READING A 0.2μm MARK USING THE MSR METHOD

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Abstract- This paper describes the MSR method for high density recording. A series of tests was conducted using magnetic field modulation combined with a laser pulse. A slider embedded with a tiny permanent magnet was developed as an initializing magnetic head. A 680 nm wavelength laser and a 0.55 NA magneto-optical head were used for recording and reading. A MSR disk is made suitable for use combining of NRZi modulation and magnetic field modulation. Using the above, we confirmed the practicality of the MSR disk at a minimum mark length of 0.2μm (0.2μm/bit).

KEYWORDS: MAGNETICALLY INDUCED SUPER RESOLUTION (MSR), DOUBLE MASK, INITIALIZING MAGNET, MAGNETIC FIELD MODULATION (MFM)

INTRODUCTION

Magnetically induced super resolution (MSR) has been proposed as a solution technique to enhance high-density magneto-optical recording [1]-[4]. There are three types of MSR: front aperture detection (FAD), rear aperture detection (RAD), and the double mask type, which combines FAD and RAD. Double mask type MSR is excellent for not only small bit pitch, but also narrow track pitch [5]-[7]. It is highly effective for high density recording, however, a large magnetic field is required for initializing. Various ideas have been proposed as attempts to reduce or eliminate this initializing magnetic field [8]-[10]. We developed an initializing magnetic head having a slider embedded with a tiny permanent magnet. This paper describes the feasibility of achieving improvement with this initializing magnet and investigates the limitations of recording density in a tangential direction of the double mask type MSR disk.

TEST SAMPLE

Table I shows the composition of films in the double mask type MSR used for the experiment. Magnetic properties of the readout layer are shown in Fig. 1, and that of the recording layer in Fig. 2. As shown in Table I, magneto-optical film consists of four magnetic layers: readout layer, subsidiary layer, intermediate layer, and recording layer. These layers are almost the same as those of the double mask type MSR proposed by Kaneko et al[4]. The magnetic properties described in Fig. 1 and Fig. 2 are the saturation magnetization (Ms) and coercive force (Hc) of a single magnetic film. They are not properties measured in the multilayer composition.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick (nm)</th>
<th>Tc (°C)</th>
<th>Hc (kOe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readout Layer</td>
<td>GdFeCo</td>
<td>50</td>
<td>&gt;300</td>
</tr>
<tr>
<td>Subsidiary Layer</td>
<td>TbFeCo</td>
<td>10</td>
<td>170</td>
</tr>
<tr>
<td>Intermediate Layer</td>
<td>GdFeCo</td>
<td>5</td>
<td>200</td>
</tr>
<tr>
<td>Recording Layer</td>
<td>TbFeCo</td>
<td>40</td>
<td>280</td>
</tr>
</tbody>
</table>

Table I Film Composition of Double Mask type MSR

Fig.1 Magnetic Characteristics of readout layer
The readout layer is composed of GdFeCo. The Curie temperature of this layer is 300°C or more, and the coercive force at room temperature is approximately 100 Oe, which is extremely small (Fig. 1). Accordingly, the readout layer is magnetized in the planar direction at 100°C or higher in the case of a single layer. In the aforementioned four-layer structure, exchange coupling forces the readout layer to be magnetized perpendicular to the plane of the disk.

The recording layer is composed of TbFeCo and maintains a high coercive force up to its Curie temperature (Fig. 2). Stable recorded domains exist in this structure even at the elevated temperatures caused by irradiation by the readout beam [11].

Initializing at readout is achieved by collapsing the domains formed in the readout layer. According to bubble theory, the shrinking force for a given domain largely depends on the size of the domain. This means that the smaller the domain size, the easier it collapses. For mark positions recording, initializing is easier because all recorded marks are small and virtually identical. However, longer marks exist in mark edge recording, which is used for high density recording. In this case, a larger magnetic field is required for initializing.

Fig. 3 shows experimental results of the test sample disk for dependence of required magnetic field on the size of mark. The figure shows magnetic field modulation (MFM) recording after pre-erasing, which is the same method used before recording in conventional light intensity modulation (LIM) recording. However, initializing was impossible under 7 kOe, when signal is recorded with MFM without pre-erasing.

In the case of MFM recording as deposition, recorded domains are not always closed. Therefore, a larger magnetic field is required since the domain wall does not effectively shrink, even in the readout layer where the state of the recording layer is copied. However, recorded domains are closed by pre-erasing because it forms a magnetizing area that is wider than the recorded mark width in one direction. Consequently, initializing requires only a small magnetic field due to the effective shrinkage of the domain wall. These conditions remain unchanged after repeated overwriting by MFM recording.

As shown in Fig. 3, initializing can be achieved with only a 4 kOe magnetic field, even for long recorded marks, by magnetizing between the tracks when manufacturing disks.

**INITIALIZING MAGNETIC HEAD**

The first double mask type MSR proposed could read out at high resolution but required a large initializing magnetic field for readout. However, we have developed an initializing magnetic head for MSR that requires a large initializing magnetic field (Fig. 4). Our initializing head employs a 2-mm thick slider embedded with a pair of tiny permanent magnets composed of NdFeB. One tiny permanent magnet is magnetized and generates the magnetic field for initializing. The other tiny permanent magnet is attached to maintain balanced weight. This one is not magnetized. The two tiny permanent magnets are made of the same materials and are otherwise identical.

Properties of the permanent magnet are shown in Fig. 5. As indicated in the Figure, a magnetic field of 4 kOe or above, which is required for initializing, is achieved by set-
ting the flying height to a maximum of 120 \mu m, because the distance from magnetic pole to slider surface is set to 80 \mu m. If the developed slider is used together with the previously developed disk coated with overcoat resin [12], it can be used as a contact type at low scanning velocity and a flying type at high scanning velocity.

**RECORDING METHOD**

We used an optical head with wavelength of 680 nm and NA 0.55 for recording and readout. One of the major characteristics of MSR is that it is able to identify and read out recorded marks smaller than the beam spot size. In other words, MSR has superhigh resolution. However, to realize this, marks smaller than the beam spot size must first be recorded.

Fig. 6 shows the dependence of readout signals, and Fig. 7 shows the dependence of recording noise on recording power when a 0.2 \mu m mark is recorded. In these figures, (a) is LIM recording with a duty ratio of 15\%, (b) is MFM recording with a continuous LD beam, and (c) is MFM recording with a pulsed LD beam having a duty ratio of 30 \%, in which pulse width is the same as that of LIM recording. In both figures, recording power is normalized at the minimum LD power for forming the recorded domain.

In LIM recording, noise level at suitable recording power is low, but the recording power allowance is as small as ±2\%, which is not practical for high-density recording. This is because adjacent recorded marks overlap, even if recording power only slightly exceeds the allowance.

In MFM recording, on the other hand, adjacent marks never overlap, even with excess recording power. Therefore, the receding power allowance is wider than ±20\%. However, the noise level is somewhat high in both continuous and pulsed LD beams. The cause of this noise has not yet been identified; however, a) the noise is reduced when recording at low power with MFM and pulsed LD, b) the noise is increased when recording at high power with LIM, and c) we have found that the noise is reduced when...
recording at low scanning velocity with longer pulse intervals. Accordingly, we can safely assume that the next mark is recorded before temperature decreases in MFM recording. The small temperature gradient used to identify the boundary of recorded marks causes a deviation in the position of the boundary of recorded marks.

Fig. 8 shows the relationship between recorded mark width and recording power in MFM recording. As shown in the figure, expansion in the width of the recorded mark due to excess recording power in MFM recording with a continuous LD beam differs from that in MFM recording with a pulsed LD beam. The restriction of narrow track pitch is determined by recording width, taking into account damage to information recorded on the adjacent track. We therefore decided to use MFM with pulsed LD beam, which can suppress expansion of mark width even at excess recording power.

Fig. 9 shows the dependence of MSR readout signal on mark length. In MSR, the aperture area used for readout signals is limited. Therefore, compared to the conventional disk, readout output signal level is low for long recorded marks, but there is less of a decrease in output for small recorded marks. This is attributable to the temperature range for the MSR opening aperture. The temperature range of the test sample MSR disk was a narrow 20°C.

Table II shows the relationship between the minimum mark length and data window at a density of 0.2μm/bit. Here, we adopted NRZi from the viewpoint that the most suitable modulation method for MSR is one that assures a wide data window even though the minimum mark length becomes shorter.

### Table II. Relationship between the Minimum Mark Length and Data Window at a density of 0.2μm/bit

<table>
<thead>
<tr>
<th>Method</th>
<th>Minimum Mark Length</th>
<th>Data Window</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRZi</td>
<td>0.20 μm</td>
<td>0.20 μm</td>
</tr>
<tr>
<td>1,7RLL-NRZi</td>
<td>0.27 μm</td>
<td>0.13 μm</td>
</tr>
<tr>
<td>2,7RLL-NRZi</td>
<td>0.30 μm</td>
<td>0.10 μm</td>
</tr>
</tbody>
</table>

### READING CHARACTERISTICS

Based on the above viewpoint, we used the newly developed initializing magnetic head to read out mark edge recording by NRZi modulation and MFM recording with a pulsed LD beam. The recording laser beam was synchronously pulse-driven with the clock. Readout magnetic field was about 200 Oe. Fig. 10 shows eye-pattern and jitter distribution for minimum mark lengths of 0.16, 0.20, 0.24, and 0.28 μm. At the minimum mark length of 0.16 μm, resolution of the eye pattern is insufficient due to poor S/N, but the minimum mark length of 0.20 μm could be completely identified. Fig. 11 shows edge-to-edge jitter (the standard deviation) for the data window. As shown in the figure, there is a large difference in jitter between the leading edge and the trailing edge. One cause is the asymmetrical shape of the aperture, but the following phenomenon can be considered the dominant cause.
Fig. 10  Eye Pattern and Jitter Distribution for Minimum Mark Lengths of 0.16, 0.20, 0.24 and 0.28 μm.
When the external readout magnetic field helps magnetic reversal in the aperture while operating MSR, magnetic reversal occurs instantaneously and jitter is reduced. On the contrary, when the external readout magnetic field disrupts magnetic reversal, transfer of domain wall slows down and it takes longer to respond to magnetic reversal. Therefore, the direction of readout magnetic field causes a difference in the amount of jitter.

Results shown in Fig. 10 and Fig. 11 use a symmetrical 3-tap equalizer. As seen in Fig. 11, we obtained a trailing edge jitter of about 8% and a leading edge jitter of about 13%, at the minimum mark length at 0.2 μm (0.2 μm/bit).

CONCLUSION

We have developed an initializing magnetic head that employs a slider embedded with tiny permanent magnets. Our initializing magnetic head generates an initializing magnetic field of 4 kOe or more to enable MSR, which requires an initializing magnetic field, to read out without a large initializing magnet. As is known, MSR disks are suitable for use by adopting the combination of NRZI modulation and MFM recording with a pulsed LD beam. Using a combination of the above and a magneto-optical head of 680 nm laser wavelength and NA of 0.55, we confirmed the practicality of the MSR disk at a minimum mark length of 0.20 μm (0.2 μm/bit). The recording power allowance was greatly improved, and a power allowance of more than ±20% was obtained. These result clearly demonstrate that the MSR disk has a high potential for practical application.

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REFERENCES