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A study on the short-wavelength and high-numerical-aperture phase-change recording*

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In this paper, we discuss the phase-change recording at a short-wavelength (514 nm) and a high numerical aperture (0.85). Effects of recording power and pulse width on the size of the recording marks are studied. The minimum recording mark with a length of approximately 220 nm has been observed. The capacity of about 17 GB for a single-layer disc of a 12 cm diameter can be obtained. The maximum carrier-to-noise ratio reaches 45 dB at a writing power of 13–14 mW.

Keywords: phase-change, short-wavelength, high numerical aperture, transmission–electron microscopy

PACC: 8130H, 4280T, 6116D

1. Introduction

In 1968, Ovshinsky discovered a new order-disorder memory phenomenon in chalcogenide film materials, later termed "Ovonic Memory", and subsequently found a laser optical memory effect.[1] The major trends in optical recording are the increase in disc storage capacity and the increase in data-rate, both for reading and for writing. The capacity of a digital versatile disc (DVD), now at 4.7 GB, is expected to increase to 15 GB in the high-density DVD format. To completely replace video tape recorders, however, a capacity of more than 45 GB per disc is needed.[2] For increasing in capacity, there are two straightforward means for reducing the optical spot size: increasing numerical aperture (NA) of the objective lens and the reduction of laser wavelength λ. For short wavelengths, various papers have reported the advantages of using green or blue light sources,[3,4] and the recent development of GaN semiconductor lasers has made it feasible for this coherent light source to be used in optical data storage. Kino and Mansfield[5] used a solid immersion lens to increase NA. Unfortunately, with increasing NA it is progressively harder to keep the focus spot to be minimized on the track of a rotating disc. The disc defocus, tilt, substrate thickness, and refractive index variations progressively degrade the writing and reading as the NA is made higher and higher.[6,7] In order to solve this problem, Yamamoto *et al*[8] developed a two-element lens system. A spherical aberration compensation mechanism was realized by controlling the distance between the two lenses in order to cancel the aberration due to variations in the disc thickness.

Our research group has been engaged in studying the phase-change optical disc for many years. We have studied the crystallization and optical characteristics of phase-change media.[9–12] In this paper, we present the results in the short-wavelength (514 nm) and high NA (0.85) phase-change recording.

2. Experiments

The structure of specimens for transmission–electron microscope (TEM) observations used in our experiment is shown in Fig.1. First, a layer of collodion was deposited on the copper mesh. A layer of carbon was then deposited on the collodion layer. A 100 nm-thick AgInTeSb phase-change film was deposited above the carbon film by dc sputtering in the argon atmosphere at a pressure of 1.0 Pa. Finally, the AgInTeSb film was covered by a 20 nm-thick ZnS-SiO_2 protective layer in order to prevent the AgInTeSb film from being oxidized.

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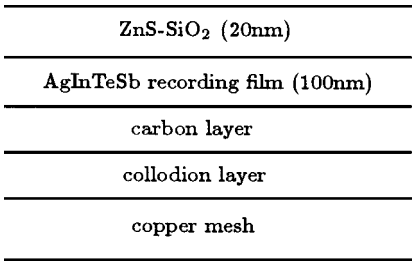


Fig.1. The cross-section of a TEM specimen.

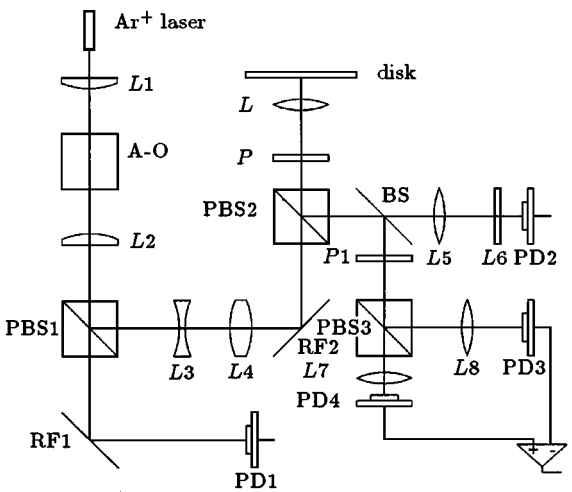


Fig.2. A sketch of the short-wavelength static tester.

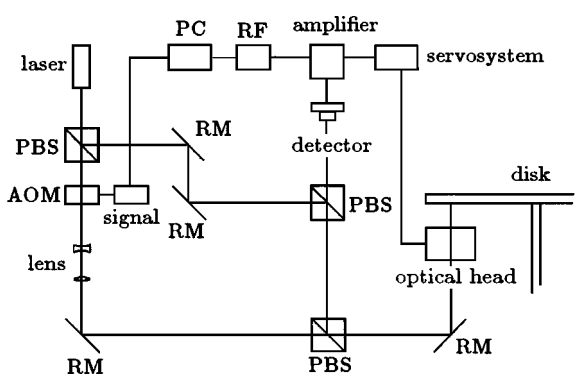


Fig.3. A sketch of the dynamic tester.

Recording marks were recorded using the short-wavelength static tester developed by our laboratory (Fig.2). The wavelength is 514.5 nm and the NA is 0.85. The layered structure of the disc used for dynamic measurement is PC / ZnS-SiO_2 (110 nm) / AgInTeSb (25 nm) / ZnS-SiO_2 (30 nm) / Al (70 nm). The dynamic tester was also developed by our laboratory (Fig.3). The recording marks were observed by TEM (Hitachi, H-600) operated at 75 kV.

3. Results and discussion

The TEM images of the recording marks obtained for different recording pulse widths are shown in Fig.4. Figures 4(b)–4(d) show the high magnification (100,000×) of the recording marks shown in Fig.4(a) (4000×). The recording power is 8 mW. The recording pulse widths are 300, 500 and 700 ns for Figs.4(b), 4(c) and 4(d), respectively. In our experiment, the initial state of the AgInTeSb film is amorphous. As shown in Figs.4(b)–4(d), it can be seen that the centre of a recording mark is a bright hole because the AgInTeSb film in the recording mark was vaporized due to the high laser power density. The edge of the bright area is the ring-like crystallization propagation front. Due to the Gaussian distribution of the monomode laser beam profile, the laser intensity in the central part of the focusing spot is greater than that in the surrounding area. This distribution of energy leads to an inhomogeneous heating in the focusing spot. That is, the centre peak temperature can lead to not only melting but also splashing of the material, and hence a tension or recoil pressure as well.[9] The size of the hole may approximately represent the splashed region, while the whole spot can be regarded as the irradiation-affected area. The irradiation spot is around 450, 550 and 800 nm for Figs.4(b)–4(d), respectively. It is obviously seen that the size of the irradiation spot increases with increasing irradiation time when the recording power is fixed, because the area expands due to its temperature much higher than the melting temperature.

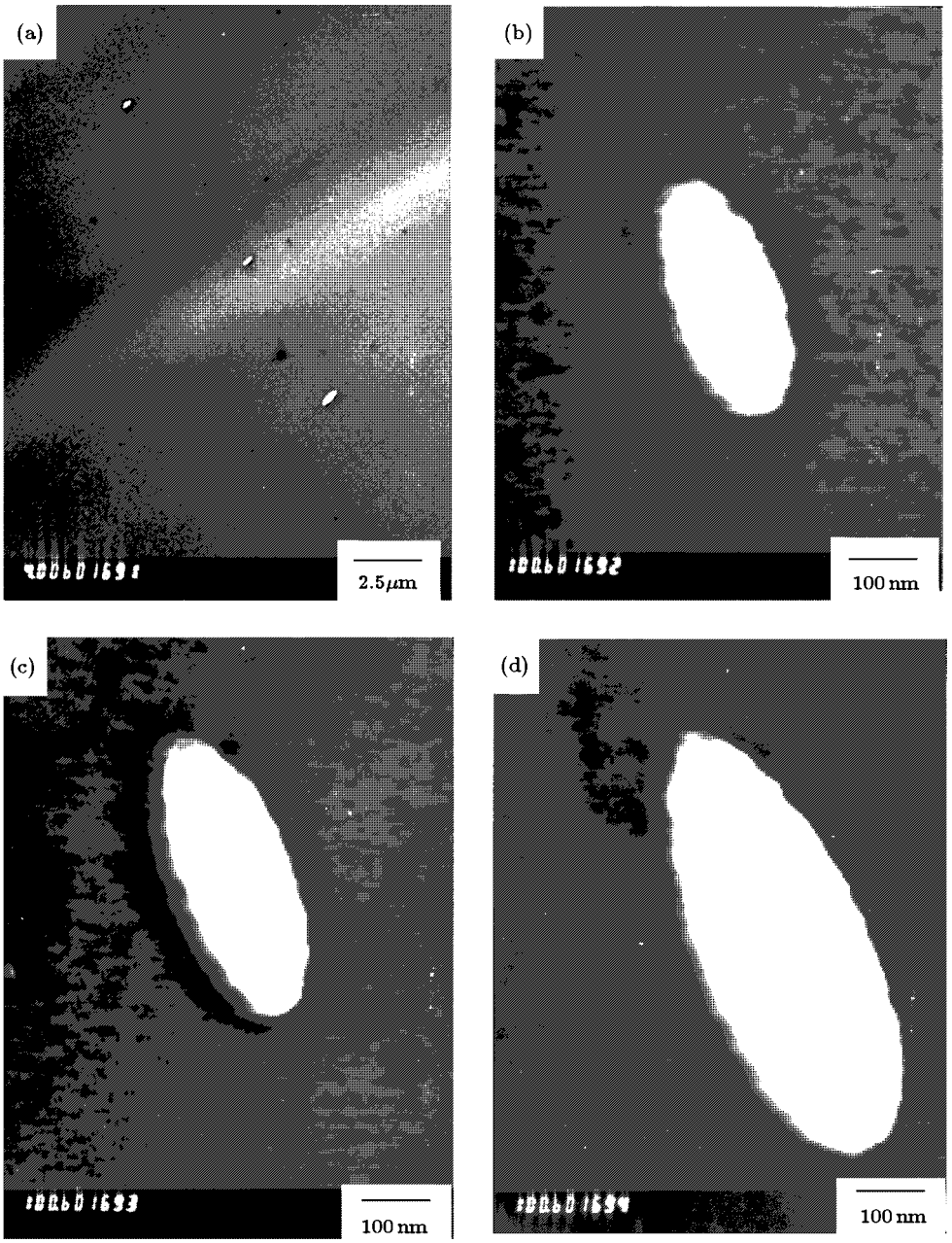


Fig.4. TEM images of recording marks obtained for different recording pulse widths.

Figure 5 shows the TEM images of recording marks obtained at different recording powers. Figures 5(b)–5(e) are the high magnification (100,000×) of the recording marks shown in Fig.5(a) (4000×). The recording pulse width is 300 ns. The recording powers are 6, 8, 9, and 11 mW for Figs.5(b), 5(c), 5(d), and 5(e), respectively. The irradiation spots are around 360, 440, 470, and 640 nm for Figs.5(b)–5(e), respectively. From Fig.5 we see that the size of the irradiation spot increases for a fixed recording pulse width when the irradiation power increases. The reason is the same as that in Fig.4.

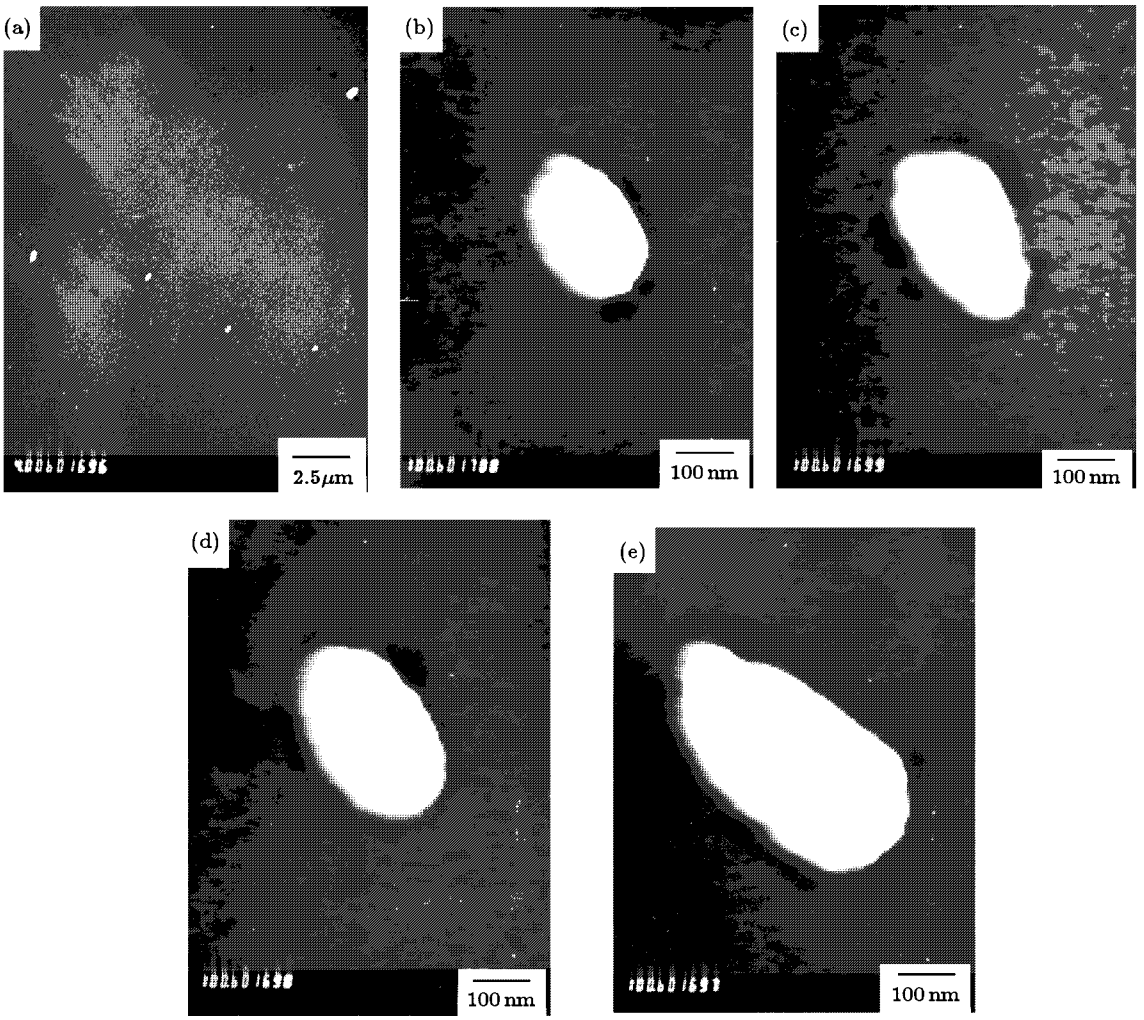


Fig.5. TEM images of recording marks obtained at different recording powers.

The minimum recording mark, whose diameter is estimated to be 220 nm, is shown in Fig.6. The recording power is 4 mW and the recording pulse width is 100 ns. The central region of the recording mark is amorphous due to the quenching from a high temperature, while the surrounding area is crystalline, since the temperature in this area lies between the melting temperature ($T_{\rm m}$) and phase transition temperature ($T_{\rm p}$).

Fig. 7 illustrates the dependence of the carrier-to-noise ratio (CNR) on the writing power and linear velocity (LV). The measurement conditions are as follows: LV=1.4 m/s (1×) and 4.2 m/s (3×), $F_{\rm w}$=2 MHz. The value of the CNR begins to saturate at approximately 13 mW at 1× and 14 mW at 3×. The maximum of CNR reaches 45 dB at 13–14 mW.

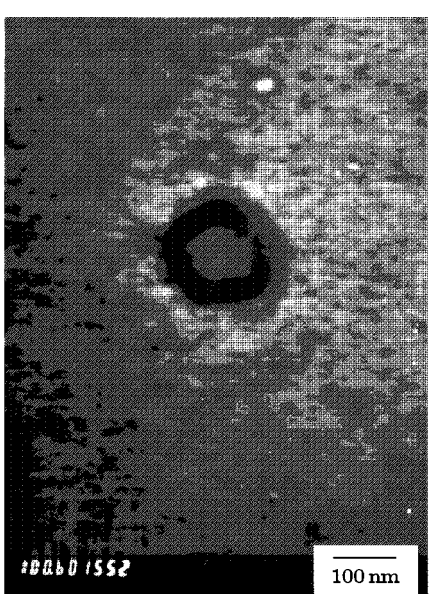


Fig.6. The high-magnification TEM image of the minimum recording mark (100,000×). The recording power is 4 mW and the recording pulse width is 100 ns.

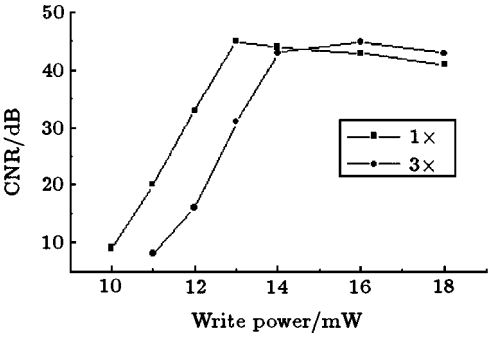


Fig.7. Dependence of CNR on the writing power and linear velocity.

4. Conclusion

Using a short-wavelength laser (514 nm) and a high numerical aperture of 0.85, we have observed the minimum recording mark, whose length is about 220 nm, in the AgInTeSb phase-change film by TEM. This is equal to a capacity of about 17 GB for a single-layer disc of a 12 cm diameter. It is shown that the centre of the recording mark is a bright hole and the edge of the bright area is the ring-like crystallization propagation front due to the Gaussian distribution of the monomode laser beam profile. The effects of recording power and pulse width on the size of the recording mark are also discussed. The size of the recording mark increases with increasing recording pulse width when the recording power is fixed. The size of the recording mark increases for a fixed recording pulse width when the irradiation power increases. The maximum CNR reaches 45 dB at a writing power of 13–14 mW.

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