**MSR MEDIA USING IN-PLANE MAGNETIZATION LAYERS WITHOUT READOUT BIAS MAGNET**

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**Abstract** - We have proposed magnetically induced super resolution (MSR) media consisting of three magnetic layers with in-plane magnetization films (T-MSR). T-MSR realize high MSR performance without readout bias magnetic field. Of two types of T-MSR, exchange-coupled media is suitable for stable readout than magnetostatic-coupled media. The recording density and data transfer rate are estimated to be 3.5 Gbit/inch² and 6 MByte/se, respectively using an optical head with wavelength of 680nm and numerical aperture of 0.55.

**KEYWORDS:** MAGNETO-OPTICAL, MSR, IN-PLANE MAGNETIZATION, RECORDING DENSITY

1. **Introduction**

The demand for optical disks with large capacity is now rapidly increasing for consumer products. In this regard, the combination of high storage capacity media and simplified drive units with low power consumption is important in the growing acceptance of optical storage products in the marketplace.

Among the various kinds of optical disks, magneto-optical (MO) disks can store huge capacity beyond the diffraction limit of light by magnetically induced super resolution (MSR) [1]. Recently various kinds of MSR methods have been proposed, which can be classified into two groups; one which needs a readout magnetic field and the other which does not. For consumer products it is not desirable to require the application of magnetic field for readout, because this increases power consumption and/or makes drives expensive. However, with media having an in-plane magnetization layer that require no readout magnetic field, it was difficult to achieve sufficient MSR characteristics due to the gradual transition from in-plane to perpendicular magnetization.

To overcome these problems, we have developed a new type of MSR media which consists of triple magnetic layers having two in-plane magnetization layers (T-MSR) [2][3][4]. T-MSR can form a double mask, consisting of an improved front mask with in-plane magnetization layers and a rear mask having good resolving power by collapsing written domains by internal field within the media. Therefore, T-MSR can eliminate the need to apply an external magnetic field for readout, while achieving high C/N and low crosstalk.

This paper describes the readout mechanism and the read/write performance of T-MSR, in comparison with other MSR media. First, we will compare various MSR methods from a fundamental point of view. Next we will describe how a double mask can be created while achieving high C/N and low crosstalk. Then we will discuss the basic performance of T-MSR, with regard to its reliability, potential for high capacity and its high data transfer rate.

2. **Comparison of MSR methods**

Table 1 shows characteristics of present typical MSR methods. There are several MSR detection methods such as front aperture detection (FAD), rear aperture detection (RAD), double mask detection and center aperture detection (CAD). FAD can increase only linear density, whereas other methods can increase both linear and track density.

As for the magnetization of readout layer at room temperature (RT), the present MSR media are classified into media with perpendicular magnetization layers, and media with in-plane magnetization layers. Although the originally proposed media with perpendicular magnetization layers require large initializing field to achieve high track density, recently developed MSR

<table>
<thead>
<tr>
<th>MSR method</th>
<th>Magnetization at RT</th>
<th>Magnetic field (kA/m)</th>
<th>Number of magnetic layers</th>
<th>C/N (dB)</th>
<th>Ref.</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>initialize</td>
<td>readout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAD</td>
<td>Perpendicular</td>
<td>0</td>
<td>24</td>
<td>3</td>
<td>46 &lt;</td>
</tr>
<tr>
<td>RAD</td>
<td>Perpendicular</td>
<td>240</td>
<td>24</td>
<td>4</td>
<td>46 &lt;</td>
</tr>
<tr>
<td>Double mask</td>
<td>Perpendicular</td>
<td>240</td>
<td>24</td>
<td>4</td>
<td>46 &lt;</td>
</tr>
<tr>
<td>CAD</td>
<td>In-plane</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>34-40</td>
</tr>
<tr>
<td>T-MSR(Double mask)</td>
<td>In-plane</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>46 &lt;</td>
</tr>
</tbody>
</table>

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media do not need initializing field. However, they still need a readout field of 24kA/m.

In general, the magnetic field generation efficiency of flying magnetic head is about 80A/m2. Therefore, when a flying magnetic head for magnetic field modulation (MFM) overwriting is used as the readout field, the magnetic head driving current is 300mA for 24kA/m and the total power consumption of the magnetic head and driver circuit exceeds 1 W. Power consumption increases more with a non-head type magnetic coil. These high power consumptions are not suitable for portables like the Mini Disc (MD). When a permanent magnet is used, drives become expensive, and MFM overwriting is difficult to execute.

On the other hand, media with in-plane magnetization layers do not need external bias fields for readout. This is because the magnetization orientation of the readout layer in the media changes from in-plane to perpendicular, as the temperature rises, so that the marks in the most heated area can be detected while the adjacent marks are masked. Of the two types of non bias field media, T-MSR can achieve higher C/N than CAD media, and has low crosstalk.

In the next chapter, we describe the detection method of our media and how they improve MSR characteristics.

3. MSR readout mechanism

Figure 1 shows the readout mechanism of T-MSR. By changing the composition of the intermediate layer, two types of MSR media, exchange (EC-MSR) and magnetostatic (ST-MSR) media can be realized. During the readout, both media are considered to exhibit MSR, with an aperture and double mask which consist of the following three areas.

In the low-temperature area, the readout layer and the intermediate layer have in-plane magnetization, and act as the front mask for both EC-MSR and ST-MSR, masking the recorded information in the memory layer. A stable front mask can be formed by strong in-plane magnetization of the intermediate layer.

In the intermediate-temperature area, the aperture is formed differently in the two media. In EC-MSR, the readout layer is a perpendicularly magnetized film, and the recorded information in the memory layer is copied onto it by exchange coupling. In ST-MSR, on the other hand, the Tc of the intermediate layer is so low that the exchange coupling between the readout and memory layers is cut, and the readout layer almost simultaneously becomes perpendicularly magnetized, thus copying the information in the memory layer onto the readout layer, by magnetostatic coupling.

In the high-temperature area, the magnetic direction of the readout layer is switched to the erase state to form the rear mask in both ST-MSR and EC-MSR.

![Fig. 1 MSR readout mechanism of T-MSR](image)
3.1 Front mask

Figure 2(a) and (b) shows remanent Kerr rotation $\theta_{kr}$ for double-layer films (CAD) and triple-layer films (T-MSR), respectively. In double-layer films, the transition does not occur suddenly at a temperature but does occur gradually over a wide range of temperatures. Although $\theta_{kr}$ at RT can be made almost zero by increasing the Gd content, the transition takes place more gradually and $\theta_{kr}$ does not reach its saturation value even at 180°C. This is because the interface wall appearing around the boundary between the two layers deeply penetrates the GdFeCo layer (Fig. 3(a)). Controlling the exchange coupling force or interface magnetic wall is a key point in improving the masking effect of in-plane magnetization film.

Therefore, we controlled the behavior of the interface wall by inserting an intermediate layer between the readout and memory layers. For high speed recording, the lower part (intermediate layer side) of the GdFeCo layer was removed to maintain the total thickness of magnetic layers constant. Using an intermediate layer having low Tc and strong in-plane magnetization at RT to control the exchange coupling force, the front masking by in-plane magnetization layer is improved (Fig.2(b)). More important point is that, in the case of higher Gd content, the triple layer films show a sudden transition namely a very steep slope of $\theta_{kr}$ while attaining zero $\theta_{kr}$ at RT. For T-MSR, the masking effect is improved, because the tendency of magnetic alignment towards the perpendicular is prevented by the decrease of the exchange coupling force due to the strong effective in-plane magnetic anisotropy of the intermediate layer (Fig. 3(b)).

The triple-layer media were confirmed to achieve carrier to noise ratio (C/N) at least 4dB higher than the double-layer media at low power due to improved front mask for a mark length of 0.40μm using a conventional optical unit with wavelength of 780nm and numerical aperture of 0.55 (Fig. 4).

3.2 Rear Mask

In Fig. 4, C/N steeply increased at high power of 3mW. This is because of the formation of a rear mask.
having clear boundary between the mask and the aperture due to turning of perpendicular magnetization. A more important point is that the rear mask is created without applying external magnetic field.

The MSR originally proposed requires the external magnetic field to create the rear mask at high temperatures. This condition has been expressed as eq. (1) where \( H_r, H_c \) and \( H_{wi} \) are the external readout magnetic fields, coercivity of the readout layer and the effective magnetic field due to exchange-coupling between the readout layer and the memory layer, respectively [1].

\[
H_r > H_c + H_{wi}
\]  

(1)

However considering the fact that the copied mark is affected not only by \( H_r \) and \( H_{wi} \), but also by effective magnetic field caused by Bloch wall energy \( H_{wb} \), magnetostatic fields such as the leakage field from the readout layer \( H_{leak} \) and from the memory layer \( H_s \) (Fig. 5), the masking condition is expressed more precisely by eq. (2).

\[
H_{wb} - H_{leak} + H_r > H_c + H_{wi} + H_s
\]  

(2)

Fig. 5 The possible effective magnetic fields applied to the copied domain in the readout layer (Exchange-coupled T-MSR).

Therefore, masking occurs even without applying \( H_r \) when \( H_{wb} \) and \( H_s \) work to collapse the copied mark. T-MSR can form a rear mask by the effect of such magnetic fields within the media, instead of applying an external field \( H_r \).

4. Read and write performance

In this chapter, we will discuss the read/write performance of T-MSR with regard to reliability, linear/track density and the data transfer rate.

4.1 Read power dependence of carrier and noise

It is desirable to reduce read power to obtain wide power margin and prevent thermal damage of domains. MSR read power can be reduced from 3.5mW to 2.5mW by decreasing the medium reflectivity from 23% to 18%, resulting in a possible wide read power margin. As shown in Fig. 6(a), for this low-reflectivity medium, the temperature rises at a lower power level, so the read power can be reduced. At the same time, \( T_c \) of the memory layer can be increased, thus an effective widening of the read power margin is possible (Fig. 6(b)).

The waveform of EC-MSR at read power of 2.5mW shows a steep rise caused by fast switching from the in-plane magnetization area to the aperture area (Fig. 7(a)). At read power of 3.0mW, the carrier level sharply increases (Fig. 4), and the rear mask is formed. This can also be inferred from the steep decline, as well as the steep rise of the front mask in the waveform (Fig. 7(b)). This phenomenon is also observed in ST-MSR, although with reverse polarity, since the sublattice moment in the

![Fig. 6](image-url)
readout layer is antiparallel to that in the memory layer (A-type). Wave form of the double mask is symmetrical. It can be more advantageous to detect the mark than nonsymmetrical detection, such as, FAD or RAD.

![Waveform of isolated marks of 0.4μm length written with 1.2 μm spacing in EC-MSR.](image)

(a) Read power: 2.5mW

(b) Read power: 3.5mW

Fig. 7 Waveform of isolated marks of 0.4μm length written with 1.2 μm spacing in EC-MSR.

4.2 Influence of magnetic field during readout
As for reliability of the MSR media, it is necessary to stabilize copied domains during readout. As for the coupling strength between the readout layer and the memory layer, magnetostatic coupling is weaker than exchange coupling, and is the locally acting force which is strongly dependent on adjacent magnetic states. Therefore, of our two types of media, the exchange-coupled media has a wider margin of magnetic field due to strong exchange-coupling, resulting in a more stable readout (Fig.8).

4.3 High linear density and High track density
Figure 9 shows C/N as a function of the mark length for MSR media and the conventional disk. EC-MSR or ST-MSR shows better C/N value than conventional disks and a high C/N of over 46 dB can be achieved at a mark length of 0.40μm. C/N using conventional detection, decreases rapidly at short mark lengths below about 0.40μm due to the ideal cut-off mark length (λ/4NA) of 0.37μm.

Figure 10 shows the results of crosstalk measurements at the effective track pitch of 0.8μm. The crosstalk was measured between land with recorded marks of 0.80μm length and its adjacent grooves for which no mark was recorded as shown in Fig. 10(a). In ST-MSR, the front mask is improved by the strong in-plane anisotropy of the intermediate layer. The crosstalk of ST-MSR is -38dB, and is approximately -10dB better than that of EC-MSR. However the EC-MSR's crosstalk of -28dB is enough to realize a track pitch of 0.8μm. As a result of our media's unique structure, high C/N of 45dB at a mark length of 0.4μm, and low crosstalk of less than -28dB at a track pitch of 0.8μm can be realized with a wavelength of 780nm and NA of 0.55 (Fig.5, 6).

When the wavelength of laser of 680nm is used instead of 780nm, the minimum mark length and track pitch would expected to be 0.35μm and 0.7μm, instead of 0.40μm and 0.8μm, respectively.

Consequently, with T-MSR, by an (1,7) RLL code, a mark length recording, the areal density of the T-MSR disk is estimated to be 3.5 Gbit/inch² at a wavelength of 680nm for a mark length of 0.35μm and track pitch of 0.7μm.

![Mark length dependence of C/N for EC-MSR, ST-MSR and conventional disks.](image)

Fig. 9 Mark length dependence of C/N for EC-MSR, ST-MSR and conventional disks.
4.4 High data transfer rate

Overwriting is an effective way of increasing the data transfer rate when recording data. Magnetic field modulation (MFM) overwriting and light intensity modulation overwritings have been proposed as data overwriting methods.

A MFM recording is considered to be an advantageous way to obtain a high-density, mark length recording, since MFM recording is free of any thermal interference in the recording process. Figure 11 shows the writing magnetic field dependence on C/N of EC-MSR. The C/N was almost saturated at a recording magnetic field of 12kNm, and was completely erased at -16kA/m. These magnetic field values are small enough to employ magnetic field modulation recording.

As for the data transfer rate during readout, T-MSR can also make the aperture area in the center of the light spot even at high linear velocity, so that high readout performance and a high data transfer rate can be both realized. Even at a high linear velocity of 12m/s, a high C/N of 45dB could be achieved at a mark length of 0.4μm.

Consequently, with T-MSR, by an (1,7) RLL code, a mark length recording, the areal density of the T-MSR disk is estimated to be 3.5 Gbit/inch² at a wavelength of 680nm for a mark length of 0.35μm and track pitch of 0.7μm. When linear velocity is 12.9 m/s, the data transfer rate is estimated to be 6 MByte/sec by

5. Conclusion

We have investigated MSR disks using three magnetic layers with in-plane magnetization films. These MSR disks show promise as a next-generation high-density MO disk, because they have a higher linear and track density than conventional disks and eliminate the need for complex drive units and high power consumption to apply magnetic field during readout. With our media, the areal density and data transfer rate are estimated to be 3.5 Gbit/inch² and 6 MByte/sec, respectively.

Acknowledgment

The authors would like to acknowledge Mr. T. Hiroki and Mr. T. Okada of Canon Inc. for their collaboration in this work and Dr. T. Kobayashi of Mie University for valuable discussions.

References