High Speed Crystallization Characteristics of Ge-Sb-Te-Bi Materials Used for Next Generation Rewritable DVD with Blue Laser and NA=0.65

K. Yusu, T. Nakai*, S. Ashida*, N. Ohmachi, N. Morishita and N. Nakamura

Toshiba Corp. Digital Media Network Company 8, Shinsugita-cho, Isogo-ku, Yokohama-shi 235-8522, Japan
*Corporate Research and Development Center, Toshiba Corp., 1, Komukai Toshiba-cho, Saiwai-ku, Kawasaki 212-8582, Japan

ABSTRACT

We have tried bismuth substitution to antimony in Ge-Sb-Te phase change recording layer in order to obtain high speed overwriting characteristics in the next generation DVD system with blue laser and Numerical Aperture (NA) of 0.65. Total substitution of Sb with Bi greatly increased the crystallization speed upon erasure and made it possible to overwrite data at the transfer rate of from 36.55 Mbps (1X) to 87.72 Mbps (2.4X). The written marks were stable and the signal quality remained practically unchanged for over 200 hours under 80 degrees and 85 % relative humidity condition. We consider that the high transfer rate was attained by high speed crystallization caused by meta-stable NaCl crystal structure with shorter lattice constant, while the mark stability might be due to the different mode of crystallization from that of erase operation.

Keywords: HD DVD-RW, high-speed crystallization, GeSbBiTe, phase change material, XRD

1. INTRODUCTION

HD DVD-RW specifications Version 1.0 using blue laser with the wavelength of 405 nm and a NA of the objective lens of 0.65 have been approved by the DVD forum in 2004. We have already demonstrated the recording characteristics, sufficient uniformity and long life durability of rewritable media having the user data capacity of 20GB at the user data transfer rate of 36.55 Mbps (i.e. data recording speed of 1X)[(1),(2)]. We have also developed the rewritable material for the high speed recording to meet the demand expected from the history of the progress of current DVD[(3),(4)]. It is generally accepted that the high-speed recording can be achieved by high erase ratio caused by easy crystallization of the recording layer. We believe that the phase change material as a recording layer and the dielectric material as the interface layer play an important role for the easy crystallization. We have tried Bismuth (Bi) substitution to Antimony (Sb) in pseudo-binary GeTe-Sb_2Te_3 alloy film as the recording layer to accelerate the crystallization speed.

2. EXPERIMENT

Layer structure of the rewritable media with low to high (L to H) polarity[(5)] used in this study is shown in Fig.1. Each film was stacked on 0.6-mm-thick polycarbonate (PC) substrate by using magnetron sputtering machine OCTAVA-II (Shibaura Mechatronics Corp.). The substrate has the land and groove format with the track pitch of 0.34 µm. Sputtered substrate was bonded with another 0.6-mm-thick PC substrate using UV resin. The completed disc was initialized by an initializer with optimized condition.

The sample discs were evaluated with a tester DDU-1000 under the condition shown in Table 1. Erase Ratio (ER), which is mainly discussed in this paper was measured as follows. Continues light was irradiated on the recorded marks, after the 11T pattern was written in a track once with the optimum condition. ER was defined as the change of 11T-carrier between before and after the irradiation.

X-ray Diffraction (XRD) measurement was also performed in order to examine the relation between the crystal structure of the recording layer and the disc performance. For the XRD measurement, 100nm-thick Ge-Sb-Bi-Te films were sputtered on the PC substrate and then crystallized by the initializer.

3. RESULTS AND DISCUSSIONS

3.1. Crystal structure of Ge-Sb-Bi-Te material

Fig.2 shows XRD patterns for three variations of phase change material, *i.e.*, GeSbTe, GeSbBiTe and GeBiTe. They showed almost the same patterns compared with the pattern of as-deposited GeBiTe. All peaks in their patterns indicate that each material has NaCl type crystal structure. It is known that the phase change material with NaCl structure enables fast crystal growth during the transition from amorphous to crystal because of its simple cubic structure[6]. We also examined Bi content dependence of lattice parameter in this NaCl structure and show the results calculated from XRD measurement in Fig.3. Bi amount is represented as Bi rate of content in total amount of Sb and Bi in Fig.3. It is shown that the lattice parameter becomes large, as the Bi content increase. It is considered that the lattice parameter increase since Sb atom is replaced by Bi atom with relatively larger atomic radius. Profound consideration, however, is required for understanding the relation between the fast crystal growth and the increase of lattice parameter. Such fast crystal growth is expected to realize high speed overwriting in the disc performance in a manner to be described.

3.2. Disc performance

Fig.4 shows the linear velocity dependence of ER of the discs with different compositions. ERs for both GeSbTe and GeSbBiTe steeply decrease to less than 20 dB as the linear velocity increases from 5.61 m/s (1X) to 13.46 m/s (2.4X). However, ER of GeBiTe stably keeps over 25dB for the linear velocity up to 39.27 m/s (7X). The disc using GeBiTe as the recording layer has a potential to develop into 7X data transfer rate, if we assume that the ER over 25dB is sufficient for complete overwriting. We also examined the dependence of the ER on the composition of Ge-Sb-Bi-Te alloy. Fig.5 shows the ER as a function of the bismuth content in pseudo-binary $GeTe\text{-}(Sb_{1\text{-}X}Bi_X)_2Te_3$ alloy. ER gradually increases as the bismuth content increases for the transfer rate of from 1.5X to 2.4X, although there is very small change in ER for all bismuth contents at 1X. It is found that GeBiTe alloy can make the transfer rate with wide margin of 1X to 7X possible. Such high ER brings high disc performance as shown in Fig.6. Fig.6 shows peak recording power dependence of SbER, which is one of the evaluation indexes of HD DVD-Rewritable, at the transfer rate of 1X to 2.4X. It is found that the peak powers can be varied from 5.6mW to 6.2mW for 1X and from 6.0mW to 6.8mW for 2.4X respectively in order to satisfy the SbER specification of under 5E-5.

It is important to balance competing goals for high speed crystallization and long life durability. Result of durability test under the condition of 80 degrees and 85% relative humidity is shown in Fig.7. Behavior of the written marks on a specific track is measured as a function of time in this test. Almost no change of SbER indicates very good durability. We consider the reason that both high speed crystallization and long life durability is completed as follows. Accelerated deterioration during life test is dominated only by the nucleation in an amorphous mark, while crystallization during erasing operation is caused by both the crystal growth at the edge of an amorphous mark and the nucleation in an amorphous mark. In other words, the nucleation does not occur in such lower temperatures as used in the life test, *i.e.*, the crystal growth is dominant. We consider that the above expectation is one of the major candidates to understand simultaneous pursuit of the high data transfer rate and the long life durability.

4. CONCLUSIONS

We have studied the performance of the rewritable disc varying the Bi substitution ratio to Sb in the Ge-Sb-Bi-Te alloy recording layer with a view to achieve high data transfer rate. The disc having a recording layer in which antimony is fully substituted with bismuth demonstrated the possibility for the high data transfer rate of up to 7X. Measured SbER of the disc indicated wide power margins of the transfer rate of 1X and 2.4X. This result suggests the feasibility of the disc for CAV (Constant Angular Velocity) recording. We also confirmed that the disc had durability for 200 hours or more under the condition of 80 degrees and 85% relative humidity. XRD measurement revealed that Ge-Sb-Bi-Te alloys had NaCl type crystal structure regardless of the amount of bismuth substitution to antimony in the alloy. We consider that the simple cubic structure of NaCl type allows high speed crystallization, resulting in high transfer rate.

REFERENCES

(1) N. Ohmachi, S. Ashida, K. Yusu, T. Nakai, K. Ichihara and N. Nakamura, Jpn. J. Appl. Phys., 43(2004)4978.
(2) K. Yusu, S. Ashida, N. Nakamura, N. Oomachi, N. Morishita, A. Ogawa and K. Ichihara, Jpn. J. Appl. Phys., 42(2003)858.
(3) T. Nakai, S. Ashida, K. Yusu, N. Ohmachi, K. Umezawa and N. Nakamura, Tech. Digest of 16th PCOS(2004)73.

(4) N. Ohmachi, N. Morishita, K. Yusu, N. Nakamura, T. Nakai and S. Ashida, Tech. Digest of ISOM/ODS2005, MP5.
(5) S. Ohkubo, M. Nakano, H. Honma, T. Ide and T. Iwanaga, Proc. SPIE Int. Soc. Opt. Eng. 3401(1998)103.
(6) N. Yamada and T. Mtsunaga, J. Appl. Phys., 88(2000)7020.

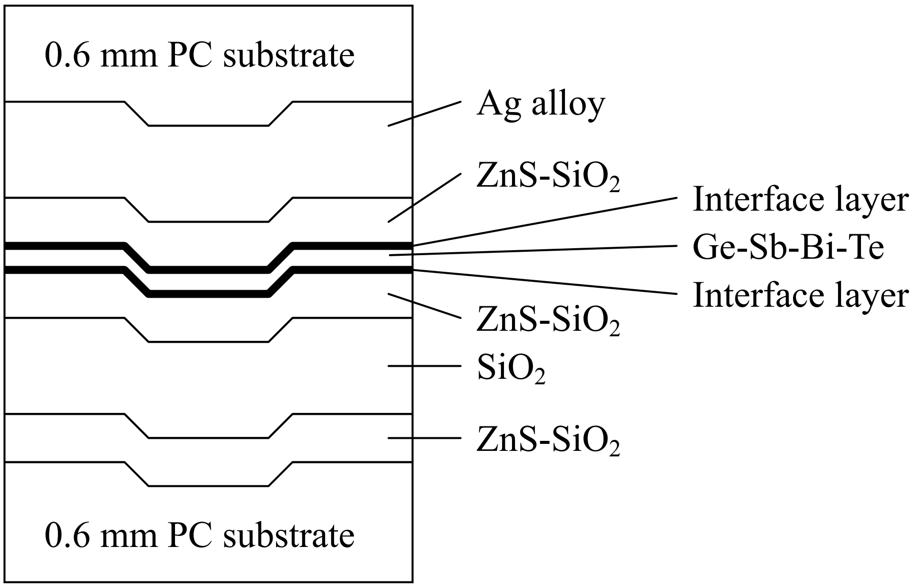

Fig.1 Cross-sectional view of the experimental disc with L to H polarity.

Table 1 Evaluating conditions and other specifications.

User capacity	20 GB
Data transfer rate	36.6 – 87.7 Mbps (1X – 2.4X)
Linear velocity	5.61 – 13.46 m/s
Laser wavelength	405 nm
NA of objective lens	0.65
Thickness of substrate	0.6 mm
Track pitch (land & groove)	0.34 µm
Data bit length	0.13 µm/bit
Channel clock frequency	64.8 – 155.5 MHz (1X – 2.4X)
Modulation code	ETM, RLL(1,10)
Data detection method	PR(1,2,2,2,1)ML

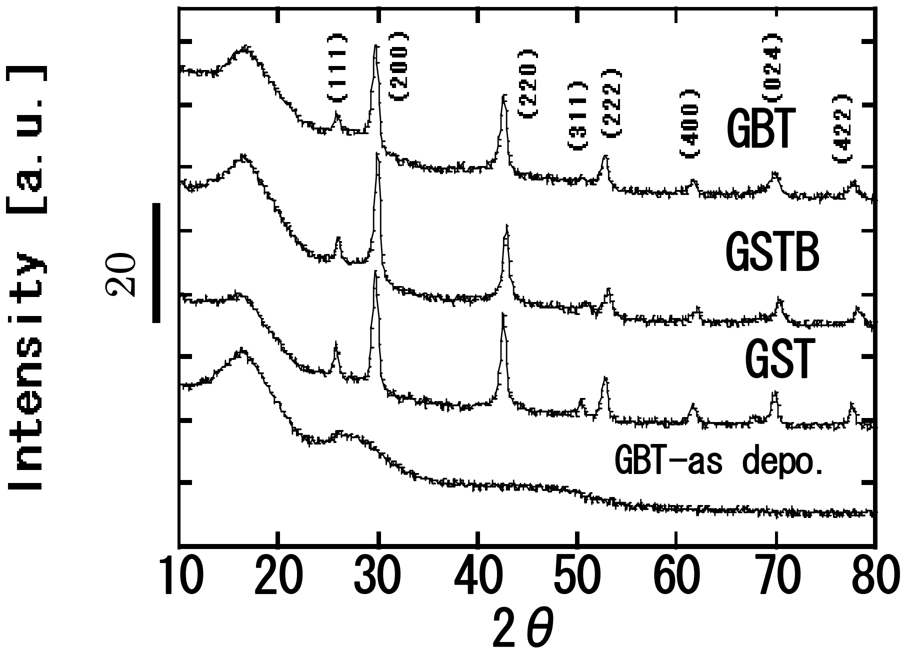

Fig.2 XRD patterns of laser induced crystallized GeBiTe, GeSbTeBi and GeSbTe films and as- deposited GeBiTe film.

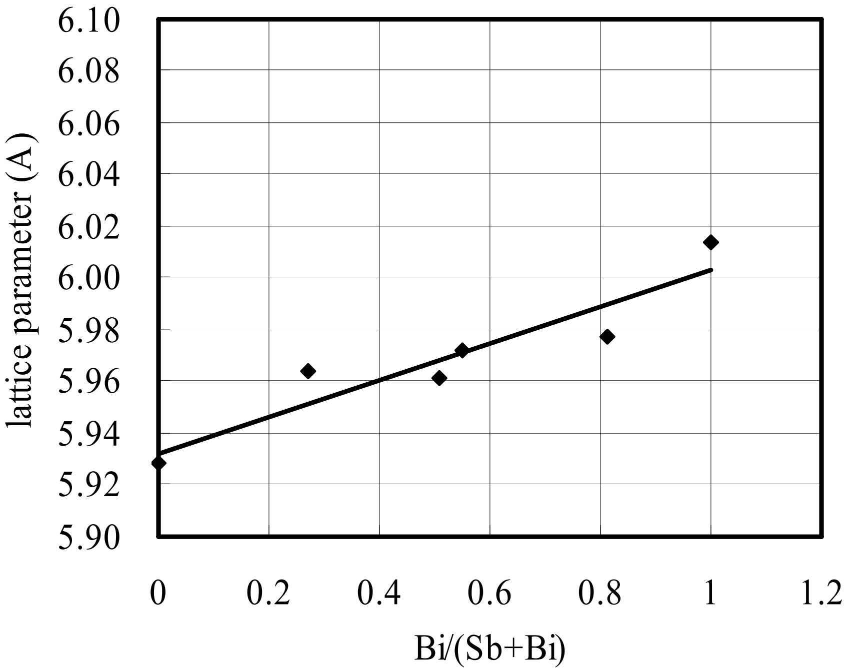

Fig.3 Bi content dependence of the lattice parameter in the NaCl structure.

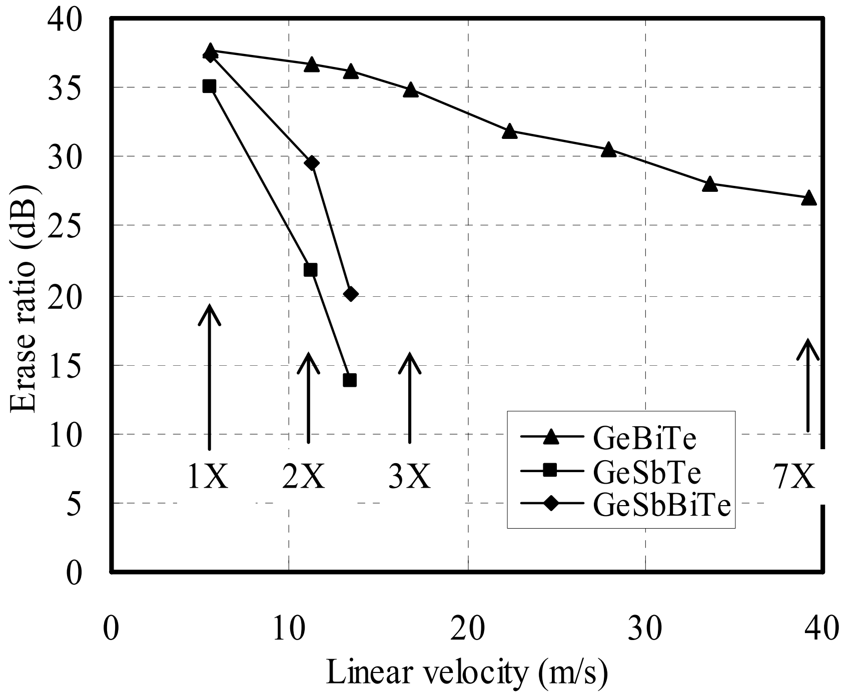

Fig.4 Linear velocity dependence of ER on groove tracks of the rewritable discs having different recording layer compositions.

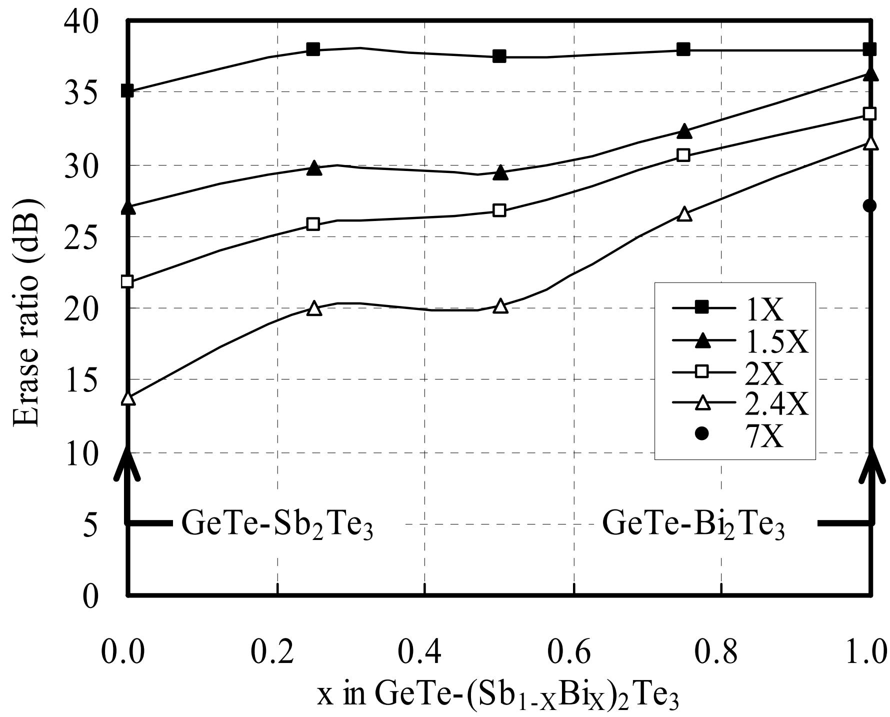

Fig.5 Bismuth content dependence of ER for our rewritable discs with the recording layer consisting of GeTe-$(Sb_{1-X}Bi_X)_2Te_3$

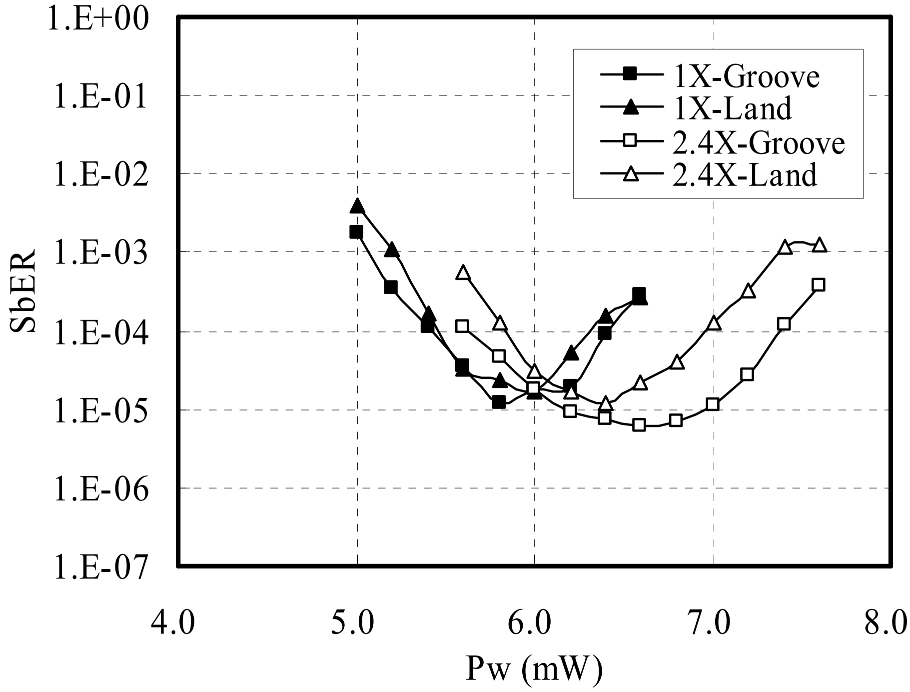

Fig.6 Peak power dependence of SbER for our rewritable disc with the recording layer consisting of GeBiTe

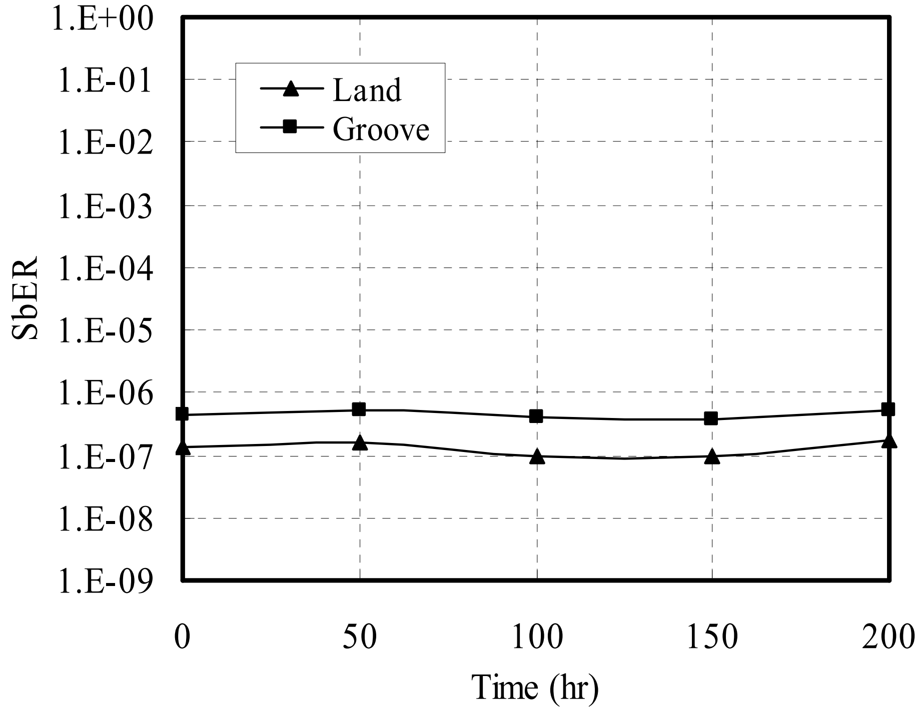

Fig.7 Time dependence of SbER for our rewritable disc with the recording layer consisting of GeBiTe under the condition of 80 deg. and 85% relative humidity.