Laser Pulse Compensation Applied to Phase-Change Recording Film to Form Nano-Sized Marks

S Furumiya¹ ² and Y Fujiwara²
¹ Storage Media Group, Digital & Network Technology Development Center, Panasonic Corporation
3-1-1 Yagumo-nakamachi, Moriguchi, Osaka 571-8501, Japan
² Division of Materials and Manufacturing Science, Graduate School of Engineering, Osaka University
2-1 Yamada-oka, Suita, Osaka 565-0871, Japan
E-mail: furumiya.shigeru@jp.panasonic.com

Abstract. We have examined the application of the laser pulse compensation to the phase-change recording film of the triple-layer optical disc by using an original writing laser pulse controller, which compensates dynamically the pulse edges in order to form the marks at the correct position. We confirmed 112 nm sized marks smaller than the optical spot formed on the thin recording film. The results of the compensation had some characteristics depending on the data pattern and/or the layer. We discussed the causes by considering about the structure of the recording films and the phase-change process to form the marks.

1. Introduction
An optical disc is well known as the medium of the high reliable data storage system, the recording is realized by forming many small marks on the recording film by the irradiation of the laser beam spot. A kind of the rewritable optical discs is made from the phase-change material of a Ge-Sb-Te for the recording film [1]. The data capacity of the disc has been increasing from 4.7 Gbyte of the digital versatile disc random access memory (DVD-RAM) by the red laser optics [2] to 25 Gbyte of the Blu-ray disc rewritable (BD-RE) by the blue laser optics [3]. The smaller laser spot size depending on the optical diffraction limit is, the larger capacity is obtained, but it seems impractical for the commercial products to use shorter wavelength of the laser or larger numerical aperture (NA) of the objective lens than now.

Recently, two effective approaches to increase the data capacity per one disc were studied. The one way is piling the recording layers. Nishihara et al. reported a structure of the rewritable phase-change triple-layer disc [4], which has very thin front recording layer with high transparent and high reflective contrast. The other way is increasing the data density by the recording method. Nakamura et al. proposed an adaptive write strategy [5], which decreases the symbol error of the high density recording at the front layer of the triple-layer disc.

In this paper, first of all, we describe an original configuration of the writing laser pulse controller, which was developed to execute the adaptive write strategy. By using this controller, we have examined the application of the laser pulse compensation to the phase-change recording film of the triple-layer disc to form the nano-sized marks. Then, we report that the results of the compensation have some characteristics depending on the data pattern and/or the layer, when the marks are formed.
on the recording films as the correct mark edges. Moreover, we discuss the causes by the relation between the thermal diffusion of the thin film and the phase-change process of the mark formation.

2. Writing laser pulse controller
The phase-change recording is performed by forming the amorphous marks and the crystalline spaces on the recording film by the irradiation of the laser pulses to the spinning disc. The writing laser pulse controller is for generating the laser pulses irradiated from the optical pick-up unit.

2.1. Writing laser pulses for the phase-change recording
Figure 1 shows the relation between the writing laser pulses and the mark and space train on the recording film. The writing laser pulses to form the mark of 2T length (2Tm), where T means a period of data clock, consist of a top pulse of the write power and a cooling pulse of the bottom power. The phase-change film is melted by the strong irradiation of the top pulse and cooled rapidly by the cooling pulse, and then the region becomes a mark of the amorphous phase. And to form the space of 3T length (3Ts) between the marks, the erase power is irradiated. The region irradiated by constant erase power becomes the space of the crystalline phase by keeping the film at a crystallization temperature.

![Figure 1.](image)

Figure 1. The circles image the mark shapes on the recording film as the length of 2 times periods of data clock T. The pulse waveform indicates the writing laser levels. The horizontal direction of the figure means the edge positions of the marks and also the time scale for the pulses.

2.2. Signal processing for the write laser pulse compensation
We have developed a writing laser pulse controller, which has the special functions of not only generating the pulses at high time accuracy, but also compensating dynamically the pulse edges adapted for the recording data pattern, so as to form each mark at the correct position consequently.

![Figure 2.](image)

Figure 2. Block diagram for the signal processing of the writing laser pulse controller. The programmable delay-line is a key part to control the timing of pulses.

![Figure 3.](image)

Figure 3. Compensated writing laser pulses with arbitrary duration are made from individually delayed clock pulses.
Figure 2 shows conceptually the block diagram of the signal processing of the writing laser pulse controller. Compensated writing laser pulses are made in the following order, firstly generating the basic writing pulses roughly, wherein the interval of each pulse is T, secondly making the delayed clock through the programmable delay-line loaded the shift value for each clock edge, thirdly latching the basic writing pulses precisely by the trigger of the delayed clock, and lastly driving a GaN laser diode by three switching current sources. Figure 3 indicates the relation between the basic writing pulses and the compensated writing laser pulses.

At the actual circuit, the processing is capable of the clock frequency of up to 800 MHz and the time accuracy of 80 ps by using four programmable delay-lines (Onsemi MC100EP195) for the processing layers divided into four time phases. As the examples, figure 4 indicates the operating pulses shifted by the step of 240 ps, and figure 5 is the optical output of the compensated writing laser pulses.

**Figure 4.** Waveform for overlapped sixteen edges by the step of 240 ps. These internal pulses of the writing laser pulse controller are measured by using the persistence mode of a digital oscilloscope.

**Figure 5.** Optical output waveform observed by an optical oscilloscope. The rising time of the laser pulse is obtained less than 1 ns.

### 3. Experimental results and discussion

In this section, we describe the experimental procedures applying the laser pulse compensation to the phase-change recording films of the triple-layer disc to form the nano-sized marks. Then, we discuss the results and the causes.

#### 3.1. Preparation of the triple-layer disc

Figure 6 shows a schematic image of the layer structure of an experimental triple-layer disc. This structure includes three important designs. First, the GeTe-Sb₂Te₃ materials are adopted as the active recording films for getting high reflectivity contrast, although thickness is very thin. Second, the silver alloy films add for the optical reflection and the thermal radiation. Third, the layer1 and layer2 have high refractive index films on the silver films for obtaining high optical transmittance.

#### 3.2. Experimental procedures and conditions

Figure 7 shows an experimental setup for data recording to the above triple-layer disc. The data is processed at the writing laser pulse controller explained in the previous section. Through the optical pick-up unit with a wavelength of 405 nm and an NA of 0.85, the laser pulses are irradiated to the spinning triple-layer disc. The reading signal measurement was done by the partial-response maximum-likelihood (PRML) detector on the computer [6,7].

The pulse width and the optical output power for writing a 2T mark are in the table 1. The major experimental conditions are listed in the table 2. The data bit length on the disc is 56 nm. By these conditions, the data capacity per one layer is 33.4 Gbyte at the Blu-ray format, so the total capacity of the triple-layer disc becomes 100 Gbyte.
Figure 6. Cross-sectional view of the triple-layer disc. Three recording layers are formed on a polycarbonate substrate. All of the inorganic material films are deposited by the sputtering method. Especially in the layer1 and the layer2, very thin films of Ag and GST material with under 10nm thickness are adopted.

Figure 7. Experimental setup for data recording. An original writing laser pulse controller was added to the Pulstec ODU-1000.

Table 1. Pulse width and the optical output power for writing a 2T mark for each recording layer of the triple-layer disc.

|                | Layer0 | Layer1 | Layer2 |
|----------------|--------|--------|--------|
| Top pulse width | 4.26 ns| 2.13 ns| 2.13 ns|
| Cooling pulse width | none   | 4.02 ns| 3.79 ns|
| Write power     | 25.7 mW| 23.5 mW| 13.6 mW|
| Erase power     | 9.5 mW | 6.3 mW | 4.2 mW |
| Bottom power    | 0.1 mW | 0.1 mW | 0.1 mW |

Table 2. Major experimental conditions for the data recording.

|                                |            |
|--------------------------------|------------|
| Recording linear velocity      | 7.38 m/s   |
| Data clock period; T           | 7.58 ns    |
| Pulse control accuracy; T/32   | 240 ps     |
| Data bit length on the disc    | 56 nm      |
| Data capacity per one layer    | 33.4 Gbyte |
3.3. Results
The photograph in figure 8 is a SEM image of recorded marks on the layer2. Amorphous marks could be formed at the minimum size of 112 nm, although the optical recording spot size is large as 250 nm at the half-width. So, we have observed the nano-sized marks smaller than diffraction limit on the phase-change film. There, it was necessary to compensate the pulse edges when the 2Tm was formed on the recording film as the correct mark edges. The characteristic results of the compensation were obtained showing in table 3. There is a dependence on recording data pattern. The compensation value is not zero for the 2Tm between the preceding 2Ts and the succeeding 3Ts or for the 2Tm between the preceding 3Ts and the succeeding 2Ts. And there is a dependence on the three layers, too. The compensation value of the layer2 was larger than the layer0 or layer1.

![Image](image_url)

**Figure 8.** The photograph is a SEM image of recorded marks on the layer2 compared with optical spot size as the schematic. It is observed forming nano-sized marks smaller than diffraction limit.

| Layer0 | Layer1 | Layer2 |
|--------|--------|--------|
| Preceding space | Succeeding space | Succeeding space |
| 2Ts | 2Tm | 2Tm |
| 3Ts | 3Ts | 3Ts |
| 0 ps | 480 ps | 0 ps |
| -480 ps | 0 ps | -480 ps |
| 0 ps | 720 ps | 0 ps |
| -720 ps | 0 ps | 0 ps |

3.4. Discussion
Figure 9 represents the relation between the data patterns on the recording film and the writing laser pulses. We estimate a reason of the dependence on the data patterns as follows. In figure 9, (a) is the symmetrical data pattern of the 2Tm-3Ts-2Tm-3Ts-2Tm, (b) is its writing laser pulses, (c) is the asymmetrical data pattern of the 2Tm-3Ts-2Tm-2Ts-2Tm just changed succeeding space from the 3Ts to the 2Ts, and (d) is its writing laser pulses. When the center 2Tm and the succeeding 2Tm are formed, the interval of the 2Ts is short enough to cause the optical interference by the overlap of the laser spot and the thermal interference through the recording film. These interferences affect the cooling process of the film, the cooling speed becomes slow. This means easy to crystallize, in other words, insufficient to form amorphous in the phase-change process, therefore, the marks shrink like (c). On the other hand, if the pulse is compensated like (f), the 2Tm can be formed at right edge position like (e). In case of the center 2Tm in the symmetrical pattern as the 2Tm-2Ts-2Tm-2Ts-2Tm, the interference seems to be balanced.
Additionally, we estimate a reason of the dependence on the layers as follows. Each layer has a silver alloy film shown in figure 6, which is very thin as 7 nm in the layer2 in contrast to 100 nm in the layer0. A thinner film tends to decrease the heat radiation efficiency for the direction of the film depth, on the other hand, to increase the heat spread for the direction of the film plane. Therefore, wide thermal interference occurs in layer2 compared with layer0, the compensation value of the layer2 becomes large as in table 3. Furthermore, there is no cooling pulse for only layer0, although it is necessary for the layer1 and layer2 as in table 1. This reason is explained by high cooling capability of the heavy silver alloy film in the layer0.

![Figure 9](image)

**Figure 9.** Relations between the data patterns on the recording film and the writing laser pulses. (a) is the data pattern of the 2Tm-3Ts-2Tm-3Ts-2Tm, (b) is its writing laser pulses, (c) is the data pattern of the 2Tm-3Ts-2Tm-2Ts-2Tm just changed succeeding space from the 3Ts to the 2Ts, which is formed by the pulses (d) without the compensation. They are shrinking because of the optical and thermal interference. Some arcs by the broken line show the interference schematically. On the other hand, the marks can be formed at right edge position (e) by the pulses (f) with the compensation.

4. **Conclusion**

New writing laser pulse control, which can compensate so as to form the correct mark edges on the thin recording film, was applied to the phase-change triple-layer disc. It has enabled to form 112 nm-sized marks smaller than the optical spot. The characteristic values of the compensation can be explained as the results of cancelling the optical and thermal interference in the phase-change process of forming the marks by considering about the spot size of the writing laser and the structure of the recording films.

**References**

[1] Yamada N, Ohno E, Akahira N, Nishiuchi K, Nagata K, and Takao M: Jpn. J. Appl. Phys. Suppl. 26-4 (1987) 61.
[2] ISO / IEC 16824: Information technology-120 mm DVD-Rewritable disk (DVD-RAM) (1999).
[3] Blu-ray Disc Association: White paper of physical format specifications for BD-RE 3rd edition (2010).
[4] Nishihara T, Tsuchino A, Tomekawa Y, Kusada H, Kojima R, Yamada N: Jpn. J. Appl. Phys. 50 (2011) 062503.
[5] Nakamura A, Kobayashi I, Narumi K, Takaoka T, Furumiya S, and Miyagawa N: Jpn. J. Appl. Phys. 49 (2010) 08KG01.
[6] Miyashita H, Nakajima T, Kimura N, Hino Y, and Ishibashi H: Jpn. J. Appl. Phys. 43 (2004) 4850.
[7] Shiraishi J, Kobayashi S, Miyashita H, and Hino Y: Tech. Dig. ISOM2009, Tu-F-08 (2009) 74.