Wall Simulation for the Domain Wall Displacement Detection (I)

Tadashi Kobayashi, Morio Masuda and Tsutomu Shiratori*
Dept. of Physics Engng., Mie Univ., Kamihama, Tsu, Mie 514-8507, Japan
*DM Project, Canon Inc., Shimomaruko, Ohta, Tokyo 146-8501, Japan

(Received October 2, 2000; Accepted October 31, 2000)

Abstract- Dependences of domain wall and interface wall on temperature have been simulated for the Domain Wall Displacement Detection, and the front process and the rear process have been considered. For the front process, abrupt decrease of the exchange-coupling contributes to small jitter of the wall displacement of the displacement layer. There exists magnitude of external magnetic field where the front process can arise and the rear process cannot in the displacement/switching/memory structure. For the rear process, the control layer disturbs that the interface wall spreads to the displacement layer, as a result, critical mark length for the ghost can be elongated in the displacement/control/switching/memory structure.

Key words: magneto-optical recording, Domain Wall Displacement Detection, wall motion, exchange-coupling, interface wall

1. Introduction

The Domain Wall Displacement Detection (DWDD)\(^1\) is a promising candidate for high density magneto-optical recording with minimum mark length less than 0.1\(\mu\)m.

The medium of the DWDD is composed by the displacement (denoted as D) layer, (the control (C) layer), the switching (S) layer and the memory (M) layer. The DWDD consists of three stages, that is (i) the start of the front process, (ii) wall motion, and (ii) the rear process. In this paper of (I), (i) the start of the front process and (ii) the rear process have been discussed using the calculation of the domain wall and the interface wall. We will describe (ii) the wall motion in the paper of (II).

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>displacement</td>
<td>300</td>
</tr>
<tr>
<td>switching</td>
<td>100</td>
</tr>
<tr>
<td>memory</td>
<td>800</td>
</tr>
<tr>
<td>control</td>
<td>50</td>
</tr>
<tr>
<td>switching</td>
<td>100</td>
</tr>
<tr>
<td>memory</td>
<td>800</td>
</tr>
</tbody>
</table>

Fig. 1 Disk structures of (a) displacement/switching/memory layer structure and (b) displacement/control/switching/memory structure.

2. Calculation method

Thickness and Curie temperature of each layer are summarized in Fig. 1. The D layer is made of Gd base heavy rare earth-3d transition metal (RE-TM) film, and other layers are made of Tb base RE-TM films.

Temperature dependence of magnetic properties in each layer is calculated by the ordinary mean field method\(^2\). The interface wall energy is calculated by the noncontinuum mean field method\(^3\) and the Andrá's method\(^4\). The wall coercivity of the D layer is assumed to be proportional to the anisotropy field of the D layer. The calculated and measured magnetization and wall coercivity of the D layer are shown in Fig. 2. Composition of the D layer is chosen so that the magnetization is to be small at the DWDD operation temperature due to small stray field and fast wall motion.

The interface wall energy plays an important role in the rear process. Figure 3(a) shows temperature dependence of the interface wall energy (the D/S/M structure) as well as the domain wall energies of the respective layers. During 430-410K, the interface wall energy increases with decreasing the temperature along the domain wall energy of the S layer. This behavior can be explained by two facts, that is (i) the S layer has the smallest domain wall energy among the three layers and (ii) the width of the domain wall of the S layer (~90\(\AA\)) is thinner than the thickness of the S layer (100\(\AA\)). Hence the interface wall is formed within the S layer as seen in Fig. 3(b) which shows angle of the magnetic moment through the film thickness. Below 410K, the interface wall energy increases along the domain wall energy of the D layer. Taking account of Fig. 3(b), the interface wall sees to the D layer below 410K.

Fig. 2 Magnetization and wall coercivity of the displacement layer.
Figure 3(c) shows temperature dependence of the domain wall widths of the respective layers. The wall width of the D layer is broad since the anisotropy is small. Small change of the widths against temperature can be seen.

Temperature profile as well as beam profile is shown in Fig. 4, where linear velocity of medium is 3 m/sec. Plus abscissa means the front side, and minus means the rear side. Position $x = 0$ indicates the center of light beam. Temperature gradient of the front side is larger than that of the rear side owing to the medium motion.

3. Start of the front process

The front process occurs under the condition of

$$\frac{\partial \sigma_s}{\partial x} > 2M_s(H_w - H_{ex}) + \frac{\sigma_w}{t},$$

(1)

where $\sigma_s$, $M_s$, $H_w$, $t$, $H_{ex}$ and $\sigma_w$ are the domain wall energy, the magnetization, the wall coercivity, the thickness of the D layer, external magnetic field and the interface wall energy, respectively. Figure 5 shows the relationship of Eq. (1). The right side of the figure is low temperature region and the left one high temperature one. The crossing point of $\partial \sigma_s / \partial x$ and $2M_s(H_w - H_{ex}) + \sigma_w / t$ is the start point of the front process. The domain wall should start to move with small jitter. Since $\sigma_w / t$ is very large at room temperature, $2M_s(H_w - H_{ex}) + \sigma_w / t$ decreases abruptly at around the crossing point. The abrupt decrease makes the jitter small.

If external magnetic field $H_{ex}$ is applied, the crossing point shifts to the right or the left according to the polarity of the magnetic field, and the slope of $2M_s(H_w - H_{ex}) + \sigma_w / t$ changes. The shift of the crossing point and the change of the slope are one possibility of edge shift and fluctuation of the jitter of reproduction signal, respectively. Another possibility will be explained in the paper of (II). Furthermore, the front process can be carried out under the magnetic field of 200 Oe. That is useful to the
suppression of the ghost signal by applying the magnetic field during readout\textsuperscript{7}.

4. The rear process

Figure 6(a) shows the interface wall energy and the domain wall energy of the D layer as a function of position. The right side of the figure is high temperature region and the left one low temperature one. When the temperature of the medium decreases to the Curie temperature of the S layer, the magnetization of the D layer begins to couple with that of the M layer (the position a). Decreasing the temperature, the interface wall increases. In the vicinity of the position b, the energy of the interface wall reaches that of the domain wall of the D layer, and the interface wall spreads over the D layer. Then, the magnetization of the D layer reverses, and two walls are created in the D layer. The right wall runs to the right side, that is the ghost signal.

If there is another wall in the M layer between the position a and b, the wall in the D layer is caught by the wall in the M layer. Therefore, the distance between the position a and b corresponds to the minimum mark length to generate the ghost signal. The distance is about 0.2\,\mu m, which is comparable to the experimental minimum mark length\textsuperscript{7}.

Next, let us consider the wall motion in the rear process. After the creation of two walls in the D layer, the condition of the wall motion in the right wall is

$$\frac{d\sigma_a}{dx} + \frac{\sigma_w}{\tau} > 2M_s(H_w - H_{str}).$$  \hfill (2)

Figure 6(b) shows the relationship of Eq. (2). The exchange-coupling helps the wall motion so that the area of the interface wall decreases. Without external magnetic field, the right wall runs to the right side (to the position of the maximum temperature). Under $H_{str} = -100$\,Oe that prevents the wall motion, the right wall is trapped near the position of a. From Fig. 5, $H_{str}$ of -200\,Oe does not prevent the front process, but on the other hand $H_{str}$ of -100\,Oe stops the wall motion at the rear process. That is the concept of the ghost suppression by external magnetic field\textsuperscript{7}.

Fig. 6 The rear process of the DWDD. (a) Creation of domain wall in the displacement layer and (b) wall motion in the displacement layer under external magnetic field.

Fig. 7 Model of the rear process.
Considering the results mentioned above, the model as shown in Fig. 7 is supposed for the rear process. The first wall of the M layer enters the area in which the temperature is lower than the Curie point of the S layer. The interface wall is formed in the S layer (a). When the first wall of the M layer reaches the position \( b \), the interface wall spreads over the D layer (b), and two walls are created in the D layer (c). The right wall in the D layer runs to the right side (c), (d). The right wall in the D layer is caught by the second wall in the M layer (d). The right wall in the D layer moves left together with the second wall in the M layer (e). That is no ghost reproduction.

The concept of the ghost suppression by the C layer\(^7\) can be explained by the interface wall energy. Figure 8(a) shows temperature dependence of the interface wall energy in the D/C/S/M structure. The S layer is put between the C and M layers which have larger domain wall energies. Therefore the interface wall energy increases with decreasing the temperature along the domain wall energy of the S layer. The interface wall is kept in the S layer as seen in Fig. 8(b) which shows angle of the magnetic moment through the film thickness. Decreasing the temperature, increasing the area of the interface wall, that is the increase of the energy. If the energy reaches to some critical point, the magnetization of the D layer reverses. Function of the C layer is cover to prevent that the interface wall seeps to the D layer. In other words, the C layer shifts the critical position \( b \) to left in comparison with that of the D/S/M structure. Consequently, the minimum mark length \((0.8\mu m)\) of the D/C/S/M structure\(^3\) becomes longer than that \((-0.2\mu m)\) of the D/S/M structure\(^5\).

**5. Conclusions**

The start of the front process and the rear process were discussed with the displacement/switching/memory structure and the displacement/control/switching/memory structure in the Domain Wall Displacement Detection.

For the front process, abrupt decrease of the exchange-coupling is thought to realize small jitter of reproduction signal.

The concept of the ghost suppression by external magnetic field can be explained by the difference of the driving force between the front side and the rear side.

The role of the control layer for the ghost suppression is cover to prevent that the interface wall seeps to the displacement layer.

**References**