High Density Near Field Optical Disc Recording using Phase Change Media and Polycarbonate Substrate

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Abstract: We developed a high density near field optical recording disc system with a solid immersion lens and two laser sources. In order to realize the near field optical recording, we used a phase change recording media and a molded polycarbonate substrate. The near field optical pick-up consists of a solid immersion lens with numerical aperture of 1.84. The clear eye pattern of 90.2 GB capacity (160nm track pitch and 62 nm per bit) was observed. The jitter using a limit equalizer was 10.0 % without cross-talk. The bit error rate using an adaptive PRML with 8 taps was 3.7e-6 without cross-talk. We confirmed that the near field optical disc system is a promising technology for a next generation high density optical disc system.

OCIS codes: (210.4590) Optical disks; (210.4770) Optical recording

1. Introduction

A next generation optical disc with huge capacity is needed for multimedia applications such as a personal video recorder and a home video server. To realize an optical disc with the capacity of more than 100 GB per single layer of 120 mm diameter, we have already reported high density near field optical readout by the combination of a GaN blue laser of 405 nm wavelength and an optical pick-up with an effective numerical aperture (NA) of 2.05 [1]. In this report, by utilizing a phase change recording media and a molded polycarbonate substrate, we have realized the recordable near field optical disc with high data capacity.

2. Experiment Conditions

We developed the near field optical recording disc system using two laser sources [2]. Figure 1 shows the schematic diagram of the near field optics. By utilizing two laser sources, the light for the focus servo can be separated from the light for the tracking servo and the recording write-pulse. Therefore the near field optics system can maintain stable focus servo during the recording process despite nanometer scale air gap. The laser wavelength for the tracking servo and the recording pulse is 405 nm. The laser wavelength for the focus servo is 780 nm. We can obtain an air gap focus servo signal optically by utilizing the total reflection on the surface of the solid immersion lens (SIL) [3]. The air gap is controlled to the height of 20 nm. The tracking servo signal is obtained from a push-pull tracking method.

Figure 2 represents the picture of the near field optical pick-up actuator with the SIL. An optical pick-up actuator for Blu-ray disc system was adapted for the near field optical pick-up. Instead of conventional objective lenses, the optical pick-up lenses of the actuator consist of a conventional low NA (0.42) objective lens and a super hemisphere SIL. Figure 3 shows the SIL. The radius of the SIL is 0.45 mm and its height is 0.548 mm. The aberration of the SIL itself is controlled by processing accurately the radius and the height. Since a tilt margin between the SIL surface and the disc surface is needed, the top of the SIL is processed with conical shape.

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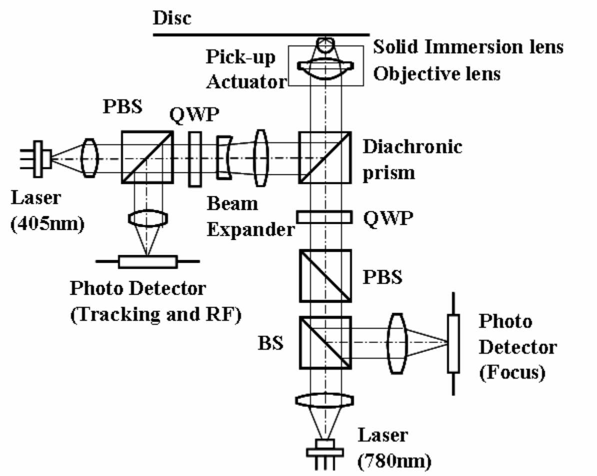

Fig. 1. Schematic diagram of the near field recording optics system with two laser sources.

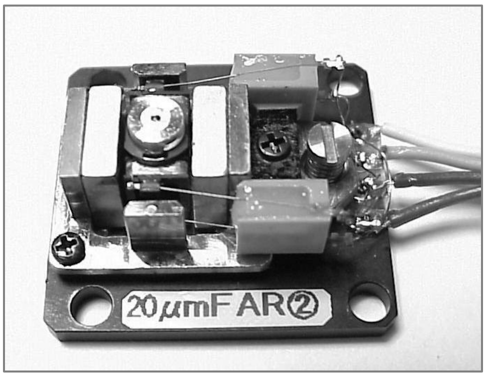

Fig. 2. Picture of the near field optical pick-up actuator with the solid immersion lens.

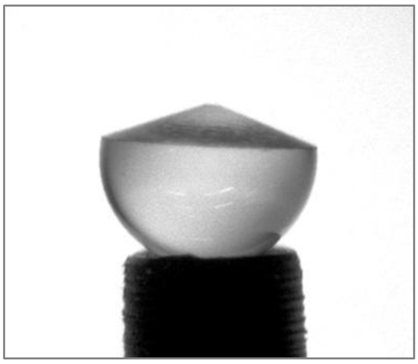

Fig. 3. Picture of the solid immersion lens.

Figure 4 shows the shape of the top of the SIL. The top radius of the SIL facing the disc surface is set to be 20 micrometers then the tilt margin for the air gap height of 20nm is +/- 0.06 degrees. The conical angle is set to be 70 degrees because the incident light angle of blue laser is 64.2 degrees [4]. The NA of the SIL is designed to 1.84 by using high refractive index glass material. The refractive index of the glass is 2.07 at 405nm wavelength [4].

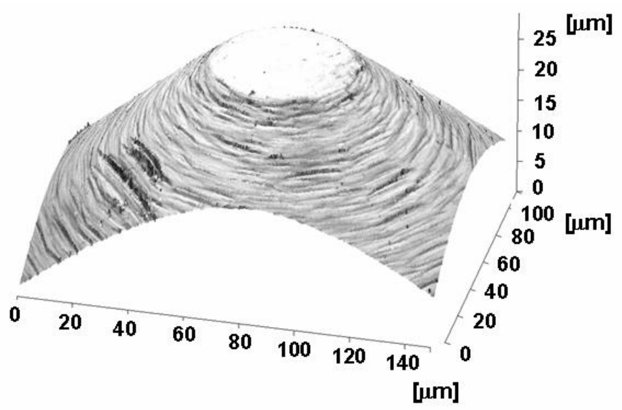

Fig. 4. Picture of the shape of the top of the Solid immersion lens.

Figure 5 shows the etched groove pattern of a silicon disc. The groove pattern on the silicon disc was made by a mastering process with an electron beam recording (EBR) and an etching process with a reactive ion etching (RIE) [5]. The disc parameters were the track pitch of 160 nm and the groove depth of 20 nm. In order to realize quad-capacity (100 GB) of Blu-ray disc, the track pitch is set to the half of the track pitch of Blu-ray disc. On the other hand, the groove depth of 20 nm is set to relative shallow depth because the nickel stamper is needed to remove easily for the narrow track pitch in the molding process. The groove duty, which is defined as the ratio of the land width and groove width, is 30 % to 50 %. As Figure 5 is shown, the fluctuation of the groove edge is approximately +/- 5% of the track pitch. The reasons of the groove edge fluctuation are the resolution of the resist for the electron beam recording.

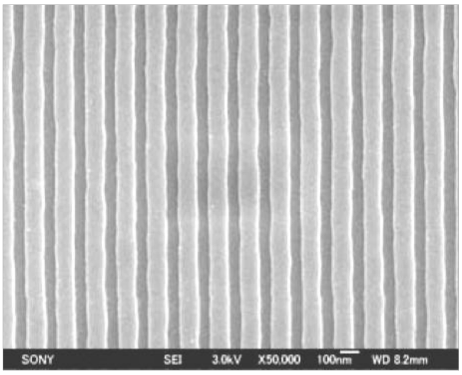

Fig. 5. Groove pattern of a silicon disc with the track pitch of 160 nm.

We prepared a nickel stamper by using the silicon disc. Then polycarbonate substrates were replicated by molding on the nickel stamper. The disc thickness is 1.1 mm. Figure 6 and figure 7 shows the groove pattern of the silicon disc and the molded groove pattern of the polycarbonate substrate, respectively. The molding condition and the polycarbonate material are practically same of Blu-ray disc. The pattern and the depth of the silicon disc are replicated accurately to the polycarbonate substrate.

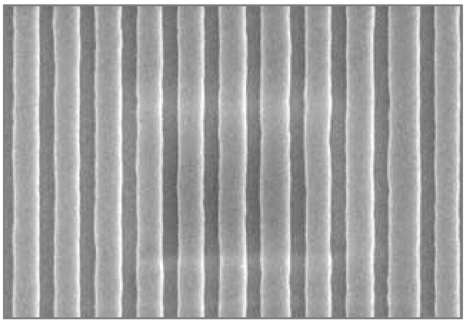

Fig. 6. Groove pattern of a silicon disc with the track pitch of 226 nm.

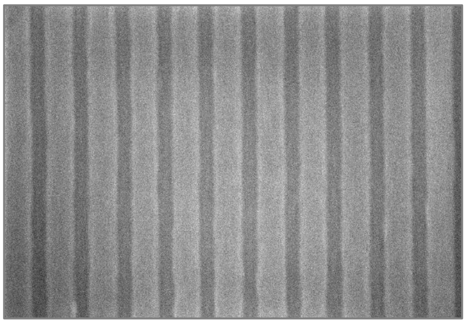

Fig. 7. Groove pattern of a molded polycarbonate disc with the track pitch of 226 nm.

Figure 8 shows a phase change recording media structure for the near field optical recording. Each layer on the polycarbonate substrate was deposited by a conventional sputtering method. The thickness of each layer was optimized by an optical enhancement calculation for the near field optics [6]. Since the refractive index of the first surface layer is influenced the NA of the SIL, SiN layer having higher refractive index than the NA value of 1.84 was employed as the first surface layer [4]. A hard coating film or a lubricant film was not used for protecting the disc surface.

SiN (15nm)
ZnS-SiO_2 (50nm)
GeSbTe (15nm)
ZnS-SiO_2 (10nm)
SiN (10nm)
Ag alloy (50nm)
Polycarbonate substrate (1.1mm)

Fig. 8. Phase change recording media structure.

Table 1 represents the recording conditions for the near field recording optical disc system. The clock of the recording write pulse is constant of 33 MHz. By changing the linear velocity, the bit length was changed from 111 nm to 46 nm. Since the bit length of 55 nm is the half of Blu-ray disc, the equivalent disc capacity with 160 nm track pitch is 101.7 GB per single layer of 120 mm diameter. The recorded signal pattern was modulated with RLL(1, 7)-pp. The user data transfer rate is 17.98 Mbps.

The write strategy was employed the same one of Blu-ray disc format. The recording power of Pw1 (first pulse), Pw2 (second pulse) and Pw3 (final pulse) was set to the same level without variation. The recorded track area is the convex part (on groove) of the disc surface. The reflectance change by the recording pulse is designed from high (crystal) level to low (amorphous) level. In order to investigate the feasibility of the near field optical disc recording system, we measured firstly the recording characteristics for one track recording in write-once.

Table 1. Recording conditions.

Wavelength	**405 nm**
Numerical aperture	**1.84**
Track pitch	**160 nm (constant)**
Clock	**33 MHz (constant)**
Linear velocity	**2.44 to 1.01 m/s**
Bit length	**111 to 46 nm**
User disc capacity	**50.4 to 121.6 GB**
Modulation code	**RLL(1,7)-pp**
User data transfer rate	**17.98 Mbps**
Recording area	**On groove**

3. Evaluation of Near Field Optical Recording

Table 2 shows the mark length dependence of carrier to noise ratio (CNR). The recording power was the same power for each mark length. The typical recording power and readout power were 4.0 mW and 0.25 mW, respectively. In the case of 111 nm per bit (50.4 GB), the CNR of 2T mark length has approximately 50 dB. Therefore the SNR of 111 nm per bit (50.4 GB) is so sufficient that we could measure the jitter and the error rate easily.

On the other hand, in case of 55 nm per bit (101.7 GB), the CNR of each mark was lower level. The reason is that, as shown in figure 9, the CNR of 2T mark length is decreased by the carrier level. Since the carrier level characteristic can be explained by the calculated resolution for the NA of 1.84, we think the CNR of 2T mark length of 55 nm per bit is limited by the optical limit. Moreover we think that the reason for insufficient CNR of 4T and 8T mark length is that the thermal structure of the phase change media and the write strategy were not still optimized.

Table 2. Carrier to noise ratio of each recording density.

	2T mark	4T mark	8T mark
50.4GB (111nm/bit)	49.6 dB	51.1 dB	51.9 dB
101.7GB (55nm/bit)	40.0 dB	45.1 dB	47.7 dB

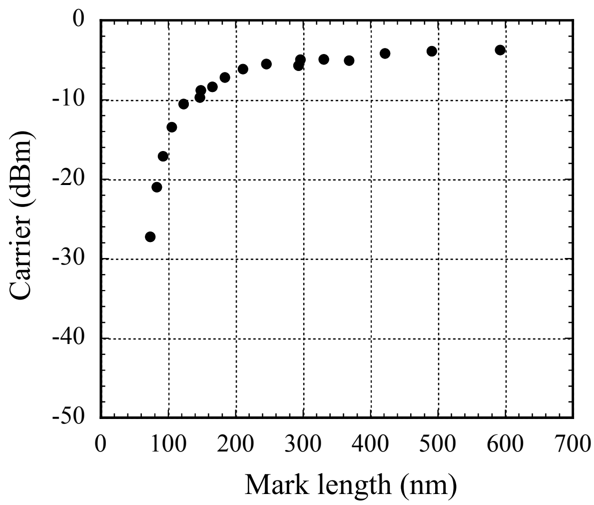

Fig. 9. Mark length dependence of carrier level.

Figure 10 and figure 11 show the raw signal of the eye pattern of 111 nm per bit (50.4 GB) and 62 nm per bit (90.2 GB), respectively. The observed track was recorded as just one track write (without cross-talk and cross-write). Therefore the adjacent tracks were erase level. The observed raw eye patterns are very clear without equalized process. The jitter of each density using a limit equalizer was 5.3 % and 10.0 %, respectively.

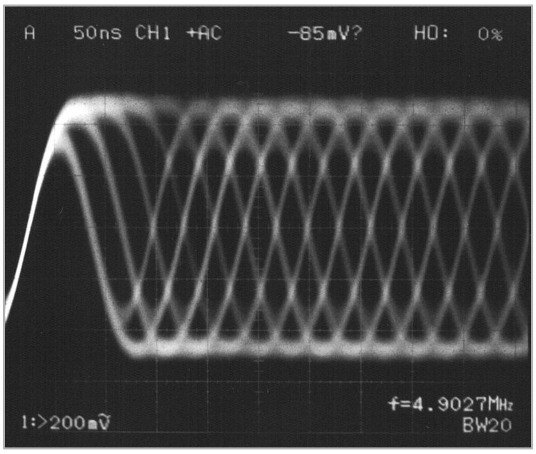

Fig. 10. Raw signal of eye pattern of 111 nm/bit (50.4 GB).

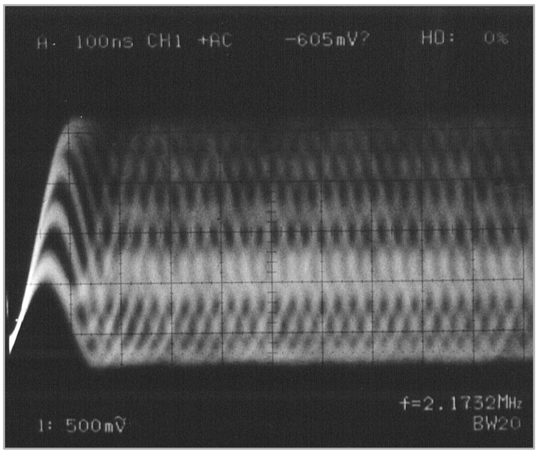

Fig. 11. Raw signal of eye pattern of 62 nm/bit (90.2 GB).

Figure 12 shows the raw signal of the eye pattern of 55 nm per bit (101.7 GB). The observed track was also recorded as one track write (without cross-talk and cross-write). Therefore the adjacent tracks were erase level. Since the CNR was insufficient as shown in table 2, the observed signal level of 2T mark was very small. Therefore the jitter using a limit equalizer was 13.2 %.

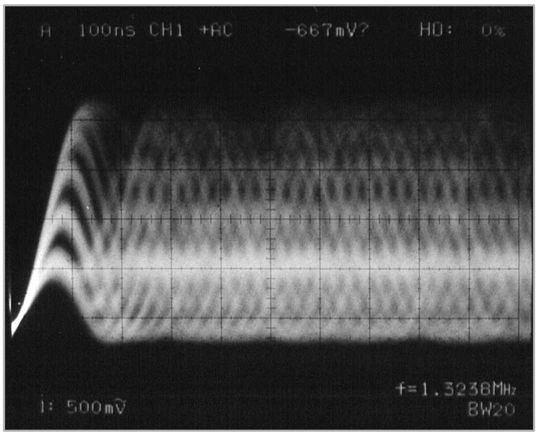

Fig. 12. Raw signal of eye pattern of 55 nm/bit (101.7 GB).

Figure 13 represents the bit length dependence of the one track write jitter. The jitter characteristic shows similar curve with the carrier level shown in figure 9. Therefore we think that the jitter for decreasing the bit length is limited by the CNR of the 2T mark length, namely the optical limit.

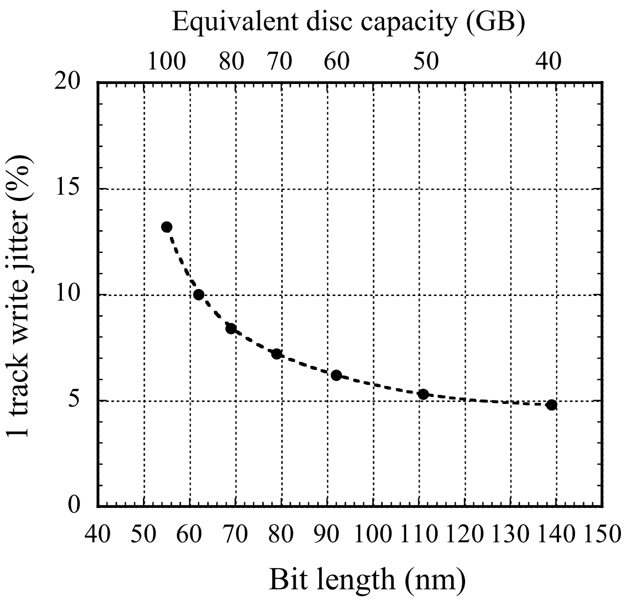

Fig. 13. Bit length dependence of the one track write jitter.

Figure 14 shows the bit length dependence of the one track bit error rate. The bit error rate was measured by the fixed 4 taps equalizer and the adaptive PRML with 4 and 8 taps. The bit error rate of 55 nm per bit (101.7 GB) and 50 nm per bit (111.9 GB) were 3.7e-5 and 2.6e-4, respectively. The bit error rate characteristic shows the possibility of the high density optical disc system by the near field optical recording.

If the influence of cross-talk and cross-write can be controlled by the track duty, the groove depth, the thermal media structure and the write strategy, the achievable capacity per single layer of 120 mm diameter disc will be approximately 90 to 100 GB. Moreover, by improving the SNR of recording media, we think that the achievable capacity will be extended to 120 GB.

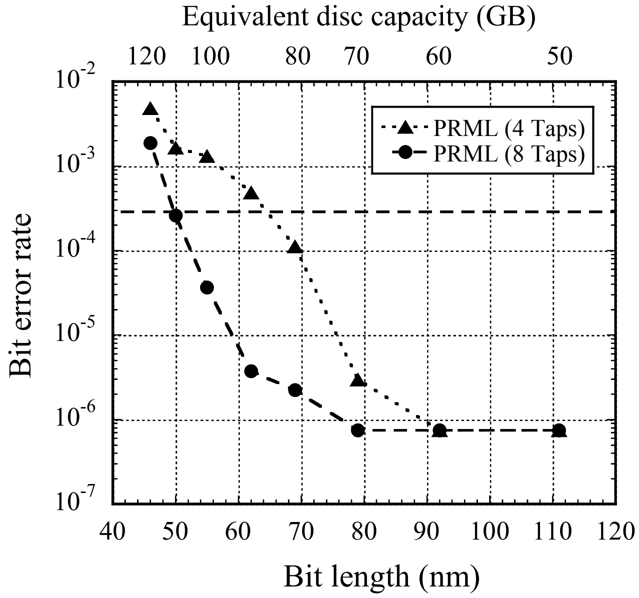

Fig. 14. Bit length dependence of the one track bit error rate.

In order to evaluate the resolution of the NA of the SIL, we measured the signal level ratio of 2T mark and 8T mark in the raw signal of the eye pattern. Figure 15 shows the calculated MTF curve of the NA of 1.84 and the experimental results. The experimental results have good agreement with the calculated MTF curve. Therefore we think that the NA of this near field optics could realize 1.84.

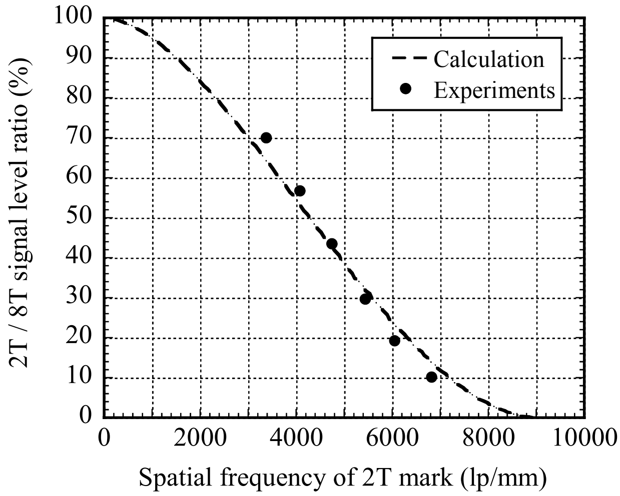

Fig. 15. Comparison of MTF between calculation and experiments.

4. Conclusion

We developed a high density near field optical recording system with a solid immersion lens and two laser sources. By utilizing two laser sources, a light for the focus servo can be separated from light for the tracking servo and the recording write-pulse. Therefore the near field optics system can maintain stable focus servo during the recording process.

We could realize a recordable near field optical disc by utilizing a phase change recording media and a molded polycarbonate substrate. We think that the recording media technology and the molding technology will be extendable from Blu-ray disc. We could observe clear raw eye pattern for 62 nm per bit (90.2 GB capacity). The one track write jitter using a limit equalizer was 10.0 %. The bit error rate using an adaptive PRML with 8 taps was 3.7e-6 without cross-talk. By controlling cross-talk and cross-write, the achievable capacity per single layer of 120 mm diameter disc will be approximately 90 to 100 GB. Moreover, by improving the SNR of recording media, we think that the achievable capacity will be extended to 120 GB.

We confirmed that the near field optical disc system is a promising technology for a next generation optical disc system.

5. Acknowledgment

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6. References

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