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Eutectic-based Phase-change Recording Materials for 1-2X and 4X Speed Blu-ray Disc

Hun Seo†, Seung-Yoon Lee*, Kwang- Lyul Lee*, Jin-Hong Kim*, and Byeong-Soo Bae**

ABSTRACT

We report some recent results in the rewritable Blu-ray Disc with enhanced overwrite cyclability by using the growth dominant eutectic based Ge(Sb70Te30)+Sb recording layer, GeN interface layer and write strategy optimization. We have developed phase-change optical media with appropriate write strategy for 36(i.e., 1X)-72Mbps(i.e., 2X) dual speed Blu-ray Disc system and for the future high speed optical data storage. For recording layer, eutectic-based Ge(Sb70Te30)+Sb material was used and Sb/Te ratio and Ge content were optimized to obtain proper erasability and archival stability of recorded amorphous marks. The recording layer is wrapped up in GeN interface layers to obtain overwrite cyclability and higher crystallization speed. In addition, we designed appropriate write strategy so called Time-Shifted MultiPulse (TSMP) write strategy where starting position of multipulse parts are shifted from reference clock. With this write strategy, the jitter characteristics of the disc was improved and we found that leading edge jitter was improved much more than trailing edge jitter in 1X-2X speed recording. Finally, we investigated the higher speed feasibility of 144Mbps(i.e., 4X) by adopting some elemental doping to the eutectic based Ag-In-Sb-Te recording layer and structural optimization of constitution layers in Blu-ray Disc. In the paper, we report the effect of Sn addition for the feasibility of higher speed recording. The addition of Sn shows increases of the crystallization speed of phase change recording layer.

Key Words : Phase Change, Optical Disc, Blu-ray Disc, Cyclability, Eutectic, GeN, Ge(Sb70Te30)+Sb Ag-In-Sb-Te , Crystallization and Jitter

1. Introduction

Optical disc technology with a laser beam for data recording and readout is one of promising route for high density digital information storage in the tremendous multimedia era. Recently, the next generation optical disc system based on 405nm laser wavelength, 0.85 numerical aperture and 0.1-mm-thick cover-layer has been developed [1] prior to the establishment of Blu-ray Disc rewritable format.

The diameter of the concentrated beam is defined by the NA value of the objective lens and the wavelength, as in the following expression:

Beam Diameter = $\alpha * \lambda/NA$

λ = wavelength, α = a constant

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As seen in the above expression, the larger NA is, the smaller the beam diameter, although NA does not exceed 1.0 in the atmosphere. The largest NA values of CDs and DVDs obtainable during mass production were 0.45 and 0.6, respectively. For Blu-ray, an objective lens with an NA value of 0.85 was adopted.

The comparison in the beam size is shown in Fig.1. The first Blu-ray Disc Rewritable (BD-RE) system with 36Mbps of data transfer rate (i.e., 1X-speed) and 23GB of data capacity was introduced in the markets in 2003 using the phase-change media for the application of high-definition digital video recording. And moreover data application for personal computer with BD-RE format will come in near future. A reliable approach to this purpose has two major issues in view of media, one is to have higher direct overwrite (DOW) cyclability and another is to have higher data transfer rate which strongly depends on crystallization characteristics of phase-change material. The recording medium which is the most important layers in phase-change optical disc data storage should provide following characteristics; a) high sensitivity, b) high resolution, c) high signal-to-noise ratio, d) real time recording and instant playback, e) high immunity to defects, f) archival storage allowing permanent recording of data and no degradation under ambient condition or prolonged readouts. It has been known that two alloy systems are promising for the rewritable phase change optical materials including GeTe-Sb2Te3 alloy systems (so called, GeSbTe)[2] and Sb-Te(+) alloy systems (so called SbTe).[3] These representative phase change material systems are shown in Fig. 2. We have developed BD 1X compatible phase-change optical disc media using eutectic-based Ge(Sb70Te30)+ Sb alloy.[4] In the previous study, we obtained some results in the rewritable BD with enhanced overwrite cyclability at 1X-speed by using the growth–dominant eutectic-based Ge(Sb70Te30)+Sb recording layer and GeN interface layer. But, the higher data transfer rate over 36 Mbps is needed in order to realize the more diversified applications in digital video recording system related with HD-TV content and to be adapted to optical data storage application for personal computer.

In this alloy system, Sb/Te composition ratio is known as a key factor for higher speed overwriting capability of the nucleation–free and growth-dominant for higher crystallization speed, but, higher Sb/Te ratio also causes mark instability or archival stability problem.[5] The mechanism of the increase of crystallization rate is possibly releted to the increase of crystalline growth speed from amorphous mark boundaries in case of increase of Sb content in Sb70Te30 eutectic alloy system.[6] Since the melt-quenched crystalline state is based on the hexagonal structure of pure Sb, the increase of Sb concentration may accelerate ordering of hexagonal structure without any other phase, resulting in fast crystalline growth. This quickly frozen solid phase solution without significant phase separation, can realize a fast crystalline growth without significant atomic diffusion.[7] The doping of only a few atomic % of Ge to (Sb70Te30)+Sb binary alloy does not affect the melt-quenched crystalline structure without significant segregation during repeated overwriting,[7] further suppresses nucleation probability and results in the stability of amorphous mark.[8] In this paper, we report BD 1X-2X(i.e., 36-72Mbps) compatible phase-change media by optimizing composition (i.e. Sb/Te ratio and Ge contents) of recording layer and multilayer structure, and by applying the so called Time-Shifted MultiPulse(TSMP) write strategy, where the shift of multipulse laser recording is optimized. With the TSMP write strategy, the media show good overwrite cyclability over 10,000 at both BD 1X and 2X speed, and good jitter values below 6% at BD 2X speed condition. Moreover, the higher speed (ex. 4X) for the next version of Blu-ray Disc application will be necessary in near future. In this paper we also summarized the recent progress of 4X media development by the modification of the phase-change recording layer. We report the effect of Sn addition for the feasibility of higher speed recording.

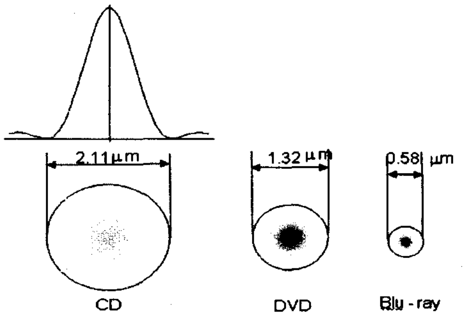


Fig. 1 Comparison in the beam size.

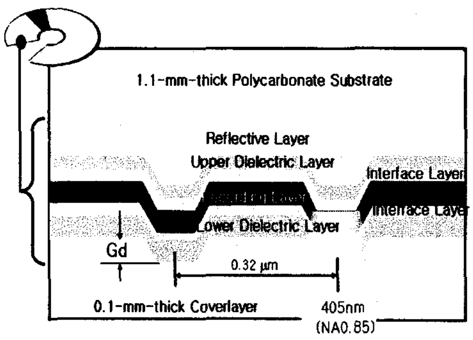


Fig. 3 Schematic diagram of BD-RE disc structure

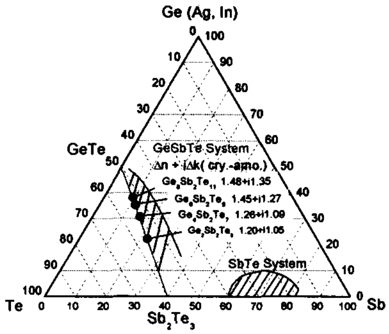


Fig. 2 Typical rewritable phase change materialsystems.

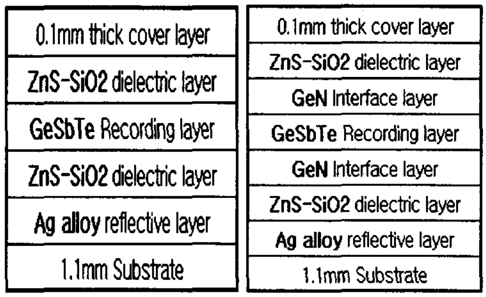


Fig. 4 Cross sectional view of disc structures

Table 1 Parameters of recording characteristics

Laser Wavelength	408 nm		
Numerical Aperture	0.85		
User Data Rate	36 Mbps (BD 1X)	72 Mbps (BD 2X)	144 Mbps (BD 4X)
Channel Clock	66 MHz	132 MHz	264 MHz
Linear Velocity	5.28 m/s	10.56 m/s	21.12 m/s
Modulation Code	17PP		
Recording Track	on-groove		
Track Pitch	0.32 um		
User Capacity	23.3 GB		

• Dynamic tester: Pulstec ODU-1000

2. Experiments

Fig.3 shows the schematic cross-sectional view of BD-RE disc. BD-RE discs used here were fabricated in two types of film structures. One is 4-layer and the other is 6-layer structure as shown in Fig.4 Ag-alloy reflective layer, ZnS-SiO2 dielectric layer, GeN interface layer, eutectic-based Ge(Sb70Te30)+Sb recording layer, GeN interface layer and ZnS-SiO2 dielectric layer were deposited by sputtering onto a 120mmΦ polycarbonate substrate with 0.32μm track pitch.

A GeN layer was suggested for use as interface layers for the purpose of diffusion barrier between ZnS-SiO2 layer and the nucleation-dominant type phase-change Ge-Sb-Te film in DVD-RAM disks.[9] We also showed improvement of direct overwrite-cyclability using this nitride interface layers wrapping active recording layer.[4] As a recording layer, growth-dominant eutectic-based Ge(Sb70Te30)+Sb alloy were used. The Sb/Te ratio in composition of the recording layer and multilayer structure for the sufficient cooling speed were optimized for the optical and thermal characteristics balance during overwriting. In particular, the optimization of film structure was focused on the thermal balance between the amorphous mark stability and the crystallization speed of recording layer because the mark stability tends to become poor as crystallization speed increases in phase-change optical disc.[10] In order to obtain the higher crystallization characterization for 4X speed application than previous alloy system, we fabricated three films containing Sn element in the Ag-In-Sb-Te phase change system. Sn additions was 0, 4.5 and 9 at% , respectively.

The chemical composition of the film were determined by by inductively coupled plasma-atimic emission spectroscopy (ICP-AES).

An 100-μm-thick transparent coverlayer was covered on the top of the 4- or 6-layered thin film stacks. As-deposited amorphous recording layer was initialized for phase transformation from as-deposited amorphous state to crystallized state with a commercialized initializer (Hitachi CP). Main recording parameters were 1-7PP channel modulation, 36Mbps user data transfer rate, 4.92m/s linear velocity.

Writing and reading characterizations were carried out by using ODU-1000 dynamic tester (Pulstec Co.) with the laser wavelength of 408 nm (NA= 0.85) and recording method was on-groove at the linear velocity of 5.28, 10.56 and 21.12 m/s which corresponds to BD-RE 1X, 2X and 4X speed, respectively. The evaluation conditions of the disc are shown in Table 1. Especially, write strategy for recording marks were optimized in the normal multipulse form and in the time-shifted multipulse (TSMP) form. Fig.5. shows the comparison between normal type of multipulse write strategy and the TSMP write strategy. Normal multipulse form means the starting point of each multipulse part for all marks coincides with reference clock as shown in figure 5(a), and the time-shifted multipulse means the starting points of each multipulse part for 4T~8T marks are shifted with the deviation time dTmp from reference clock as shown in figure 5(b).

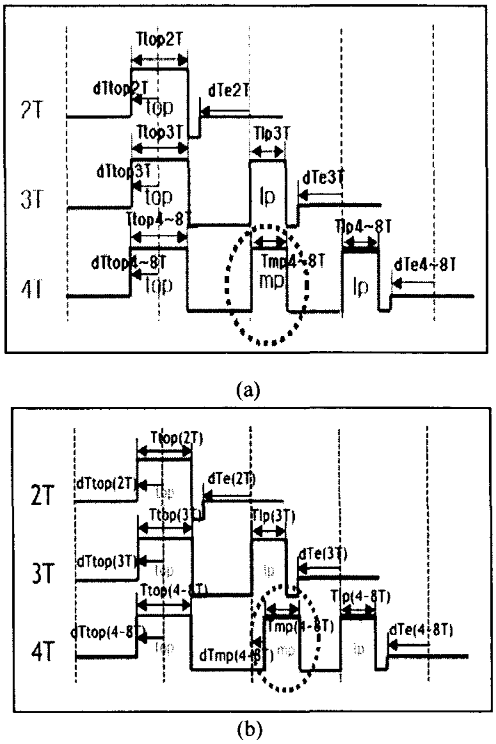


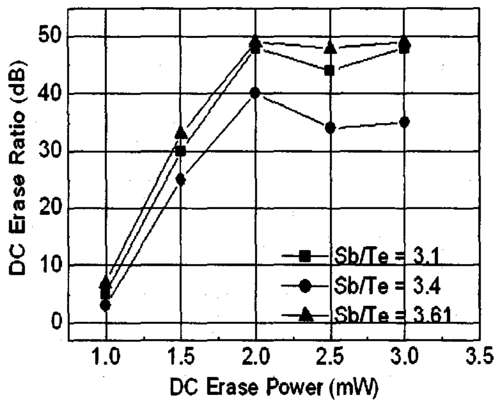
Fig. 5 Write strategy forms. (a) normal ultipulse write strategy(N-1 pulse type) and (b) time-shifted multipulse write strategy(TSMP), respectively. Where N means the recorded mark length. For example, N is 4 in 4T mark recording.

3. Results and discussion

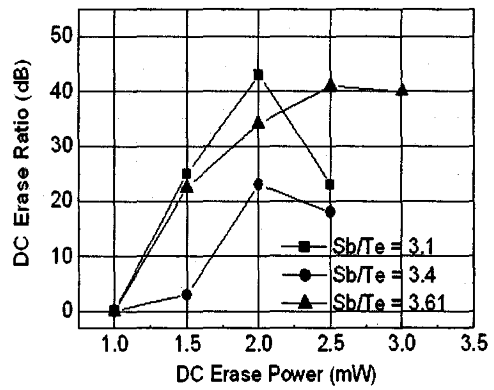
To achieve high speed overwriting, we should consider the fast crystallization rate of recorded amorphous marks and the resulting erase ratio with DC-erase laser beam. Fig.6. shows the dependency of DC erase ratio as a function of DC erase power with respect to Sb/Te concentration ratio in Ge(Sb70Te30)+Sb alloy. From this figure we can consider the accelerating effect of crystallization of recorded amorphous mark is increased with the increase of Sb/Te ratio. This phenomenon is possibly related to the increase of crystalline growth speed from amorphous mark boundaries in case of increase of Sb content in Sb70Te30 eutectic alloy system .[6]

The DOW characteristics of BD-RE specification requires the jitter value shall not exceed 10% using conventional equalizer mode and 6.5% using limit equalizer mode. The 6-layered disc having GeN interface layers shows lower jitter bump and much longer direct overwrite (DOW) cyclability than the 4-layered disc as shown in Fig.7 In this figure, DOW cycles of 4-layered disc is 16,000 and 6-layered disc shows about ten times of DOW cycles(~160,000) compared to 4-layered disc.

The effect of GeN interface layer on the jitter bump and DOW cycles might be correlated with the fast crystallization of the growth–dominant eutectic-based Ge(Sb70Te30)+Sb recording layer from the GeN interface zone, same phenomenon as previous study using GeSbTe and GeSbTeSn with GeN interlayer[9] and also with prohibiting atomic diffusion of sulphur of ZnS-SiO2 into the recording layer, same phenomenon as the previous report.[11] The important writing strategy parameters, which can make it possible to enhance the DOW cycles, include trailing edge (TE) cooling time duration from the end of NRZI signal and mark size balance between 2T~3T and 4T~8T group. Fig. 8 shows the comparison of direct overwrite jitter between normal write strategy and TSMP write strategy. It can be seen that jitter characteristics of single track is improved by applying TSMP write strategy. The conventional equalized jitter value is reduced more than the limit equalized jitter value. By applying TSMP write strategy, conventional equalized jitter was lower than 10% and limit equalized jitter were lower than 6% within 1000 direct overwrite cycles. Table 2 shows the leading



(a) 1x



(b) 2x

Fig. 6 the dependency of DC erase ratio as a function of DC erase power with respect to Sb/Te concentration ratio in Ge(Sb70Te30)+Sb alloy. a) 1x speed characteristics and b) 2x speed characteristics.

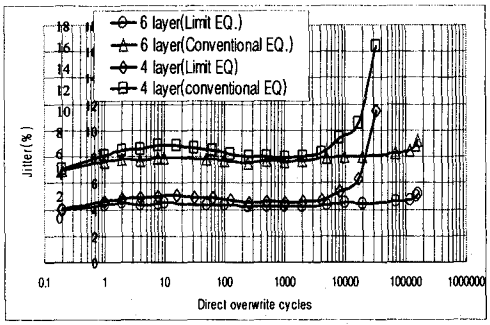


Fig.7 Direct overwrite characteristics of jitter (1X)

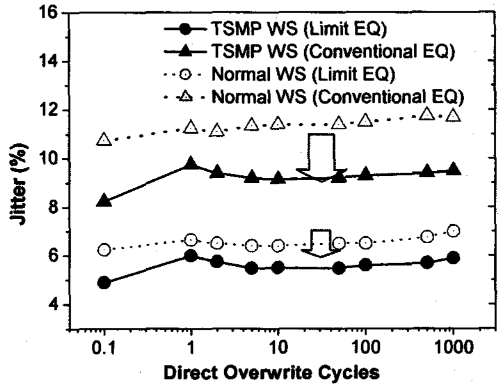


Fig. 8 Comparison of jitter characteristics between normal write strategy and TSMP write strategy(2X)

edge and trailing edge jitter values at the conditions of normal write strategy and TSMP write strategy.

These measurements were done after 10 direct overwrite cycles on a five adjacent tracks. In these tests, TSMP write strategy case also showed better jitter characteristics and especially trailing edge jitters were more improved than leading edge.

Fig.9 shows the amorphous mark simulation. From this figure we can expect that the time-shifted multipulse gives better mark shape of leading and trailing edge and it results in the reduction of jitter value. We found from the jitter measurement that trailing edge jitter was more improved than leading edge, although leading edge jitter was also improved. The reason for this jitter behavior is not clear yet, but some possibility is that shift of multipulse toward last pulse influences on thermal history of trailing edge and make mark edge shape better.

We previously reported the effect of GeN interface layers and TSMP write strategy on improvement of DOW cyclability at 1x speed.[4] In this study, we also used same interface layer structure and TSMP write strategy for good DOW cyclability at speed 2X. Fig.10. shows direct over-write jitter characteristics in both 1X and 2X compatible BD recording by using a dual-speed disc. In both case, cyclability over 10,000 were obtained. Limit EQ jitter was lower than 5.5% at 1X and lower than 6.5% at 2X speed, respectively.

Table 2 Leading edge and trailing edge jitter when normal WS and TSMP WS are applied.

Jitter (%)		Normal WS	TSMP WS	Jitter difference
CEQ	Total	12	10.5	-1.5
	Leading Edge	11.4	10.95	-0.45
	Trailing Edge	12.9	10.25	-2.65
LEQ	Total	7.65	6.45	-1.2
	Leading Edge	7.5	6.6	-0.9
	Trailing Edge	7.9	6.3	-1.6

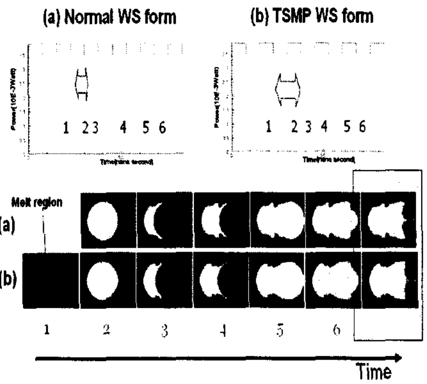
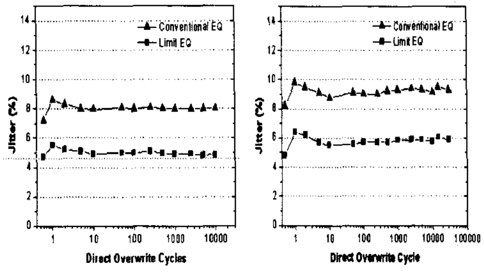


Fig. 9 Amorphous mark formation simulation



(a) (b)

Fig. 10 Direct overwrite jitter characteristics; (a) 1X speed recording and (b) 2X speed recording.

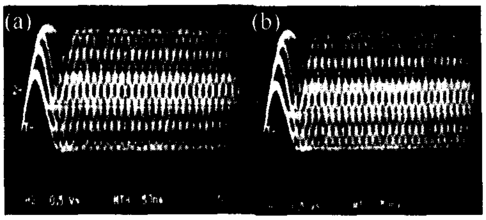


Fig. 11 Eye patterns in conventional EQ mode; (a) after initial recording and (b) after 10,000 direct overwrite cycles.

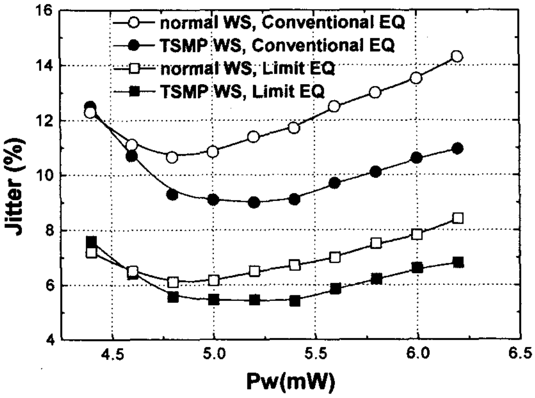


Fig. 12 Comparison of write power margins between normal multipulse and TSMP write strategy after 10direct overwrite cycles. TSMP write strategy showswider power margin.

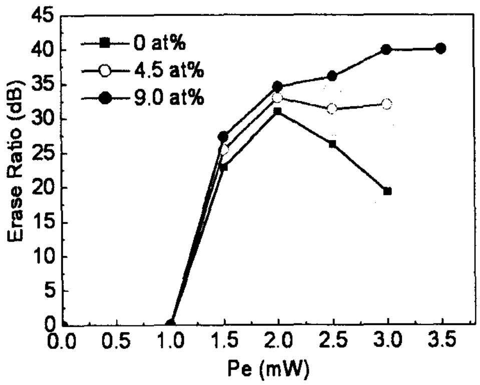


Fig. 13 Erase ratio change as a function of erase power and content of Sn addition (4X).

Fig. 11. shows equalized RF signals in case of initial write and after 10,000 direct overwrite cycles. It also clearly shows eyes are opened in the signal even after 10,000 DOW cycles.

Fig.12 shows the comparison of write power margins between normal multipulse and TSMP write strategy. It shows wide margin was obtained in case of TSMP write strategy and was closely related to low jitter level.

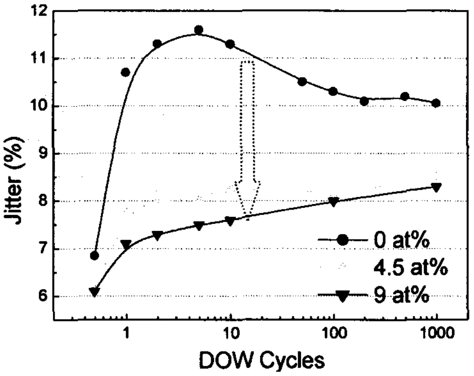


Fig. 14 Jitter change as a function of DOW (Direct OverWrite) cycles and content of Sn addition(4X).

Fig.13 shows erase ratio change as a function of erase power and content of Sn addition at 4X speed. This figure shows the acceleration effect of crystallization by Sn addition. Fig.14 shows Jitter change as a function of DOW cycles and content of Sn addition.

From these two figures, we can expect the assisting effect of Sn on the crystallization behavior of phase change layer. We think this behavior of Sn is closely related with the increase of nucleation rate and complete.

crystallization that are bring about by numerous nucleation in the amorphous phase layer in the presence of Sn. This behavior of Sn is similar to the previous research in the GeSbTe alloy system.[11]

4. Conclusion

We achieved 1.6×10^5 DOW cycles in 6-layered BD-RE disc using the growth–dominant eutectic-based Ge(Sb70Te30)+Sb recording layer and GeN interface layer. The present study suggests that the combined use of GeN interface layer and the optimized write strategy contributes to enhanced DOW media cyclability. We developed 1X-2X compatible dual speed Blu-ray Disc which shows an appropriately good jitter value and DOW cyclability over 10,000 by optimizing material composition of eutectic Ge(Sb70Te30)+Sb recording layer and multilayer structure, by using GeN interface layer, and by applying time-shifted multipulse(TSMP) write strategy. After 10,000 direct overwrites in 2X speed recording, limit EQ jitter value was maintained below 6.5%. The TSMP write strategy is effective to improve trailing edge jitter more than leading edge jitter, though leading edge jitter was also improved. It also shows wide margins were proved experimentally and were closely related to low jitter level with TSMP write strategy.

Finally, we investigated the higher speed feasibility of 144Mbps(i.e., 4X) by adopting Sn addition to the eutectic based Ag-In-Sb-Te recording layer and structural optimization of constitution layers in Blu-ray Disc. We found the effect of Sn addition for the feasibility of higher speed recording. The addition of Sn shows increases of the crystallization speed of phase change recording layer.

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