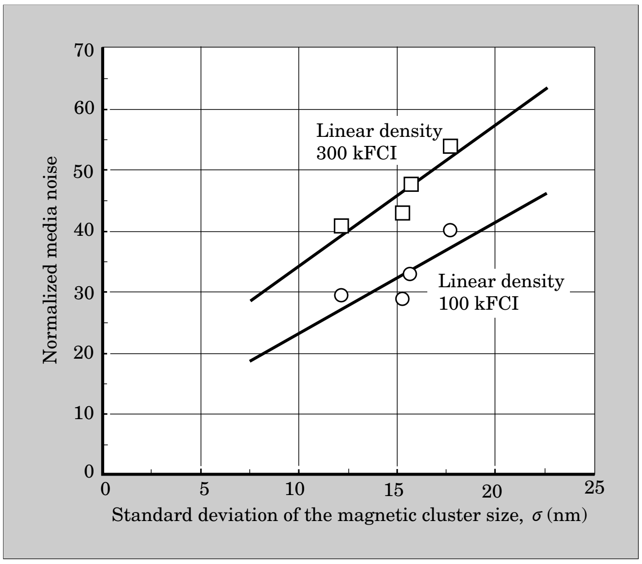
4. Evaluation and Analysis Technique for Perpendicular Recording Media

In the development of excellent magnetic recording media, evaluation and analysis techniques are indispensable. Especially, for quantitative discussions of the noise characteristics of high-density recording media, the micro recording bits have to be observed and evaluated directly, and then the causes of noise generation must be investigated. For this purpose, we are developing an evaluation and analysis technique for the magnetized patterns of perpendicular magnetic recording media using an MFM and are working jointly with the Science & Technical Research Laboratories of NHK.[3] In this paper, we would like to introduce a technique for evaluating and analyzing magnetic cluster size in an ac erased state, which is considered to have a strong correlation with media noise.

The number of magnetic clusters in the oriented magnetization can be viewed by observing ac erased media with an MFM. After image processing of the observed image, we approximated each cluster with a circle and obtained its diameter D and standard deviation σ. Figure 7 shows the relationship between standard deviation σ of the magnetic cluster and normalized media noise of the perpendicular magnetic recording media for several magnetic recording materials and layer structures. The standard deviation σ shows a strong correlation with the media noise and the media noise decreases with the decrease of σ. It is also clear that the size of the cluster has a strong correlation with the recording resolution.

Such analysis is very effective for quantifying the target magnetic cluster size necessary for higher recording density and lower noise. Therefore, this analysis technique is useful for the design of media. Now, we are investigating procedures for achieving better resolution of the MFM image, so that an even more precise evaluation can be obtained.

Fig.7 Relation between normalized media noise and standard deviation of the magnetic cluster size



5. Conclusion

Fuji Electric is performing comprehensive research and development of perpendicular magnetic recording media for ultra-high-density recording, including the magnetic domain control and the evaluating analysis technique. In addition to the development of the $CoCrPt-SiO_2$ granular film magnetic recording layer for 100 to 200 Gbits/in^2, we are developing amorphous film which has the potential to realize ultra-high recording densities of more than 300 Gbits/in^2. We are working toward realization of the high capacity AV-HDD which is expected to become a major sales item on the market. Lastly, we extend our thanks to Prof. Yoshihisa Nakamura and Prof. Hiroaki Muraoka of the Research Institute of Electrical Communication, Tohoku University, and to Dr. Takahiro Tamaki, Senior research engineer of the Science & Technical Research Laboratories, NHK for their helpful advice.

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