High density recording using an ordinary structured MO disk with field modulation

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Abstract - SNR of a polycarbonate MO disk with a narrow track of 0.85 μm and with a quadrilayer structure was improved by optimizing and improving the groove geometry, film composition / thickness, and birefringence of the substrate. By using a 690 nm LD, an NA of 0.55, magnetic field modulation, and RLL(1,7) coding, a high areal recording density of 2.5 Gbit/in² was obtained. Moreover, the PRML detection of PR(1,2,1) increased the density up to 2.9 Gbit/in².

KEYWORDS: SNR, Field modulation, Recording density, Polycarbonate, Birefringence, RLL(1,7), PRML

INTRODUCTION

Hartley and Shannon's equation¹⁾ (eq.1) describing a channel capacity C in a data transmission channel with a bandwidth W (Hz) and signal-to-noise ratio SNR is convenient for evaluating^{2,3)} the recording density of various optical disks regardless of the signal processing applied modulation codes, equalizing, and so on.

$$C = W \log_2 (1 + \text{SNR}) \text{ bit/s.} \quad (\text{eq.1})$$

In the case of optical disks, W is proportional to $(v/L) \cdot (NA/\lambda)$, where v is a disk scanning velocity and L is the equivalent minimum mark length ($L = v / (2 f_{\text{max}})$, where f_{max} = maximum signal frequency) in units of λ/NA . The areal recording density D in units of $(\lambda/NA)^2$ is given by dividing C by v and by the track pitch p normalized by NA/λ . D is therefore expressed as

$$D \propto (1/Lp) (NA/\lambda)^2 \log_2 (1 + \text{SNR}). \quad (\text{eq.2})$$

For an optical disk medium, the quantity of $(1/Lp) \log_2 (1 + \text{SNR})$ is the key for improving D .

In general, parameters such as L , p , and SNR are not independent of each other. For example, making $1/(Lp)$ larger results in a decrease in SNR due to a decrease in CNR or to an increase in crosstalk or W . For an ordinary structured MO disk,

improving the SNR at narrow track pitches and finding a good combination of L , p , and SNR are required to improve D .

The purpose of our study is to estimate the maximum areal recording density D_{max} obtainable in an ordinary structured MO disk whose SNR has been improved.

EXPERIMENTAL CONDITION

Quadrilayer structured MO disks as shown in Fig.1 were studied under the experimental conditions listed in Table 1. The laser wavelength was 690 nm and the NA of the objective lens was 0.55. A periodically pulsed laser synchronized with a data clock was used^{4,5)}. This writing method has the advantages of writing desired length marks easily and accurately with low writing noise in comparison with the light intensity modulation recording method and the MFM method with a continuously emitting. Although the experimental results were obtained by MFM, these results should be similar to those obtained from light intensity modulation recording as long as the SNR remains unchanged and the techniques used for write-compensation or signal retrieving are sufficiently good. Disk scanning velocity was 4.5 m/s for the CNR and crosstalk measurements and was varied from 3.1 to 4.6 m/s when changing the bit length. The CNR was measured at 4.3 MHz with a resolution bandwidth of 30 kHz and the crosstalk was measured at 1.6 MHz except when measuring the CNR and crosstalk dependences on the mark length.

Table 1. Experimental conditions.

λ	690 nm
NA	0.55
Tracking	Continuous
Recording area	Groove
Read power	1.2 mW
Magnetic field	150 Oe
Write peak power	10 - 14 mW
Write pulse width	15 ns

Substrate	1.2 mm
First Si nitride	h1
GdFeCo	5 nm
TbFeCo	15 nm
Second Si nitride	h3
Pure Al	60 nm
Protective layer	

Fig.1. Layer structure of disk.

IMPROVEMENT of SNR

As reported previously⁶⁾, an ordinary structured MO disk with high SNR including high CNR and low crosstalk was developed. Let us review the disk optimizing process.

First, the thicknesses of the MO layer, the Si nitride layers, and the Al layer were fixed at $h_1=70$ nm, $h_2=20$ nm, $h_3=25$ nm, and $h_4=60$ nm. The magnetic layer was a TbFeCo(15nm)/GdFeCo(5nm) exchange-coupled double layer to improve magnetic field sensitivity. The Curie temperature of the TbFeCo layer was 210 C which is high enough to saturate the Kerr rotation at room temperature. Each film thickness was adjusted to maximize the CNR using a glass 2P substrate even though the CNR was not a sensitive function of the film thickness.

Second, the groove geometry including the track pitch, the groove depth and the groove width were optimized using glass 2P substrates. Narrowing the track pitch decreases the CNR as shown in Fig.2, which is caused by both a noise increase arising from the groove-land boundary and a carrier level decrease due to the narrower groove width. Narrowing the track pitch also increases crosstalk as shown in Fig.3. These results mean that the

SNR decreases with narrowing pitch. We chose the track pitch of $0.85 \mu\text{m}$ after referring these results as well as to equation (eq.2) to obtain high areal recording density. The groove width was around $0.57 \mu\text{m}$ and the depth was 70 nm. This combination of groove geometry is close to optimum for obtaining D_{max} , but is not guaranteed to be the best.

Fig.2. CNR vs. mark length for various track pitches⁶⁾. Fig.3. Track pitch dependence of cross-talk⁶⁾.

PLASTIC SUBSTRATE

Injection molded polycarbonate substrates with the same groove geometry as described above were studied. The narrow grooves in the stamper were successfully replicated onto a plastic substrate, which was confirmed by an SEM and an STM. Two poly-carbonate resins with different opto-elastic coefficient resulting in different birefringences were injected. A comparison

of the two substrates is shown in Table 2, where dN_{xz} is the index difference between the components for the thickness direction and the in-plane direction, which stands for the vertical birefringence.

Table 2 Comparison of polycarbonate substrates.

	dN_{xz}	CNR	Crosstalk
Conventional	5×10^{-4}	46.3 dB	-25 dB
New composition	2×10^{-4}	46.8 dB	-31 dB
Glass 2P	0×10^{-4}	47.2 dB	-33 dB

The birefringence in the in-plane direction was less than 1×10^{-5} for both disks. Major differences between the two substrates were found in the crosstalk. A polycarbonate disk made of the new composition shows a CNR and crosstalk comparable to those of a glass substrate.

FINAL TUNING of a DISK

Due to the birefringence in the substrate or other factors, parameters suitable for a glass disk are not always suitable for the birefringent polycarbonate substrate. Processing conditions such as mastering, injection molding, and sputtering, and parameters including groove geometry and film thickness of the nitride layers (h_1 and h_3) were studied again in order to improve the SNR of the polycarbonate substrate.

The groove width was changed to $0.59 \mu\text{m}$, which contributed a CNR gain of 0.8 dB for the substrates of both glass and polycarbonate. The change also resulted in an increase in crosstalk by 1.5 dB; the increase, however, was compensated by optimizing h_1 and h_3 as described below.

The film thickness dependences of CNR and crosstalk on h_1 and h_3 for the polycarbonate substrate are shown in Fig.4 and Fig.5.. A disk with $h_1 = 40 \text{ nm}$ shows higher CNR by 1 dB than that with $h_1 = 70 \text{ nm}$ which was the best thickness for a glass substrate. The thickness h_3 of the second nitride layer was changed while keeping $h_1 = 40 \text{ nm}$. Both the CNR and the crosstalk were improved by 2 dB and 4.5 dB, respectively, at $h_3 = 40 \text{ nm}$. Such dependences as shown in Figs.4 and 5 may be caused by optical complications involving the birefringence, the groove geometry, the Kerr ellipticity, and so on.

From the preceding experiments, the disk based on polycarbonate substrate was finalized with the specifications and characteristics shown in Table 3.

Fig.4 CNR dependence on h_1 .

Fig.5 CNR and crosstalk dependence on h_3 .

Table 3. Disk specifications and characteristics.

h_1	40 nm
h_2	20 nm
h_3	40 nm
Groove width	$0.59 \mu\text{m}$
Groove depth	70 nm
Track pitch	$0.85 \mu\text{m}$
dN_{xz}	1.5×10^{-4}
dN_{xy}	1.0×10^{-5}
Reflectivity	0.17
Kerr rotation	0.82 deg
Kerr ellipticity	-0.50 deg

The mark length dependences of the CNR and crosstalk of the disk are shown in Fig.6. A high CNR of 58.4 dB was obtained at the mark length of $1.9 \mu\text{m}$. The CNR is almost the same as that without the groove noise arising from the groove-land boundary. When changing h_3 to thinner values, crosstalk was increased not

only at just 1.6 MHz but for all frequencies.

Fig.6. CNR and crosstalk vs. mark length.

LINEAR RECORDING DENSITY

The linear recording density was studied using two different detection methods. One was the conventional method, and the other was the PRML method of PR(1,2,1)ML⁷. The modulation code RLL(1,7) with a channel clock of 18 MHz was used for the both detection methods.

Figure 7 shows the bit error rate vs. the bit length. The minimum error rate was limited to 1.2×10^{-7} due to the number of bit measured in our system.

Fig.7. Bit error rate vs. bit length

High linear recording densities of 0.305 μm/bit and 0.260 μm/bit were obtained at an error rate of 1×10^{-5} by conventional detection and PRML detection, respectively. These linear recording

densities are equivalent to the areal densities 2.5 Gbits/in² and 2.9 Gbits/in², respectively.

CONCLUSION

The SNR of an ordinary structured MO disk of a polycarbonate substrate was improved by optimizing and improving the groove geometry, the birefringence in the substrate, and film composition / thickness. The improvements in SNR resulted in the high areal recording density of 2.5 Gbits/in² by using a 690 nm LD, and an NA of 0.55. Moreover, with the help of PRML detection, the density increased to 2.9 Gbits/in².

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