Land/groove optical recording with GeTe/Sb_2Te_3 superlattice-like structure

Wei Qiang (墙 威)[1], Luping Shi[2], Towchong Chong[2], and Yang Cao (曹 阳)[1]

[1] *School of Electronics Information, Wuhan University, Wuhan 430072*

[2] *Data Storage Institute, DSI Building, 5 Engineering Drive 1, Singapore 117608*

Received March 1, 2004

A superlattice-like (SLL) structure was applied to phase-change optical recording. The recording layer consisting of alternating thin layers of two different phase-change materials, GeTe and Sb_2Te_3, were grown by magnetron sputtering on polycarbonate substrates. Land/groove optical recording was adopted to suppress crosstalk and obtain a large track density. Dynamic properties of the SLL disc were investigated with the shortest $1T$ pulse duration of 8 ns. Clear eye pattern was observed after 10000 direct overwrite cycles. Erasability above 20 dB was achieved at a constant linear velocity of 19 m/s. Carrier-noise ratio (CNR) kept above 46 dB when the recording frequency reaches 21 MHz. The SLL phase change optical disc demonstrates a better recording performance than the $Ge_1Sb_2Te_4$ and $Ge_1Sb_4Te_7$ discs in terms of CNR, erasability, and overwrite jitter.

OCIS codes: 210.0210, 210.4590, 210.4770, 160.4670.

Research of phase-change recording materials dates back to more than three decades ago[1,2]. In 1968, Ovshinsky discovered a new order-disorder memory phenomenon in chalcogenide film materials, later termed "Ovonic memory". In addition to the electrical switching effect, these materials also exhibit laser optical memory effect[3]. Since then, a number of great improvements have been made[4]. In 1985, Chen *et al.* reported that the erase time of less than 30 ns could be achieved without compromising data stability by using a medium based on stoichiometric compounds, which greatly enhanced the practicality of a phase-change recording system[5]. In the last decade, the development of high-density phase-change optical recording has drawn increasing attention for its unique features of large capacity, direct overwrite (DOW), low cost, and non-contact data retrieval. Data storage density and recording performance are the two mostly concerned aspects. The former is limited by the optical diffraction limit and crosstalk between adjacent tracks, whereas the latter is mostly related to structure and properties of the optical media. In order to improve the recording performance of high-density phase-change optical media, stoichiometric compounds of GeSbTe and AgInSbTe systems were widely applied in rewritable phase-change optical recording for their featuring characteristics of suitable crystallization and melting temperatures for laser induced phase changes and rapid transition in nanosecond range[6]. On the other hand, more complicated disc structures were invented to improve the performance of the optical media[7], wherein additional layers were used, including a thermal balance layer, an optical compensation layer, and interface layers, etc.. Recently, we proposed a novel superlattice-like (SLL) structure phase-change optical recording technology, in which a SLL structure of phase-change materials is introduced into the recording layer of the optical media to accelerate the crystallization process and enhance the structural stability of the recording layer[8,9].

In this letter, we report the latest progress of this new recording technology. The GeTe/Sb_2Te_3 SLL structure was applied to land/groove optical recording, which permits double track density. The dynamic recording performance of the SLL discs was investigated with the shortest $1T$ pulse duration of 8 ns and was compared with the typical conventional $Ge_1Sb_2Te_4$ and $Ge_1Sb_4Te_7$ discs, which were identified to have structural stability and fast recording speed, respectively.

Figure 1 depicts the structure of the SLL phase-change optical disc. Quadri-layer thin films are formed on the polycarbonate substrate: the lower dielectric layer with the thickness of 100 nm, the upper dielectric layer of 23 nm, and the reflective layer of 100 nm. The phase-change recording layer is sandwiched by the two dielectric protective layers of ZnS-SiO_2, and the reflective layer of Al alloy is attached. The phase-change layer was prepared by alternative sputtering of two different phase-change materials, GeTe and Sb_2Te_3, with thickness varying from 2 to 6 nm. Samples were prepared on 0.6-mm-thick polycarbonate substrates, with land/groove spiral type tracks. Discs with the recording layer of $Ge_1Sb_2Te_4$ and $Ge_1Sb_4Te_7$ with similar structure were prepared for comparison.

The sputtering system used in the experiment is Balzers cube system. It consists three target chambers, two direct current (DC) sputtering chambers and one radio frequency (RF) chamber, which enable alternative sputtering of GeTe and Sb_2Te_3 without exposure to the atmosphere. DC sputtering was used to deposit electrically

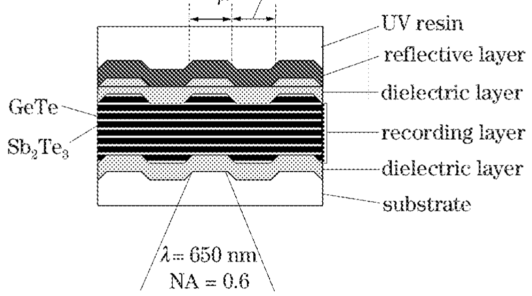

Fig. 1. Cross-section view of SLL phase-change optical disc.

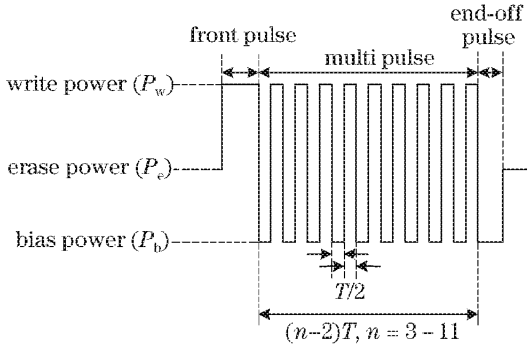

Fig. 2. Schematic diagram of the write strategy.

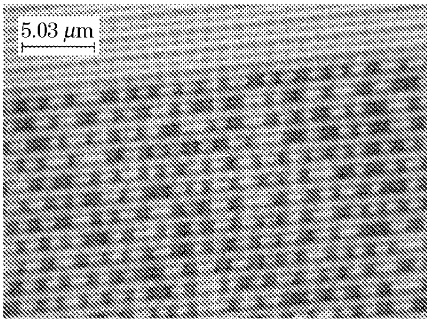

Fig. 3. Microscopic photo of mark spots on SLL phase-change optical disc.

conducting materials GeTe, Sb_2Te_3, and Al alloy. RF sputtering was used to deposite non-conducting material ZnS-SiO_2. The background vacuum was at the level of 7×10^{-5} Pa. The work pressure was $(4.5-5.5)\times10^{-1}$ Pa, while the processing gas was 15 sccm Ar.

The dynamic properties of writing, reading, and erasing were tested using a commercial dynamic tester (ShibaSoku DVD TESTER LM330A). In order to reduce the influence of thermal interference, multi-pulse recording method with pattern adaptive compensation function was adopted. Figure 2 shows a schematic diagram of write strategy used in this experiment. In the dynamic measurement, the power and waveform of the laser were properly set to achieve the best performance of the disc. If the pulse width and power were not optimized, the amorphous marks from the previous recording cannot be completely erased. This will cause the distortion in the overwritten marks, and hence a high noise level.

Data marks of the universal disc format (UDF) were written on the discs, and were then examined using a Zeiss Optical Axioplan microscope. The image of mark spots observed at the magnification of 2000 times is shown in Fig. 3. The recording marks can be clearly identified with various mark lengths, which indicates high carrier-noise ratio (CNR) and low overwrite jitter.

A comparison is made between the SLL phase-change disc and the conventional four-layer discs of $Ge_1Sb_2Te_4$ and $Ge_1Sb_4Te_7$. The dependence of CNR on recording frequency is shown in Fig. 4, which was measured at a constant linear velocity (CLV) of 19 m/s with different signals from $3T$ to $14T$ ($1T$ = 8 ns). The CNR of SLL disc keeps 51 to 46 dB from 4.5 to 20.8 MHz recording frequency, which corresponds to signals $14T$ to $3T$, and mark length 3.14 to 0.67 μm. It is much higher than those of the $Ge_1Sb_2Te_4$ and $Ge_1Sb_4Te_7$ discs, and is enough for the information retrieving from the discs. The SLL disc has an erasability ranging from 31 to 22 dB, which is much higher (about 6 dB) than the $Ge_1Sb_2Te_4$ and $Ge_1Sb_4Te_7$ discs. This is vital for the disc to be directly overwritten.

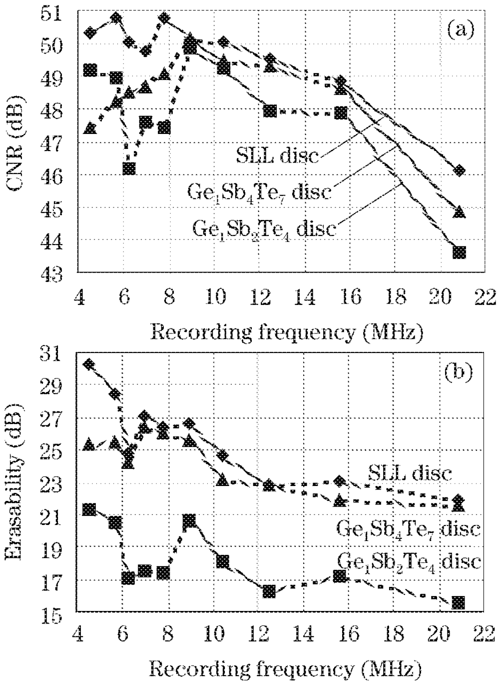

Fig. 4. Dependence on recording frequency of CNR (a) and erasability (b).

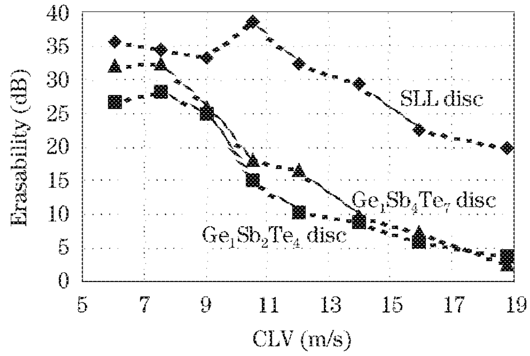

Fig. 5. Dependence of erasability on CLV.

As well known, data transfer rate of DOW discs are limited by the erasability. Figure 5 shows a comparison of the dependence of erasability on CLV between the SLL phase-change disc and the reference discs. Increasing the CLV from 6 to 19 m/s, the erasability value drops from 32 to 2 dB for the $Ge_1Sb_2Te_4$ disc and from 27 to 3 dB for the $Ge_1Sb_4Te_7$ disc, whereas it just drops form 35 to 20 dB for the SLL disc, which indicates that SLL structure is more suitable for high speed phase-change recording.

Figure 6 shows the dependence of jitter on overwrite cycle number when the discs were written by $3T - 14T$ random signals. The jitter of the SLL disc remains below 9% after 1000 times of DOW cycles. For the reference

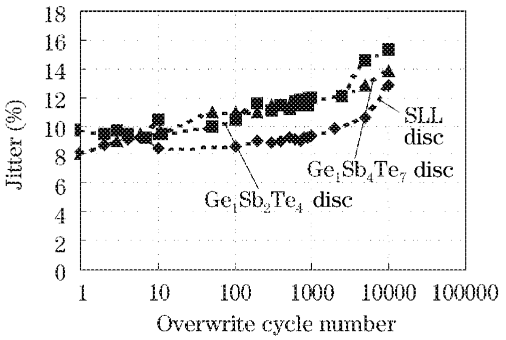

Fig. 6. Dependence of jitter on overwrite cycle number.

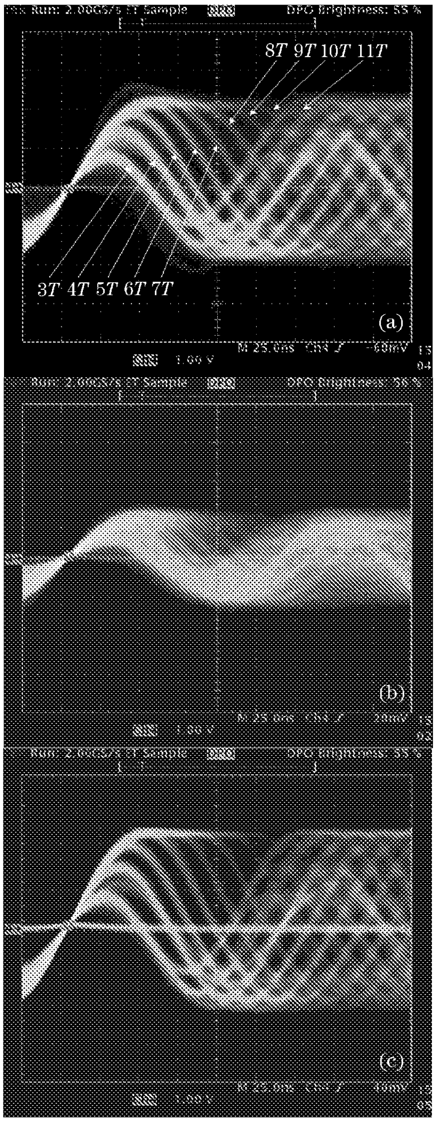

Fig. 7. Eye patterns of the discs after 10000 DOW of SLL disc (a), $Ge_1Sb_4Te_7$ disc (b), and $Ge_1Sb_2Te_4$ disc (c).

discs, jitters are higher from the beginning, and increase during the overwriting process. This shows that the SLL structure can inhibit the degradation of the phase-change optical disc and improve the overwrite properties.

Figure 7 shows the eye patterns of repeatedly overwritten tracks after 10^4 cycles. The eye patterns are clearly observable for the optical disc with SLL phase-change recording layer. The signals from $3T$ to $14T$ ($1T = 16$ ns) can be easily distinguished even after 10^4 cycles. Although the eye patterns of $Ge_1Sb_2Te_4$ reference disc are fairly good after 10^4 DOWs, it has a very low erasability (see Fig. 4). For the $Ge_1Sb_4Te_7$ disc, after 10^4 cycles, the eye pattern becomes obscure and cannot be recognized.

In conclusion, we have deposited two phase-change materials, GeTe and Sb_2Te_3, alternatively on a polycarbonate substrate to form a SLL structure, which was sandwiched by two dielectric layers. Although neither GeTe nor Sb_2Te_3 could be used as a phase-change material for practical applications, present experimental results revealed that the phase-change optical disc with the SLL structure demonstrated an excellent dynamic recording property that could meet practical recording requirements. It was demonstrated that better CNR, erasability, overwrite property, and sensitivity could be achieved as compared with the $Ge_1Sb_2Te_4$ and $Ge_1Sb_4Te_7$ reference discs with a single recording layer. The SLL structure gives an alternative to increase the recording performance of the phase-change optical disc. Further work is required to investigate the mechanism and physics that lie behind the experimental results.

Work described in the letter was performed at Data Storage Institute, Singapore. The authors gratefully acknowledge the financial support by the National Natural Science Foundation of China under Grant No. 60132030. W. Qiang's e-mail address is qiangwei_sg@yahoo.com.

References

1. Y. Kasami, Y. Kuroda, K. Seo, O. Kawakubo, S. Takagawa, M. Ono, and M. Yamada, Jpn. J. Appl. Phys. **39,** 756 (2000).
2. T. Ohta, K. Nishiuchi, K. Narumi, Y. Kitaoka, H. Ishibashi, N. Yamada, and T. Kozaki, Jpn. J. Appl. Phys. **39,** 770 (2000).
3. M. Mansuripur, *The Physical Principles of Magneto-Optical Recording* (Cambridge University Press, New York, 1995) pp. 1–18.
4. J. Park, M. R. Kim, W. S. Choi, H. Seo, and C. Yeon, Jpn. J. Appl. Phys. **38,** 4775 (1999).
5. M. Chen, K. A. Rubin, and R. W. Barton, Appl. Phys. Lett. **49,** 502 (1986).
6. J. H. Coombs, A. P. J. M. Jongenelis, W. van Es-Spiekman, and B. A. J. Jacobs, J. Appl. Phys. **78,** 4906 (1995).
7. N. Yamada, M. Otoba, K. Kawahara, N. Miyagawa, H. Ohta, N. Akahira, and T. Matsunaga, Jpn. J. Appl. Phys. **37,** 2104 (1998).
8. W. Qiang, T. C. Chong, L. P. Shi, P. K. Tan, and X. S. Miao, in *Proceedings of Optical Data Storage Topical Meeting 2001* MC3, 43 (2001).
9. T. C. Chong, L. P. Shi, W. Qiang, P. K. Tan, X. S. Miao, and X. Hu, J. Appl. Phys. **91,** 3981 (2002).