HIGH DENSITY LAND & GROOVE RECORDING WITH MODIFIED OPTICS AND PA-MFM RECORDING.

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Abstract - Land & groove recording on MO disk with modified optics and PA-MFM are investigated. Cross-talk cancellation by phase compensation is achieved and it is suppressed down to -30dB. DSB(Double Shading Band) enlarges the carrier level for short mark.

KEYWORDS: LAND AND GROOVE RECORDING, PA-MFM, DSB, PHASE COMPENSATION, \(\lambda/8\) AND CROSS-TALK CANCELLATION.

INTRODUCTION

To realize high density recording of an optical disk, the semiconductor laser of short wavelength in the blue-green region is required. But the demand for the high density recording cannot wait till the 21st century for the progress of short wavelength light source. And the methods to reproduce signals from shorter marks than diffraction limited beam spot, such as MSR [1] and PRML [2] are developed. In order to increase the recording density, it is important to shorten track pitch. Land & groove recording is a quite attractive way for high density recording. However, for its implementation, cross-talk suppression is such a critical matter that some methods [1], [3] have been proposed for cross-talk cancellation.

PA-MFM(Pulse Assist Magnetic Field Modulation) method [4],[5] has the advantages of durability and easy control of mark width as compared with the DC laser power MFM recording. PA-MFM MO is a promising method for precise mark edge recording.

On the above points we investigated the land & groove recording with modified optics and PA-MFM recording. For cross-talk cancellation, phase compensation method using two optical read channels is investigated. The effect of quasi-super-resolution with DSB (Double Shading Band) is also investigated. In this paper the possibility of realization of 4.7GB single sided 120mm MO disk with conventional TbFeCo film is described as well.

EXPERIMENTAL PROCEDURES

MO DISK

Fig.1 shows the schematic cross-section of the MO disk. Glass substrates are prepared which have land and groove formed by photoresist with different groove depth of 43, 54, 62 and 86nm. The track-pitch is set at 1.4 \(\mu\)m and the duty ratio of land and groove is set about 50:50. Conventional quadrilayers (SiNx/TbFeCo/SiNx/Al) MO film are sputtered on the substrates. The reflectivity of the MO film is about 18% and Kerr rotation angle is 0.9 deg. at 680nm wavelength.

OPTICAL PICK-UP

Fig.2 shows a block diagram of an optical pick-up. The objective lens NA is 0.55 and the laser wavelength is 680nm. A push-pull method is used for tracking servo and an astigmatic method for focusing servo. The tracking both on land

![Fig.1 Schematic cross-section of MO disk.](image-url)

![Fig.2 Schematic diagram of optical pick-up.](image-url)
5.7m/sec and the Resolution Band frequency increases about 3 to 5dB by al. [6] showed the enlargement of CNR in high frequency marks. region with single or X-shaped shading band and explained point of view to place each shading band at the place stated it is supposed to be the most effective way from a total jitter right above since the carrier level of long marks are unfortunately reduced by shading the whole range of the groove. The measuring parameters include write laser through knife edge is placed about -1.1mm through -0.8mm. Accordingly it is supposed to be the most effective way from a total jitter point of view to place each shading band at the place stated right above since the carrier level of long marks are unfortunately reduced by shading the whole range of -1.1mm through +0.8mm. In a way DSB has functions as equalizer on the longer marks and quasi-super-resolution on the shorter marks.

RESULTS AND DISCUSSIONS

QUASI SUPER RESOLUTION BY DSB

In order to decide the location of the DSB, the change of carrier level by shading the collection path of MO signal with knife edge at a right angle to the groove is measured on 0.5μm marks recorded on the groove of 54nm depth. The result is shown in Fig.3. Carrier level increases when the knife edge is placed about -1.1mm through +0.8mm. Especially the carrier level is improved remarkably about -1.1mm through -0.6mm and +0.3mm through +0.8mm. Accordingly it is supposed to be the most effective way from a total jitter point of view to place each shading band at the place stated right above since the carrier level of long marks are unfortunately reduced by shading the whole range of -1.1mm through +0.8mm. In a way DSB has functions as equalizer on the longer marks and quasi-super-resolution on the shorter marks.

Fig.4 shows the write frequency dependence of CNR on the groove. The measuring parameters include write laser pulse power 6.0mW, duty of laser pulse 37%, magnetic field ± 200 Oe, reproducing laser power 1.0mW, linear velocity 5.7m/sec and the Resolution Band Width 30kHz. Initially the whole recording surface is bulk erased. The CNR in high frequency increases about 3 to 5dB by DSB. T.D.Milster et al. [6] showed the enlargement of CNR in high frequency region with single or X-shaped shading band and explained the mechanism with the scalar diffraction model. However, their experimental results of high frequency CNR enhancement is not so remarkable compared to the results of this paper. In [6] LIM (Light Intensity Modulation) method is employed. In general, a short mark formed by LIM has very small width, then the CNR decreases steeply with shorter mark recorded. To the contrary, PA-MFM forms precise short marks with little change of mark width and the CNR is not so degraded. After all, drastic improvement of high frequency CNR is obtained by the combination of DSB and PA-MFM.

CROSS-TALK CANCELLATION BY PHASE COMPENSATION

The phase compensation dependences of cross-talk and carrier level are measured on 0.65μm marks. The phase is controlled by 1/2 wave-plates tilted with a certain angle. The relation between the tilt angle and the phase is calibrated with Soleil-Babinet compensator. Figs.5 show the phase dependence of carrier level and cross-talk level each of the land and the groove on different groove depths. The curves of carrier level of the land and the groove split to each other, and cross-talk level as well except Fig.5(a). The deeper the groove depth is, the smaller the maximum carrier level is. According to the deeper groove, the carrier level on the land slides to the positive phase direction, on the other hand, the cross-talk from the groove slides to the negative phase direction. In the case of the groove the carrier level and the cross-talk level, vice versa. In particular at 1/5 λ depth, the phase conditions of the minimum cross-talk level of both the land and the groove coincide. In any cases shown in Figs.5, the minimum cross-talk level is suppressed to less than -30dB.

Subsequently the origin of this cross-talk cancellation is simulated with a simple model. The electric field of the elliptically polarized light from the land and the groove are shown respectively eq. (1),(2) and (3),(4) where, angular velocity of electric field is ω, Kerr rotation is θ, Kerr

Fig.3 Knife edge position dependence of carrier level.

Fig.4 Write frequency dependence of CNR with DSB.
Fig. 5 Phase compensation dependence of carrier level and cross-talk level on 0.65μm marks for various groove depths (experiments).

ellipticity is $\eta_k$, wavelength is $\lambda$ and groove depth is $d$. The real part of the electric field shows the element of the polarized direction of the illuminated light and the imaginary part shows that of diagonal direction.

$$E_{ip} = A \cdot e^{i(\omega t - \theta_k)} + B \cdot e^{i(-\omega t - \theta_k)}$$  
$$E_{im} = B \cdot e^{i(\omega t - \theta_k)} + A \cdot e^{i(-\omega t - \theta_k)}$$  
$$E_{gp} = A \cdot e^{i(\omega t + \theta_k + 2\pi \frac{d}{\lambda})} + B \cdot e^{i(-\omega t + \theta_k - 2\pi \frac{d}{\lambda})}$$

In this simulation the effect of diffraction is not taken into account, also supposing that the disk has rectangular groove and is bulk erased to the $+\theta_k$ state in advance.

$$E_{pp} = KL \cdot E_{ip} + KG \cdot E_{gp}$$  
$$E_{pn} = KL \cdot E_{ip} + KG \cdot E_{gp}$$  
$$E_{np} = KL \cdot E_{ip} + KG \cdot E_{gp}$$  
$$E_{nn} = KL \cdot E_{ip} + KG \cdot E_{gp}$$

The reproduced signals are represented by (6) to (9) and $KL$ and $KG$ are coefficients which show the ratio of reproducing light intensity for the land and the groove respectively.

$$E_{lc} = E_{pp} - E_{np}$$  
$$E_{lc} = E_{pp} - E_{pn}$$

For instance, the carrier level and cross-talk level of on the land are given by eq. (10) and (11) respectively.

Fig. 6 shows a schematic model of phase compensation for the land and the groove. In this case zero Kerr ellipticity

$$E_{kn} = B \cdot e^{i(\omega t - \theta_k + 2\pi \frac{d}{\lambda})} + A \cdot e^{i(-\omega t - \theta_k - 2\pi \frac{d}{\lambda})}$$  
$$\tan \eta_k = \frac{\Lambda}{2\pi}$$

Without phase compensation.

Optimized for groove.

Optimized for land.
The calculation of phase dependences of carrier level and cross-talk level at 1/4, 1/6 λ and 1/8 λ depth are shown in Figs.7. At λ /8 depth the phase of the maximum carrier level meets that of the minimum cross-talk level and at λ /4 depth the phase of the maximum carrier level meets that of the maximum cross-talk level. It is found out that the curves slide to both directions depending on the Kerr ellipticity, the illuminated light portion between the land and the groove and the groove depth. However, the relationship in the phase compensation between the carrier level and that of cross-talk level for the land is fixed in accordance with the depth, and for the groove as well.

Comparing the experiments and calculations, there are differences of the curve position of the carrier level and that of the cross-talk level. The differences are supposed to be derived from the groove shape. Since the substrates used in the experiments do not have exactly rectangular groove, the effective groove depth is smaller than the length between the top of the land and the bottom of the groove. Then the experimental result at λ /8 depth shown Fig.5(a) almost corresponds to the calculated result at λ /8 depth.

Aratani et al. [7] and Ooki [8] reported that cross-talk is cancelled at groove depth around λ /6 on land & groove MO disk recording. Even in our calculation the cross-talk is vanished without phase compensation when the 80% of the illuminated light focused on a reading track. Fig.5(a) almost agrees with [7] since λ /5 depth is equivalent to the λ /6 effective as stated above even though there is -20 deg. phase shift. However, in practical use such a rigid condition is easily broken by Kerr ellipticity, birefringence, change of beam profile and so on. Therefore it is rather effective to introduce independent phase compensation for the land and the groove with two optical read channels positively. In that case, it is found out that λ /8 depth is quite suitable according to the calculation. Fig.8 shows the calculated result of the groove depth dependences of carrier level and cross-talk level at the optimum phase compensation for the maximum carrier level on the land. The carrier level decreases accord-

Fig.7 Phase compensation dependence of carrier level and cross-talk for various groove depths (calculation). The parameters include θ k=0.9deg. η k=0deg. and illuminated light ratio on focusing track 72%.

is supposed for simple comprehension. Without phase compensation the MO lights corresponding to + θ k and - θ k are shown as linearly polarized light and elliptically polarized light respectively. Optimizing the phase on the groove, the electric fields of + θ k and - θ k component from the groove are separated clearly, on the other hand, the lights from the land have the same ellipse with different circular direction. In that case, the cross-talk signal from the adjacent land is almost vanished; in the case of reproducing the land, vice versa.

Fig.8 Groove depth dependence of carrier level and cross-talk level for land at the maximum carrier level phase condition.
Write laser power dependence of Jitter on RLL1-7 random pattern with minimum mark 0.55μm.

Fig. 9

Write laser power dependence of cross-talk on 2.0μm mark.

Fig. 10

According to the increase of the groove depth and the cross-talk is vanished at λ/8 depth. For the groove, the same result is obtained with the phase compensation whose polarity is opposite to the condition on the land. This groove depth is also convenient because the push-pull signal has its maximum value.

Write power dependence of jitter is measured to examine the actual performance on RLL 1-7 random signal of minimum mark length 0.55μm with the presented methods as shown in Fig. 9. The measuring parameters include duty of laser pulse 37%, magnetic field ±200 Oe, reproducing laser power 1.0mW, linear velocity 4.65m/sec. The jitter value is measured as the interval between leading and trailing of spaces and marks. In the range of 5.0mW to 6.5 mW write laser power less than 8% jitter value is obtained for land and groove. The write power margin of cross-talk with 2μm mark is also measured and shown in Fig. 10. In the range of 4.5mW to 6.0mW write laser power the cross-talk value is less than -25dB. Moreover less than 8% jitter value is also obtained even on the minimum marks of 0.50μm recorded at 5.5mW. As shown Figs. 11, very clearly opened
eyepatterns are obtained. As a result, the realization of 1.5GB single sided 3.5" MO disk is possible. In addition, with track pitch 1.20μm, high density land & groove recording of EFM+ random pattern with 0.50μm minimum marks is tried. Figs. 12 show the eyepatterns which have less than 14% jitter value. This result shows the possibility of realization of 4.7GB single sided 120mm MO disk.

CONCLUSION

High density land & groove recording with PA-MFM, DSB and 2-channel phase compensation are performed with a conventional MO film. The combination of PA-MFM writing and reproducing with DSB improves CNR for short marks. Optimizing the phase compensation for each of the land and the groove, the cross-talk is reduced less than -30dB for effective track pitch 0.7μm. It is cleared that λ /8 groove depth is suitable for land & groove recording since the maximum carrier level and the minimum cross-talk level are obtained at the same phase compensation. Applying the technique described in this paper, less than 8% jitter is obtained for RLL 1-7 random pattern with 0.50μm minimum marks. And furthermore less than 14% jitter is obtained for effective track pitch 0.6μm and EFM+ random pattern with 0.50μm minimum marks. From these results, 1.5GB single sided 3.5" MO disk or 4.7GB single sided 120mm MO disk will be implemented with even 680nm wavelength laser. Since the methods described in this paper are universal, further increase of recording density is expected combining with other methods such as MSR, PRML and so on.

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REFERENCES