READOUT SIGNAL ANALYSIS FOR LAND/GROOVE MAGNETO-OPTICAL DISKS WITH BOUNDARY ELEMENT METHOD

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Abstract - Three-dimensional Boundary Element Method (BEM) analysis of noise characteristics has been done to determine a suitable reproduction method for land/groove recording of magneto-optical disks. This analysis shows that groove depth fluctuation noise is much larger than groove width fluctuation noise or groove shape fluctuation noise. Noise in TM-polarization was also found to be lower than that in TE-polarization under calculation conditions which closely replicated practical disk conditions. The calculation results obtained agree well with experimental results. Finally, we propose a suitable reproduction method and substrate for use in magneto-optical disk land/groove recording.

KEY WORDS: magneto-optical disk, Boundary Element Method, land/groove, noise characteristics, polarization

INTRODUCTION

Recently, both land and groove area recording (land/groove recording) are considered highly attractive methods for achieving a high density magneto-optical disk[1,2]. One of the most important issues for land/groove recording is to optimize the land/groove shape and incident beam polarization. To attain this optimization, it is necessary to estimate the scattered light from a pre-grooved magneto-optical disk.

Many analyses of scattered light from optical disks have been performed with various methods, e.g., the scalar theory[3], the exact solution[4], the Boundary Element Method(BEM)[5,6], 2 × 2 matrices method[7,8]. However, scattered light from a pre-grooved magneto-optical disk has not been calculated while satisfying the boundary conditions. In order to solve this problem, we have developed a calculation method using the three-dimensional BEM[8,9,10]. Our method can calculate the scattered light from magnetic material with a groove, and estimate contributions of the groove and incident beam polarization to Kerr rotation.

Fig. 1 Calculation model.
equations. Because of the cross-dependence of each component, and the additional terms in the fundamental equations for isotropic magnetic materials, we use the iterative method. In this method, the equations for BEM in isotropic magnetic materials have a volumetric integral as follows:

\[ E_i = \int_{\Gamma} G \frac{\partial E}{\partial n} d\Gamma - \int \left( \int_{\Omega} (L + P) \cdot G d\Omega \right) \frac{\partial E}{\partial n} dS. \tag{3} \]

In this equation, \( E_i \) means electric field at an arbitrary point. \( E \) means \( E_x \) or \( E_y \) and \( L \) and \( P \) mean \( L_x \) or \( L_y \) and \( P_x \) or \( P_y \), which are defined as follows:

\[ L_x = -\frac{\varepsilon_{xx}}{\varepsilon_{xx}} \frac{\partial}{\partial y} E_x, \quad L_y = \frac{\varepsilon_{yy}}{\varepsilon_{xx}} \frac{\partial}{\partial x} E_y, \quad \tag{4} \]

\[ P_z = \left( \frac{\varepsilon_{xx}}{\varepsilon_{xx}} \frac{\partial}{\partial y} \frac{1}{\varepsilon_{xx}} + \frac{k_0^2 \varepsilon_{xy}}{\varepsilon_{xx}} \right) E_x, \quad P_y = -\left( \frac{\varepsilon_{xx}}{\varepsilon_{xx}} \frac{\partial}{\partial x} \frac{1}{\varepsilon_{xx}} + \frac{k_0^2 \varepsilon_{xy}}{\varepsilon_{xx}} \right) E_y. \tag{5} \]

\( \Gamma \) is a surface integral and \( \Omega \) is a volumetric integral. \( n \) is the normal vector and \( G \) is the Green function expressed as follows:

\[ G(r) = \frac{1}{4\pi r} \exp(-ikr). \tag{6} \]

In this equation, \( r \) is the distance between a boundary element and an arbitrary point. This is the same Green function as the one in free space. One of the merits in using the iterative method is that the Green function is simple like eq.(6). The equation for BEM in free space is the equation for which the volumetric term is subtracted from eq.(3).

The boundary conditions are determined by the following relations:

\[ E_i = \frac{E_x}{\gamma}, \quad \frac{\partial E}{\partial n} = \gamma \frac{\partial E}{\partial n}, \tag{7} \]

where subscripts 1 and 2 indicate regions 1 and 2, respectively. With these equations, the boundary conditions are defined as follows:

for TE-polarization,

\[ \gamma = 1, \tag{8} \]

and for TM-polarization,

\[ \gamma = \frac{n_1}{n_2}, \tag{9} \]

where \( n_1 \) and \( n_2 \) are refractive indices in the free space and an isotropic magnetic material, respectively.

By dividing the infinite surface into boundary elements and making a matrix in the same way as in conventional BEM, the electric fields at the infinite surface are calculated. Scattering light is obtained by using these electric fields, and Kerr rotation \( \theta \) is calculated by the following equation:

\[ \theta = \tan^{-1} \left( \frac{E_z}{E_x} \right) \cos(\phi), \tag{10} \]

where \( E_x \) and \( E_z \) are electric fields for the incident polarization component and the cross polarization component, respectively, and \( \phi \) is phase delay between \( E_x \) and \( E_z \).

We calculated noise caused by groove width fluctuation, groove shape fluctuation and groove depth fluctuation. Each type of noise was estimated by differentiating \( R \cdot \theta \) with respect to groove width \( w \), slope length \( s \) and groove depth \( d \) (see Fig.1). \( R \cdot \theta \) indicates the product of Kerr rotation angle and scattered beam intensity, which is proportional to the readout signals of a magneto-optical disk. Consequently, the equation for noise estimation is represented as follows:

\[ \text{Noise} = \left| \frac{\partial [R \theta(w, s, d)]}{\partial X} \right|, \tag{11} \]

where \( X \) is \( w, s \), or \( d \).

**CALCULATION RESULTS**

The calculation parameters we used in our analyses are summarized in Table 1. We used an incident beam with a wavelength of 680nm and a beam waist of 80nm, which corresponds to a 0.5 numerical aperture (NA) of an objective lens. The beam is incident along the \( z \)-direction and is focused on the zero point, which is set at the center of a land or a groove. In this paper, lands and grooves correspond to the concave and convex grooves in magnetic materials, respectively. The free space has a relative dielectric constant of 1. The magnetic material has \( \varepsilon_{xx} \) of 2 and \( \varepsilon_{yy} \) of 0.1, values which cause Kerr effect. If \( \varepsilon_{xx} \) or \( \varepsilon_{yy} \) has imaginary part, much smaller boundary elements than we used are required because of rapid change of Green function. Therefore, we chose the values of \( \varepsilon_{xx} \) and \( \varepsilon_{yy} \) listed in Table 1. We can obtain qualitative results by these parameters. In our analyses, we calculated scattering light intensity and Kerr rotation at the distance of \( 10^4 \lambda \) from the zero point. This distance is almost the same as the actual distance between a magneto-optical disk and an optical head.

Figure 2(a) shows the groove width fluctuation noise obtained when the groove shape is rectangular and the groove depth is 85nm. In almost all ranges of groove width, land noise in TE-polarization and groove noise in TM-polarization are higher than in other reproduction methods. The groove width dependence of \( R \cdot \theta \) is shown in Fig.2(b). As shown in ref.[9], \( R \cdot \theta \) of lands is larger than that of grooves in TM-polarization and vice versa in TE-polarization. It is confirmed in ref.[9] that these characteristics are mainly caused by the difference in \( \theta \). Additionally, \( R \cdot \theta \) levels for lands in TE-polarization and for grooves in TM-polarization are much lower than that.
of a plane surface which corresponds to \( w=0 \) or \( w=\infty \), in comparison with \( R \cdot \theta \) levels of other reproduction methods. Because of this fact, the differential with groove width for them is much larger than in other reproduction methods in almost all ranges of groove width.

Figure 3 shows the groove shape fluctuation noise and the slope length dependence of \( R \cdot \theta \) when the groove width is 680nm and the groove depth is 85nm. In addition to the groove width fluctuation noise, the land noise in TE-polarization is larger and that in TM-polarization is smaller in almost all ranges of slope length. On the other hand, where groove depth is around 130nm, reverse is true. The relationship is a little complicated at a groove depth of around 85nm, which corresponds to the value of \( \lambda/8 \).

Figure 4(c) shows groove depth dependence of \( R \cdot \theta \) when groove width is 680nm and slope length is 170nm. The relationship among the noise levels near the 50nm groove depth is nearly the same as that among the groove methods. On the other hand, where groove depth is around 130nm, reverse is true. The relationship is a little complicated at a groove depth of around 85nm, which corresponds to the value of \( \lambda/8 \).
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width fluctuation noise. This is because $R \cdot \theta$ levels of lands in TE-polarization and those of grooves in TM-polarization are much lower than that of a plane surface which corresponds to $d=0$, in comparison with $R \cdot \theta$ levels of other reproduction methods. As a result,

(a) $TM, Land$  
  $TE, Land$  
  $TM, Groove$  
  $TE, Groove$

(b) $TM, Land$  
  $TE, Land$  
  $TM, Groove$  
  $TE, Groove$

(c) $TM, Land$  
  $TE, Land$  
  $TM, Groove$  
  $TE, Groove$

Fig.4 Groove depth fluctuation noise and $R \cdot \theta$ as a function of groove depth when groove width is 680nm (Calculation results)

(a) groove depth fluctuation noise with slope length of 0nm 
(b) groove depth fluctuation noise with slope length of 170nm 
(c) $R \cdot \theta$ with slope length of 170nm.

Near 130nm groove depth, $R \cdot \theta$ levels of lands in TE-polarization and those of grooves in TM-polarization approach their minimums, although groove depth is not 170nm where scattered light intensity generally reaches minimum value. This phenomenon is the reason that land noise in TE-polarization and groove noise in TM-polarization are smaller near a groove depth of 130nm.

Next, we compare the three types of noise to find which type is the most dominant. Figure 5 compares the three type of noise when groove width is 680nm and groove depth is 85nm. Two results, for slope lengths of 0nm and 170nm, are shown. In both cases, the groove depth fluctuation noise is extremely large, while the groove width fluctuation noise is small. Thus, the main noise source is considered to be the groove depth fluctuation.

In order to investigate the main noise characteristics on practical magneto-optical disks, we calculated the groove depth fluctuation noise as a function
of groove width at a groove depth of 85nm. Two results, for slope lengths of 0nm and 170nm, are shown (Fig.6). Under these conditions, the noise in TE-polarization tends to be larger than that in TM-polarization, with the TE-polarization land noise being the largest and the TM-polarization land noise being the smallest throughout the entire groove width range.

EXPERIMENTAL METHOD AND RESULTS

We carried out verification experiments to confirm the results we obtained in our calculations. We measured the recording frequency dependence of carrier level, noise level and C/N ratio for a land/groove magneto-optical disk. In this measurement, incident beam wavelength was 685nm, and linear velocity was fixed at 9.42m/s. Recording power was 5mW and objective lens NA was 0.55. A GdFeCo/TbFeCo disk [1] with 1.2 μm track pitch was used, where the land width was 0.53 μm and the groove width was 0.57 μm. The land depth and groove height are about 50nm. The slope angles of the lands and grooves in this disk are considered to be nearly equal to those of the lands and grooves with 170nm slope length in our calculations.

Figure 7 shows the recording frequency dependence of carrier level and noise level for combinations of lands or grooves and incident beam polarizations. The noise level in TE-polarization is higher than that in TM-polarization throughout the entire
recording frequency range. Moreover, the noise on lands in TE-polarization is relatively high and that on lands in TM-polarization is relatively low. These results agree with the calculated results. In TM-polarization, the carrier level of lands is higher than that of grooves in almost the entire range of recording frequency, and in TE-polarization, the carrier level is lower. These relations among lands, grooves and polarizations match the calculation results, as shown in ref. [9].

The noise level results suggest that TM-polarization is better than TE-polarization in both lands and grooves. On the other hand, in terms of carrier level, TM-polarization is better than TE-polarization when recorded marks on lands are reproduced, and vice versa when those on grooves are reproduced.

In order to consider a suitable reproduction method in terms of total readout signal, figure 8 shows the recording frequency dependence of C/N ratio for various land, groove and polarization combinations (Experimental results).

![Recording frequency dependence of C/N ratio for various land, groove and polarization combinations](image)

Fig. 8

In order to consider a suitable reproduction method in terms of total readout signal, figure 8 shows the recording frequency dependence of C/N ratio for various land, groove and incident beam polarizations. The C/N ratio for lands in TM-polarization is the largest and that for lands in TE-polarization is the lowest. The C/N ratio for grooves is almost the same in both TE- and TM-polarization. Thus, TM-polarization is better than TE-polarization when recorded marks on land are reproduced in land/groove recording. Although the C/N ratio for grooves is almost same in both TE- and TM-polarization, TE-polarization is better when recorded marks on grooves are reproduced, because of its low cross-talk. The above-mentioned reproduction method can produce the highest C/N ratio and the lowest cross-talk in both lands and grooves.

In land/groove recording, the same C/N ratio in both lands and grooves is also one of the important issues from the standpoint of drive technology. If the same C/N ratio in both lands and grooves is high in the priorities, it is recommended to use a substrate whose land width is not equal to groove width, because of groove width dependence of carrier, as shown in Fig. 2(b). For both polarizations, we can obtain the same C/N ratio for both lands and grooves, in this type of substrate. When this type of substrate is used, TM-polarization is obviously better than TE-polarization from the viewpoint of high C/N ratio, as seen in Fig. 8.

CONCLUSION

We have analyzed magneto-optical disk noise by using our analysis method [8,9,10], in order to determine the most suitable reproduction method and substrate for land/groove recording. Three types of noise - for fluctuation in groove width, groove shape and groove depth - were calculated. The calculations indicate that the groove depth fluctuation is the main noise source. Experimental results were found to agree with calculated results. Considering the carrier [9] and noise characteristics for polarizations and grooves, we propose the following approaches for land/groove recording:

1. Use of a substrate in which the land width is not equal to the groove width,
2. Use of a reproduction method where lands and grooves are reproduced by TM- and TE-polarization, respectively.

With the first method, we can obtain the same readout intensity for both lands and grooves. In this method, TM-polarization is more suitable for obtaining high C/N ratio. With the second one, maximum readout intensity and low cross-talk can be accomplished.

REFERENCES