A New Perpendicular Magnetic Recording Method with a Magnetic -Optical Common Preformat

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We have developed a new perpendicular thermo-magnetic recording method coupled with magnetic flux detection. Using a medium based on the material of a magneto-optical (MO) medium, we detected enough signal by a giant magneto-resistive (GMR) sensor, and the resolution is substantially improved. Compared to that of the latest magneto-optical disk drives ¹⁾ (0.4 $\mu\text{m}/\text{bit}$), the carrier-to-noise ratio of a reproduced signal from the shortest repetition (mark, space: 0.53 μm) is 5 dB higher, and the recording density reaches 0.13 $\mu\text{m}/\text{bit}$. Moreover, an optical signal and a magnetic flux signal from common embossed-pits were detected. This method can generate a tracking servo signal for a flux channel.

Key words: thermo-magnetic recording, flux detection, perpendicular magnetic recording, magneto-optical (MO) recording, giant magneto-resistive (GMR) sensor, embossed pit

1. Introduction

In conventional optical disk drive, the read/write channel consists of a red laser diode, and its optical spot is about 1 μm in diameter. With this 1- μm spot, areal density of about 2 Gbit/inch² is achieved. In order to boost recording density, shortening the wavelength of the laser diode is the most straightforward method. But developing a device with a shorter wavelength and a high output-power is difficult, and it cannot satisfy the growing demand for larger storage capacity. So, in recent years, the research on near-field optics, such as the SIL (solid immersion lens), has been a hot topic ²⁾. When the SIL is combined with a blue light source, the optical spot is shrunk to 250 nm (assuming wavelength: 400 nm, refractive index of SIL: 2, numerical aperture of focusing lens: 0.8). Using the SIL and a blue light source, it is expected that recording marks corresponding to 30 Gbit/inch² or higher can be formed stably. But energy density within the optical spot may become too high and destroy the recorded marks when the optical spot is simply shrunk. To avoid this problem, reducing readout power (this may cause noise problems such as a background noise and a shot noise) or reducing the recording sensitivity of the medium (this means requirement of

more powerful laser diode) is necessary.

In magnetic disk drives, the sensitivity of signal detection is increased by utilizing GMR devices. Furthermore, in the near future, it is expected that tunneling magneto-resistive (TMR) devices will become practical. But it is gradually becoming hard to form "well-formed" magnetic domains, which have a smooth domain-wall and no internal micro-domains of reverse magnetization. Furthermore, the data loss by thermal fluctuation becomes a severe problem in longitudinal recording ³⁾. To solve these problems, a Co/Pt multilayer, perpendicular magnetic recording medium has been developed ⁴⁻⁶⁾. But domains cannot be formed well by conventional magnetic recording. On the other hand,

Fig. 1: Diagram of recording tester. Wavelength of the light source is 685 nm and the numerical aperture of the objective lens was 0.55.

Table I: Experimental conditions

	Parameter	Value	Unit
optical channel	spot size	1.2	μm
	substrate thickness	1.2	mm
flux channel	gap length	0.2	μm
	track width	1	μm
common	domain width	0.5	μm
	linear velocity	5 - 10	m/s

in the case of magneto-optical recording medium consisting of TbFeCo amorphous alloy, well-formed perpendicular magnetic domains can be formed by thermomagnetic writing.

So we propose a new recording method combining magneto-optical disk technology, which can form perpendicular magnetic domains well, and hard disk technology, which enables high-sensitivity and high-resolution detection.

Fig. 2: Detected magneto-optical signal. Amplitude of 1- μ m cycle pattern is degraded because of resolution limitation.

Fig. 3: Detected flux signal from long domains. (without tracking servo)

Fig. 4: Detected flux signal from short domains. (without tracking servo) Compared with the optical detection, resolution is substantially improved.

2. Experiment

A diagram of a recording tester is shown in Fig. 1. In this work, we did not use near-field optics but conventional optics to confirm the advantage of the new method. In the recording process, perpendicular domains are formed by thermo-magnetic recording, which is the same as in the MO drive. In the reproduction process, the GMR sensor mounted on the slider detects the signal from the perpendicular component of leakage flux. Simultaneously, an optical signal is also detected and compared with one from the GMR sensor. The experimental conditions are listed in Table I. Wavelength of the light source is 685 nm and the numerical aperture of the objective lens is 0.55. Domain width was observed by magnetic-force-microscope (MFM). In this study, we assumed (1, 7) encoding that is the same as in the latest MO disk drives. The gap length of the GMR sensor is about 0.2 μ m and the track width is about 1 μ m.

A recording medium based on the material of MO medium was specially prepared for flux detection ⁷⁾. It has a flux read-out layer on the memory layer. Thicknesses of the memory layer and the read-out layer are 40 and 70 nm, respectively. These magnetic layers were deposited on the polycarbonate substrate of a conventional MO disk and sandwiched between silicon-nitride layers for protection. The residual magnetization of the readout layer is 230 emu/cm³ at room temperature. On the surface of the substrate, embossed pits were also formed.

Fig. 5: Resolution of each detection method. The experimental resolution almost matches with calculated resolution.

3. Results and Discussion

At first, we recorded domains by two methods: laser-strobe magnetic-field-modulation⁸⁾ (LS-MFM) and light-intensity-modulation (LIM). Then, signals were detected by these two methods. Figures 2, 3 and 4 show the reproduced signals detected by each method. Under the recording condition of the latest MO disk drives, where the shortest mark and space are both 0.53 μm , the carrier-to-noise (C/N) ratio of the flux detection from the shortest repetition pattern was 52 dB, while that of the optical signal was 47 dB. According to this flux detection, a 47-dB C/N ratio is estimated to be detected at about 0.18- μm mark/space. These domains can be recorded stably by the LS-MFM method. It corresponds to the 0.13- μm /bit linear density of (1, 7) encoding, and the areal density will reach about 8.3 Gbit/inch² when track pitch is set to 0.6 μm . The resolutions of each method estimated from step responses are compared in Fig. 5. A remarkable improvement in detection resolution is shown. Simulated resolution is also plotted on Fig. 5¹¹⁾. The simulation assumes rectangular domains on the actual medium of longitudinal magnetic recording. Resolution degradation arising from the crescent shape of the thermo-magnetically recorded domain has been anticipated, especially in the case of LS-MFM recording. But the experimental resolution almost matches the calculated resolution. This is due to the finite transition width of the longitudinal magnetic recording medium. There is a little difference between LS-MFM recording and LIM recording below 0.5- μm mark/space. This is because LIM-recorded domain becomes narrow when the length of the domain is shorter than 0.5 μm .

Second, we tried to detect an embossed-pit signal by using the GMR sensor. Sharing common address information is a key issue because preparing it for each channel leads to a degradation of format efficiency. Moreover, servo writing processes in conventional magnetic disk drives can be omitted by utilizing these signals detected from the embossed pits. Similar techniques using a longitudinal recording film have been reported¹⁰⁾⁻¹¹⁾. The flux-detected signal reflects magnetization direction and the shape of a substrate surface. In these methods, the recording film was initialized with a magnetic field according to the spacing between the magnetic head and the recording film. From the viewpoint of head-disk interface, shallow pits are favorable. Moreover, the shallow pits are desirable for manufacturing disk substrate, especially in the case of small pits. In the initializing process, we used heating by the optical spot, in addition to field-initializing, because the recording film's coercivity at a room temperature is too large. Namely, the recording film was heated in the initializing field to be magnetized uniformly as usual.

Fig. 6: Signal from embossed pits by optical detection.

Fig. 7: Signal from embossed pits by flux detection. Similar signal to optical detection was detected.

Fig. 8: Relation between the amplitude of flux-detected signal from the embossed pits and the off-track distance of the GMR sensor.

Then, in the opposite field of the initialization, it was heated again below the Curie temperature. It is well known that there is the difference of coercivity depending on the surface condition of the substrate¹²⁾. And in the second heating process, the magnetization in the area of

lower coercivity was reversed selectively. Figures 6 and 7 show the signals from the same pits detected by each detection method. The depth of the pits used for this experiment is about 160 nm, and the radial width is about 450 nm. The flux-detected signal is noisier than the optically detected signal because the pits were still deep and the signal amplitude is small. But it was confirmed that a similar signal can be detected by each method and the common embossed-pits of address information can be shared. A disk initializer can perform this initialization in short time. To shorten the initializing time more, it can be performed by a flash initialization.

In addition, in each method, it is also important to generate a tracking servo signal from common structures. In the optical disk system, methods of generating a tracking servo signal are roughly divided into two groups: continuous servo and discrete servo^{10), 11), 13)}. But the continuous servo method is inappropriate for the flux channel because there is no distinction of radial direction in the flux sensor. So applying the discrete servo method to the flux-channel is considered to be easier. Figure 8 shows the relation between the amplitude of the flux-detected signal from the embossed pits and the off-track distance of the GMR sensor. Track pitch is 1.6 μm . As the off-track displacement becomes larger, the amplitude of the signal becomes smaller. But the signal still remains at the middle of the two tracks. This is because the signal is detected from the adjacent track. Consequently, the tracking servo signal for the flux-detection channel can also be generated from wobbled pits, and the relative position between the optical spot and the flux detector can be controlled.

In this study, recording was carried out through the transparent substrate. But in the case of near-field recording, recording is made from the surface side of the medium. So both sides of the recording medium can be utilized for recording. The optics are used mainly for recording and detect only reflectivity. Therefore the energy efficiency of the optics can be improved. Moreover, the flux detection contributes to a robust design because the aberration of optics has no influence on the reproduced signal.

4. Summary

We have developed a new recording method combining thermo-magnetic recording and flux detection. Under the recording condition of the latest MO disk drive (0.4 $\mu\text{m/bit}$), the C/N ratio of the flux-detected signal from the shortest repetition pattern (mark/space: 0.53 μm) was 5 dB higher than that of the optically detected signal. According to the flux detection, a 47-dB C/N ratio is estimated to be detected at about 0.18- μm mark/space. This corresponds to the 0.13- $\mu\text{m/bit}$ linear density of

(1, 7) encoding, and the areal density will reach about 8.3Gbit/inch² when track pitch is set to 0.6 μm . This method has good affinity with near-field optics such as SIL. The areal density can be further boosted by improving the media and detection sensitivity and by utilizing the near-field optics. Moreover, by using the thermally-selective initialization, the addressing information of the optical channel is shared with the flux channel.

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