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Read-out of a read-only super-resolution optical disc with a Si mask*

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A novel read-only super-resolution optical disc structure (substrate/mask layer/dielectric layer) is proposed in this paper. By using a Si thin film as the mask layer, the recording pits with a diameter 380nm and a depth 50nm are read out on the dynamic measuring equipment; the laser wavelength λ is 632.8nm and the numerical aperture is 0.40. In the course of reproduction, the laser power is 5mW and the rotation velocity of the disc is $4\text{m}\cdot\text{s}^{-1}$. The optimum thickness of the Si thin film is 18nm and the signal-to-noise ratio is 32dB.

Keywords: super-resolution, optical storage, Si thin film
PACC: 7550S, 4265G, 8160C

1. Introduction

Super-high-density information storage is very attractive for high-definition television systems and computer network servers,[1,2] which require the size of recording marks to be very small. Recently, Tominaga *et al*[3,4] proposed the super-resolution near-field structure (super-RENS) technique and recorded the smallest size of mark of about 60–100nm. However, in an optical storage, the recording density is generally limited by the read-out technique rather than the recording process when the size of the recording marks is smaller than the read-out light spot. There are many recording mark signals within a read-out spot; based on the principle of general optics, they cannot be read out. Therefore, in order to realize super-high-density optical storage, the read-out of the marks whose size is smaller than the optical diffraction limit is very important and of interest. Yasuda *et al*[5] first realized the read-out of the super-resolution marks in the read-only optical disc, whose structure is 'polycarbonate substrate/dielectric layer/reflective layer/dielectric layer/mask layer/dielectric layer'. Wu and co-workers[6,7] proposed theoretically to use a double-mask-layer super-resolution optical disc structure to realize the read-out of super-resolution pits. Recently, we have investigated super-resolution optical storage.[8,9] In this paper, a Si thin film is used to replace the Al reflective layer in the conventional read-only optical disc, i.e. the optical disc structure is 'polycarbonate substrate/mask layer/dielectric layer', which realizes the read-out of the super-resolution pits.

2. Experiments

The disc structure used is shown in Fig.1.



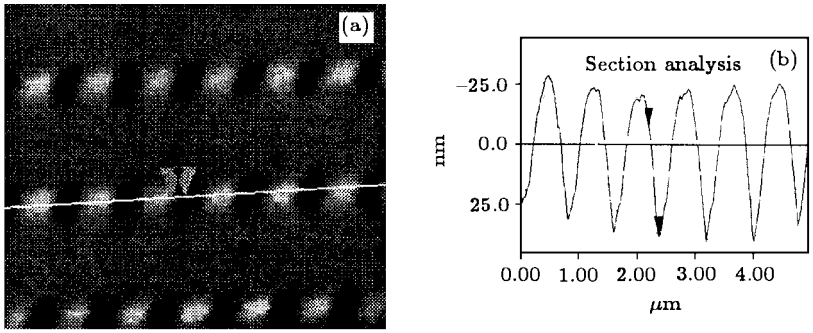
Fig.1. Optical structure.

Polycarbonate substrates with a diameter of 120mm and a thickness of 1.2mm are fabricated. The pit depth is about 50nm and the pit (space) diameter is 380nm (shown in Fig.2). A SiN film is used as the dielectric layer. The Si thin film is deposited by radio-frequency sputtering on the substrate at a background pressure of less than 1.0×10^{-4}Pa. The dielectric layer of SiN is used as a protective film. In the case of the deposition of SiN, the reactive sputtering technique

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is carried out with a Si target by introducing a gas mixture of Ar and N_2. The mixture ratio of N_2 to the total gas pressure is fixed at 15%. In our experiment, the SiN thin-film thickness is fixed at 50nm. The refractive index of the deposited film is evaluated as 2.15+0.02i at λ of 632.8nm. Disc measurement is carried out using a home-made dynamic measuring equipment whose wavelength λ is 632.8nm, and its numerical aperture (NA) is 0.40 (shown in Fig.3). Generally, the resolution limit of the optical read-out is given by $\lambda/4NA$. Therefore, the resolution limit of the equipment is about 400nm. The read-out velocity is fixed at $4m{\cdot}s^{-1}$ and the read-out power is 5mW.



(a) AMF image of the recording pits. (b) Section analysis.

Fig.2. Atomic force microscopy analysis of the substrate.

3. Results and discussion

The optical discs, with a Si thin-film thickness of 18nm, are measured on the equipment shown in Fig.3, and the results are shown in Fig.4. The results show that the recording pits can be read out and the carrier-to-noise ratio (CNR) is 32dB. By analysing the optical structure shown in Fig.1, in the course of read-out of the conventional optical disc, there are two or more recording pits within a light spot (as shown in Fig.5(a)), and they cannot be read out because their spatial frequency is higher than $4NA/\lambda$. In contrast, using Si to replace Al in the reflective layer in the conventional optical disc, during the signal reproduction, because of the Gaussian distribution of the read-out laser beam intensity, the temperature rise at the rear portion of the spot is higher than that of the front portion due to the rotation of the disc. When the temperature of the Si thin film exceeds its melting threshold temperature, the Si thin film changes from the solid to the molten state. However, at the front portion of the spot, Si is still in the solid state (shown in Fig.5(c)). We know that the reflectivity of the Si thin film in the molten state is much higher than that in the solid state, while the transmittance in the molten state is much lower than that in the solid state.[10] This leads to a crescent-shaped solid-state Si thin-film region in the front portion and the ellipsoid-shaped molten-state Si thin-film region in the rear portion of the spot (shown in Fig.5(b)). In the course of reproduction, the reflective light coming mainly from the rear portion of the spot is received by the equipment shown in Fig.3. The front portion of the spot can be effectively masked

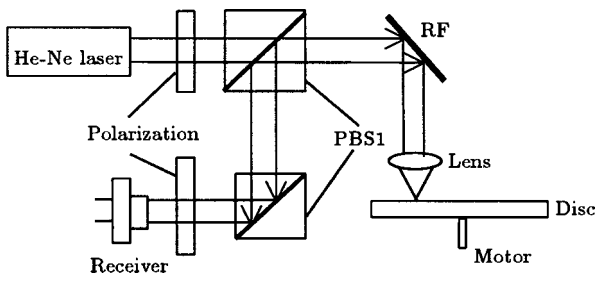


Fig.3. Optical disc dynamic measurement.

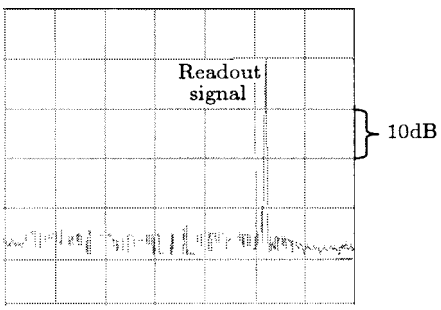


Fig.4. Dynamic measurement results (Si film thickness 18nm).

by the solid-state Si thin film, which is equivalent to a spot size reduction and achieves the super-resolution effect, as shown in Figs.5(b) and 4.

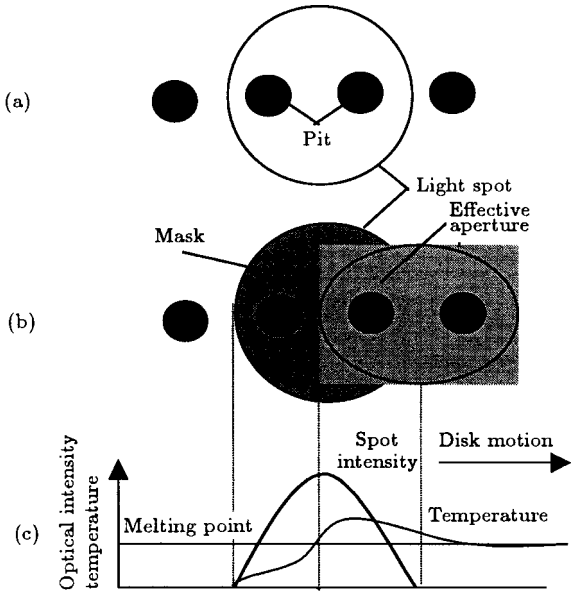


Fig.5. Principle of the super-resolution optical disc: (a) conventional disc read-out; (b) super-resolution disc read-out; (c) temperature and laser beam energy distribution.

In addition, Fig.6 shows the dependence of the signal-to-noise ratio on the Si film thickness. With the increase of the Si film thickness, the signal-to-noise ratio increases; when the thickness is 18nm, the signal-to-noise ratio is maximum (32dB). This is because, as the thickness increases, the reflectivity of Si in the molten state increases. This leads to the increase of the reflectivity contrast between the solid and the molten states, and thus the signal-to-noise ratio increases. With a further increase of the thickness, the signal-to-noise ratio reduces because, when the film thickness further increases, the reflectivity of the solid state also increases. This leads to the reduction of the reflectivity contrast between the solid and the molten states, and thus the signal-to-noise ratio is reduced.

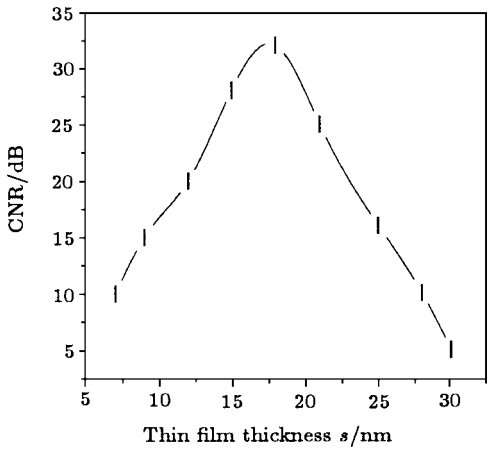


Fig.6. Dependence of signal-to-noise ratio on film thickness s.

4. Conclusion

By using Si to replace Al in the reflective layer in the conventional read-only optical disc, the recording pits with a diameter 380nm and a depth 50nm are read out on the dynamic measuring equipment; the laser wavelength λ is 632.8nm and the numerical aperture is 0.40. In the course of reproduction, the laser power used is 5mW and the rotation velocity of the disc is $4\mathrm{m}\cdot\mathrm{s}^{-1}$. The optimum Si film thickness is 18nm and the maximum CNR is 32dB.

Acknowledgments

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