近接場光プローブと相変化メディアによる大容量光メモリシステムの可能性

Recording amorphous marks on a phase change disc by optical near field

高橋　淳一* 三浦　博* 豊島　伸朗* 川崎　俊之* 林　嘉隆*
Jun-ichi Takahashi　Hiroshi Miura　Nobuaki Toyoshima　Toshiyuki Kawasaki　Yoshitaka Hayashi
藤田　俊介* 大塚　正也**
Shunsuke Fujita　Masaya Ohtsuka

要　旨

AgInSbTeを表面記録層として持つ相変化メディアを作製し，従来の光学系により記録されたアモルファスマークをSEMにより観察した．記録ストラテジーを最適化することにより，100nmの大きさのアモルファスマークが記録できることを確認した．一方，近接場光プローブを用いて，相変化メディアにアモルファスマークを記録／再生／消去することができた．これらにより，近接場光と相変化記録材料の組み合わせで，100Gb/in^{2}以上の記録密度を持つ光記録システムが可能であることがわかった．

ABSTRACT

A new type of an optical disc with surface recording layer of AgInSbTe was fabricated. By observing the recording layer by SEM, it was found that uniform 100nm marks could be recorded on the discs by a conventional optical system, if the write strategy was optimized. Furthermore, amorphous marks on the recording layer of AgInSbTe could be read, erased, and recorded by an optical near field fiber probe. Therefore, an optical memory system whose recording density is more than 100 Gb/in^2 will be possible using optical near field and phase change recording material

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* 研究開発本部　中央研究所
Research and Development Center, Research and Development Group
** 電子デバイスカンパニー　プロダクト技術室
Product Engineering Department, Electronic Devices Company

1. INTRODUCTION

In the first decade of the 21st century, the network scale and the transfer rate of the Internet will increase more than thousand times compared with those of today. Under this circumstance, data storage system of which recording density is more than 100 Gb/in^2 and transfer speed is more than 100 Mb/s will be needed. To satisfy these requirements, there are some technical candidates for a high density and high speed data storage system, which are a magnetic hard disc drive (HDD), an optical memory using short wavelength light, a holographic memory, an optical near field memory and so on. However, most of them need technological breakthrough. The recording density of the HDD will be limited to 100 Gb/in^2 because of super paramagnetic effect[1-3]. On account of the diffraction limit, the recording density of the optical memory is limited to 40 Gb/in^2 even if ultraviolet light source is used. Though holographic memory was invented several tens of years ago, it is still being studied because its suitable recording material is not found yet and its performance is very sensitive to wavelength drift of laser light source and others. On the other hand, optical near field memory has a potential for recording density of 1 Tb/in^2 theoretically using a laser diode of which wavelength is more than 400 nm and phase change recording material for example[4-6]. In this paper, phase change memory discs having a recording layer on its surface were fabricated. Furthermore, trial of readout/erasing/recording amorphous marks on the recording layer was made by near field optical system in illumination-correction mode to study feasibility of high density optical near field data storage system.

2. Characteristic of optical near-field

Optical near field is the alternative electromagnetic field generated near a small aperture in an optical shield irradiated with light. If an ideal metal film has an aperture of which diameter is less than wavelength of the light and it is irradiated with the propagation light as shown in Fig.1(a) [7], free electrons concentrates in the edge of the aperture. As a result strong electrical field is generated adjacently to the aperture, specifically within the same distance as the aperture size, from the shield as shown in Fig.1(b). The frequency of the field is equal to that of the light. So this electromagnetic field is called "optical near field". Optical near field stays in the region of the aperture as mentioned above. Therefore, the resolution of an optical near field probe is determined by the size of the aperture which is about 100 nm or less in practical, which means optical near field can overcome the optical diffraction limit. Consequently, the phase change disc must have ability to record amorphous marks smaller than 100 nm.

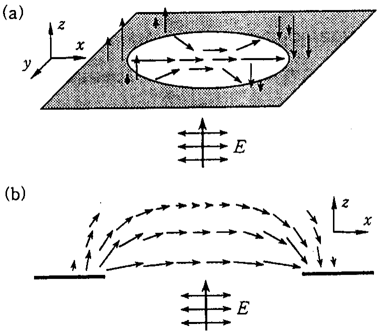

Fig.1 The optical near field, (a) in the plane of the aperture and the optical shield, (b) near the aperture[7].

3. Recording 100 nm amorphous marks on surface recording disc

3-1 Experiments

A phase change disc of which recording layer is located close to a surface of the disc is necessary for the optical near field recording system because the optical near field can exist only near the aperture as mentioned above. In the beginning, to estimate the performance of the surface recording disc, amorphous marks of around 100 nm were recorded on the disc by using a conventional far field optical pickup. Then, the shapes and their uniformity were investigated by a scanning electron microscope (SEM).

Figure 2(a) shows the structure of surface recording disc. The Ag reflective layer, lower ZnS-SiO$_2$ protective layer, AgInSbTe recording layer and upper ZnS-SiO$_2$ protective layer were stacked on a polycarbonate substrate. The substrate is the same design as in DVD system, of which track pitch is 740 nm. The optical pickup including a 660 nm laser diode (LD) and an objective lens with a numerical aperture of 0.65 was used in this experiment.

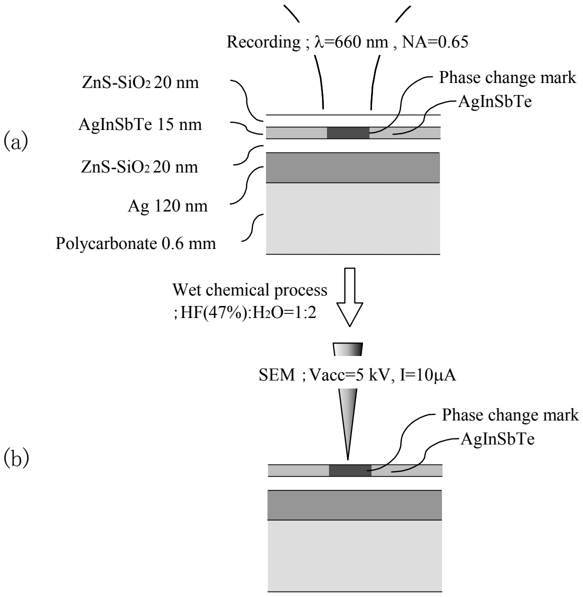

Fig.2 The structure of surface recording disc and the specimen of SEM observation. (a)The amorphous marks was recorded on the disc by a far field optical pickup with λ = 660 nm and NA=0.65. (b)The upper ZnS-SiO$_2$ layer was removed by a wet chemical process, and the AgInSbTe surface was evaluated by FE-SEM at Vacc=5 kV and I=10 μA.

Amorphous marks with length of around 100 nm were recorded in the following way. The laser power was modulated by a square wave, which corresponded to the 3T signal of 8-16 modulation in DVD systems, and the 3T mark/space signal was recorded on the disc, as illustrated in Fig.3. The laser power was changed at three levels, that is, write power (Pw), erase power (Pe), and bias power (Pb). On this occasion, Pb was fixed at 0.1 mW, and the power ratio of erase to write (Pe/Pw) was changed between 0.39 and 0.61. By changing the clock frequency and linear velocity, the linear density was changed from 270 to 80 nm/bit, as shown in Table 1.

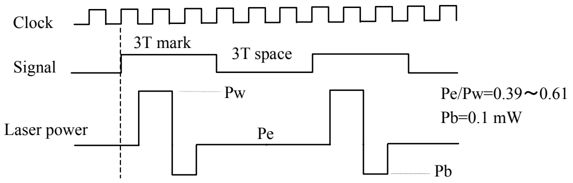

Fig.3 Schematic diagram of the recording strategy used in this experiment. 3T mark/space signal was recorded on the disc. Pb was fixed at 0.1 mW, and Pe/Pw was changed from 0.39 to 0.61.

Figure 2(b) shows the structure of specimen for SEM observation. After recording, the upper ZnS-SiO$_2$ layer was removed by an acid solution of HF (47%): H$_2$O=1:2 at room temperature. Then, shapes and lengths of amorphous marks were evaluated by observing the AgInSbTe surface using SEM with a field emission gun (FE-SEM). It is possible to observe numerous marks in a large area by X-Y scanning. Furthermore, specimen preparation is much easier than that of conventional method using TEM. So this evaluation method using SEM was more convenient than that using TEM.

Table 1 The recording conditions for 3T marks. The linear density was changed between 0.27 and 0.08 μm/bit. The minimum length of 3T mark was 0.125 μm at 0.08 μm/bit.

Clock frequency (MHz)	26.2	30	35	40	50	60	60
Linear velocity (m/sec)	3.5	3.5	3.5	3.5	3.5	3.5	2.5
Linear density (μm/bit)	0.27	0.23	0.20	0.18	0.14	0.12	0.08
Mark pitch (μm)	0.80	0.70	0.60	0.52	0.42	0.35	0.25
Mark length (μm)	0.40	0.35	0.30	0.26	0.21	0.175	0.125

3-2 Results and discussion

Figure 4(a) shows SEM image of 3T marks which were recorded at Pe/Pw=0.5 for 270 nm/bit. In the image taken after removal of the upper ZnS-SiO_2 layer, the amorphous marks were observed in clear contrast to the crystal field. In this experiment, the distance between front and back edges of the mark was defined as the mark length, as illustrated in Fig.4(b). The mean length and standard deviation of fifty marks were measured on the SEM image.

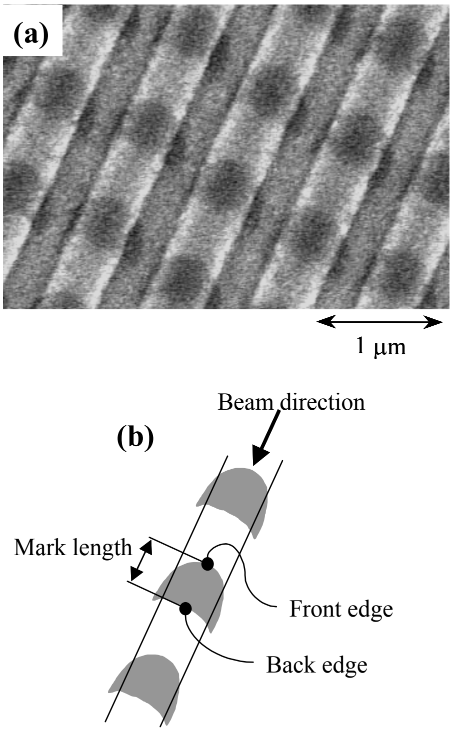

Fig.4 (a) SEM image of 3T marks which were recorded at Pe/Pw=0.5 for 0.27 μm/bit. (b) The method of measuring mark length. The mark length was measured along the center of track from the front to the back edge.

Figure 5(a) shows the mean length as a function of linear density at different power ratios of erase to write (Pe/Pw). The mark length became shorter as the power ratio was increased. In high density regions, below 140 nm/bit, the mark length changed significantly as can be seen in the difference in the slopes at Pe/Pw=0.39 and Pe/Pw=0.61. The mean length was 100 nm at Pe/Pw=0.61 for 80 nm/bit, and it was 190 nm at Pe/Pw= 0.39 for the same linear density, as indicated by A and B in Fig.5(a). Thus, as the power ratio increased from 0.39 to 0.61, the mark length decreased by half. Figure 5(b) shows the standard deviation of mark length. Fluctuation of the mark length depended on the power ratio, and it was possible to record uniform marks at linear densities between 80 and 270 nm/bit for Pe/Pw=0.61.

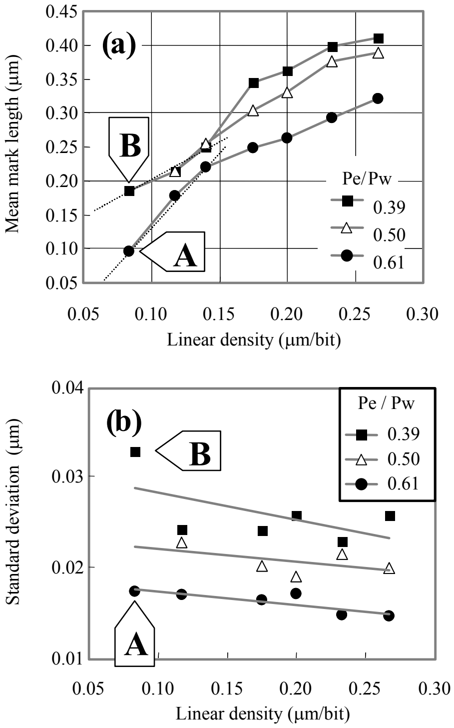

Fig.5 (a) The mean mark length as a function of linear density. The mark length was 0.09 μm at A, and it was 0.19 μm at B. As Pe/Pw was increased from 0.39 to 0.61, the mark length decreased by half at 0.08 μm/bit.
(b) The standard deviation of mark length. The standard deviation was 0.017 μm at A, and it was 0.033 μm at B.

Figure 6 shows the mark shapes at A and B on Fig.5. The mark shapes in A were uniform crescents. While, in B, the back edges of marks were indistinct, and interference between marks was also observed. Thus, in AgInSbTe phase change material, the shapes of recorded marks varied notably with changing the power ratio of erase to write. The back edge of an amorphous mark is formed by an interaction between cooling and erasing processes. The reason why the mark shapes between A and B are different is thought to be that the process dominating the mark shape in each condition is different. The crescent shape in

A suggests that the erasing process mainly acted on the formation of the back edge. By erasing the back edge, it is possible to record uniform marks even if the mark size is around 100 nm.

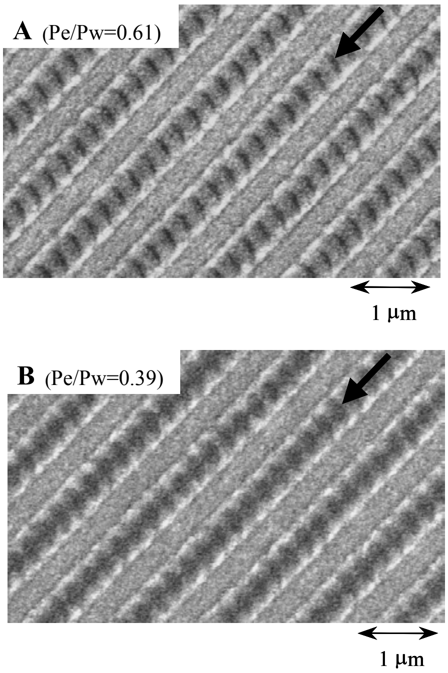

Fig.6 The mark shapes at A and B on Fig.4. The arrows show the beam direction. The mark shapes in A were uniform crescents. In B, the back edges of marks were indistinct, and interference between marks was recognized.

4. Readout/erasing/recording of amorphous marks by near field optical system

4-1 Experiments

Readout, erasing and recording of amorphous marks on the surface recording disc was tried by the near field optical system. The experimental setup is shown in Fig.7., which is based on a scanning near field optical microscope (SNOM) in illumination-collection mode so that the amorphous marks on the recording layer over the reflective layer can be read out. A laser diode with a wavelength of 785 nm and with a maximum power of 85 mW was used as a light source. The laser light went through a beam splitter, and then is condensed on an end of a fiber probe by a lens. An aperture of 720 nm in diameter was fabricated at the other end of the fiber probe so that it could generate the optical near field. An SEM image of the tip of the fiber probe is shown in Fig.8. The diameter of the beam spot generated by the aperture was approximately 400 nm. The apertured fiber probe was attached on a quartz fork so that the distance between the fiber probe and a surface of a disc could be controlled by shear force technique. The near field light was irradiated on the surface of the disc and the light reflected from the disc went back through the fiber probe. An intensity of reflected light from the disc was detected by a photo diode. A polarizer in Fig.7 was used to obtain the contrast between the amorphous marks and the crystallized field. The direction of the polarizing angle was adjusted to obtain the most high contrast image.

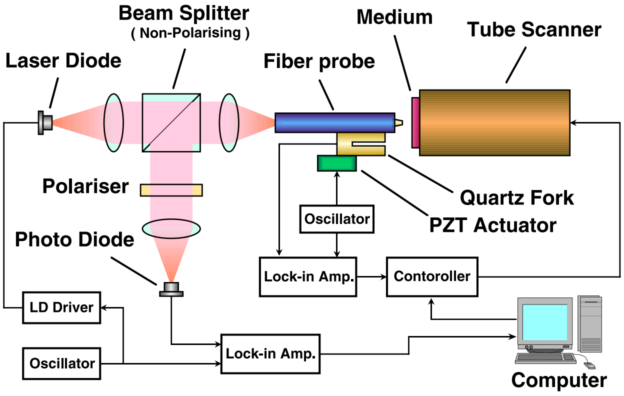

Fig.7 Schematic diagram of near field optical system.

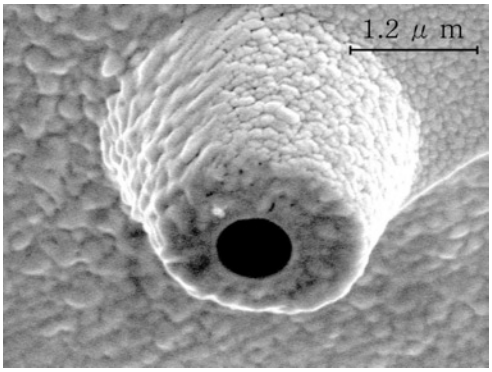

Fig.8 SEM image of the apertured fiber probe. The dark circle in the center of the probe is the aperture of 720 nm in diameter.

4-2 Results and discussion

The amorphous marks were observed by the near field optical system shown in Fig.7, after recording the marks by the conventional far field optical pickup in the manner of Fig.3. The mean length and the period of the marks were 230 nm and 400 nm respectively. Figure 9(a) shows readout image taken by the near field optical system. The amorphous marks were clearly observed as bright contrast. Then, two of the amorphous marks were selected for erasing, and the pulse of optical near field was irradiated on the marks with the apertured fiber probe. Figure 9(b) shows the image after erasing in the illumination-collection mode. In the image, two dark parts (surrounded with circles) correspond to erased marks could be clearly observed. It was found that the amorphous marks were erased selectively by the near field optical system. Furthermore, the amorphous marks were recorded on the surface recording disc by the same system.

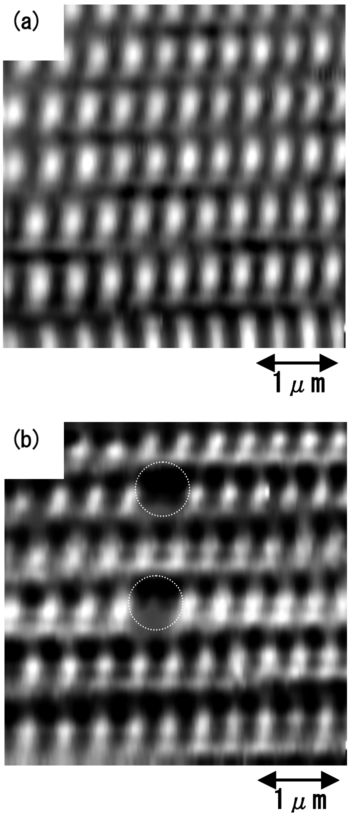

Fig.9 (a) Readout image of amorphous marks by near field optical system.
(b) Image after erasing. Tow dark parts (surrounded with circles) correspond to erased marks.

Figure 10 shows the image after recording in the illumination-collection mode. The five bright spots in Fig.10 are recorded amorphous marks. The diameter of marks, which were measured from the image, was around 250 nm. Thus, it is possible to record amorphous marks on the surface recording disc by the near field optical system.

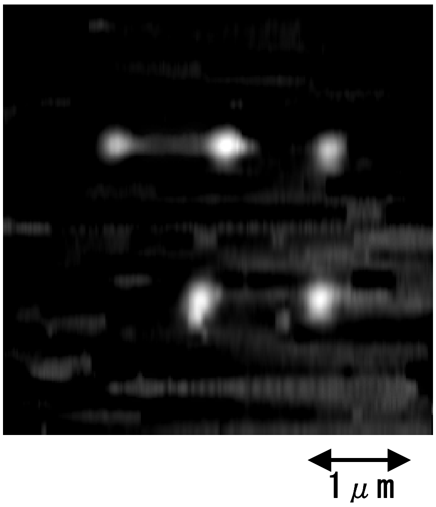

Fig.10 Recording of amorphous marks by near field optical system.The five bright spots indicate recorded amorphous marks.

5. CONCLUSIONS

The surface recording disc with AgInSbTe phase change material was fabricated. Amorphous marks on the disc could be observed clearly as dark contrasts by SEM. The SEM observation showed that the mark length varied notably with changing the power ratio of erase to write. By increasing the power ratio, the mark length could be reduced to around 100 nm. The shapes were crescents, and fluctuation with scaling down was hardly visible. We also demonstrated readout/erasing/recording amorphous marks on the surface recording disc, by the near field optical system in the illumination-collection mode. These results suggest that the combination of the near field optical system having resolution of 100 nm or less and the surface recording discs using AgInSbTe will allow the disc capacity increase to 100Gb/in^2 or over.

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7. REFERENCES

1. N.E. Abara, and T. Suzuki: “Thermal stability of Narrow Track Bits in a 5Gbit/in^2 Medium”, 1997 Digest of INTERMAG '97(Apr.1997), CP-17.
2. Y. Hosoe, *et al.*: “Experimental study of Thermal Decay in High Density Magnetic Recording Media”, 1997 Digest of INTERMAG '97(Apr.1997), FC-08.
3. H. Uwazumi, J. Chen, and J. H. Judy: “Thermal Decay of Magnetization and Readback Signal of Ultra-Thin Longitudinal $CoCr_{12}Ta_2$/Cr Thin Film Media”, 1997 Digest of INTERMAG '97(Apr.1997), FC-09.
4. M. Ohtsu: “Nanometric fabrication by light and its applications”, OYO BUTURI, Vol.68, No.4, pp. 431-434 (1999) (in Japanese)
5. T. Nakano, J. Tominaga, and N. Atoda: “Near-field optical readout for phase changed marks”, Proceedings of Far- and Near-Field Optics: Physics and Information Processing (1998), pp. 268-273.
6. J. -H. Park, M. R. Kim, and W. Jhe: “Feasibility Study of $Ge_2Sb_2Te_5$ Phase-change Optical Recording using reflection mode NSOM System”, Technical Digest of the 5th International Conference on Near Field Optics and Related Techniques (1998), pp. 371-372.
7. T. Saiki, and M. Ohtsu: “Application of Near-field Optical Microscope to the Spectroscopy of Condensed Matter”, Solid State Physics, Vol. 33, No. 5, pp. 395 (1998) (in Japanese)