Study of a Super-Resolution Optical Structure: Polycarbonate/ZnS–SiO₂/ZnO/ZnS–SiO₂/Ge₂Sb₂Te₅/ZnS–SiO₂

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A new super-resolution near-field optical structure was demonstrated. The structure, polycarbonate/ZnS–SiO₂(130 nm)/ZnO(15 nm)/ZnS–SiO₂(30 nm)/Ge₂Sb₂Te₅(15 nm)/ZnS–SiO₂(20 nm), has the ability in recording the small marks beyond the diffraction limit. At a readout power of 5 mW, the carrier to noise ratio (CNR) of more than 33 dB was measured for the recorded marks with the size of 100 nm by a digital versatile disc (DVD) tester. Transmission electron microscope (TEM) images of such structure displayed local orderly nanograins in 15 nm ZnO thin film. Ensemble effects of these ZnO nanostructures of the active layer are the key of the near-field super-resolution. [DOI: 10.1143/JJAP.42.1029]

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The first super-resolution near-field optical structure (super-RENS) was reported by Tominaga and coworkers in 1998. A multilayered structure of polycarbonate/SiN(170 nm)/Sb(15 nm)/SiN(20 nm)/Ge₂Sb₂Te₅(15 nm)/SiN(20 nm) was used to retrieve small marks beyond the diffraction limit. A carrier to noise ratio (CNR) of more than 10 dB for 90 nm mark trains was observed by using an optical system with a laser wavelength of 686 nm and an objective of 0.6 numerical aperture (NA).^{1,2)} A 15 nm Sb thin film was used as a nonlinear optical active layer of the super-RENS. Its function is to reduce the dimension of the focused spot. A 20 nm SiN layer between Sb and Ge₂Sb₂Te₅ layers was used as a spacing layer. It can maintain a fixed distance between Sb and Ge₂Sb₂Te₅ layers in the near-field region. The use of the super-RENS is considered a more feasible method for near-field optical recording because the optical properties of the active layer, and the near-field distance between the active layer and recording layer can easily be controlled by the reactive sputtering process.

The super-RENS has the advantages of simpler recording head design, less mechanical damage, and higher recording speed than the conventional near-field optical recording method. Direct near-field measurements of an Sb-type super-RENS were reported in 2000 by Tsai and coworkers,^{3,4)} and localized surface plasmon effects of the super-RENS were observed. Subsequently, a super-RENS with the structure of polycarbonate/ZnS–SiO₂(170 nm)/AgO_x(15 nm)/ZnS–SiO₂(40 nm)/Ge₂Sb₂Te₅(20 nm)/ZnS–SiO₂(40 nm) was demonstrated by Tominaga and coworkers.^{5,6)} The function of the AgO_x active layer is interesting; the AgO_x nano thin film can reversibly decompose into highly scattered silver clusters under the laser pulse of the recording and retrieving process. Dissociated silver particles or clusters act as a scattering center for activating the near-field recording and retrieving process. The interaction and coupling of these silver particles and the recording marks are the key processes for the super-resolution storage and readout.^{7–9)} In this paper, we report a new super-resolution optical structure, polycarbonate/ZnS–SiO₂/ZnO/ZnS–SiO₂/Ge₂Sb₂Te₅/ZnS–SiO₂. The nanostructure and optical property of this novel super-resolution structure are investigated as well.

Figure 1 shows the disk structure of the super-RENS we

Fig. 1. Scheme of the structure of the new super-RENS, polycarbonate/ZnS–SiO₂/ZnO/ZnS–SiO₂/Ge₂Sb₂Te₅/ZnS–SiO₂.

used in this study. A polycarbonate disk with 0.74 μm track pitch is used as a substrate. In order to prevent heat shock and oxidation, a protective layer of 130 nm ZnS–SiO₂ film is prepared. A 15 nm ZnO thin film works as an active layer of the super-RENS. The ZnO nano thin film is fabricated by a reactive rf sputtering process. The flow ratio of O₂ to the total gas (O₂ and Ar) is optimized. A 30 nm ZnS–SiO₂ thin film acts as a spacing layer in order to control the fixed near-field distance between ZnO and the recording layer. An as-deposited thin film of 15 nm Ge₂Sb₂Te₅ serves as the phase-change (PC) recording layer. The CNR is obtained by using a DVD optical disk tester from Pulstec Inc. (DDU-1000, wavelength = 637 nm, NA = 0.6). Marks are recorded at the lane of the disk with a writing power of 14 mW at a constant linear velocity (CLV) of 3.5 m/s. The readout signals of the recorded marks are measured at the same constant linear velocity. The recording frequency is changed from 3.5 MHz to 22.5 MHz to record different marks with sizes of 500 to 60 nm. The readout power is adjusted from 1 mW to 4 mW to obtain the CNR values of various recorded mark sizes.

Figure 2 shows the readout results for a ZnO-type super-RENS and a normal PC recording medium of polycarbonate/ZnS–SiO₂/Ge₂Sb₂Te₅/ZnS–SiO₂. The write power, bottom power, and readout power are 14 mW, 0 mW, and 3 mW, respectively. The duty cycle of the writing pulse is 50%. For the optical pickup head with a 0.6 NA objective and 637 nm working wavelength, the diffraction limit of the optical recording system is around 300 nm. Results shown in Fig. 2

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Fig. 2. CNR values of various recorded mark sizes for the phase-change DVD disk and ZnO-type super-RENS.

indicate that the CNR of a normal DVD recording medium, ZnS-SiO₂/Ge₂Sb₂Te₅/ZnS-SiO₂, decays quickly to zero when the size of the marks is less than the diffraction limit. However, the readout CNR of our ZnO-type super-RENS is excellent and stable when the size of the marks is less than the diffraction limit. For a readout power of 4 mW, the CNR is around 14 dB for recorded marks with a size of 70 nm in our experiments. Figure 3 shows the CNR peak on the screen of a frequency spectrum analyzer. For the recorded marks with a size of 100 nm and the readout power of 5 mW, a clear and stable peak shows a CNR of 33.23 dB. Because the limit of the readout power of our tester is 5 mW, we are not able to obtain CNR results for the readout power above 5 mW.

The TEM micrographs of the ZnO-type super-RENS are shown in Figs. 4(a) and 4(b). A magnified micrograph of Fig. 4(a) is displayed in Fig. 4(b). Nanostructured ZnO layers look like nanoteeth sandwiched by two ZnS-SiO₂ thin films. The interesting property reported by Huang and coworkers¹⁰⁾ may imply that the novelty of the nanowire or nanorod could be applied to the ZnO layer of super-RENS. Thus, it is suggested that the ensemble effects of these ZnO

Fig. 3. Retrieved readout signal of 100 nm mark trains is shown with a CNR of 33.23 dB. The recording conditions are write power (P_w) of 14.0 mW, CLV of 3.5 m/s and pulse frequency of 17.5 MHz (duty cycle: 50%). The readout conditions are readout power (P_r) of 5 mW and CLV of 3.5 m/s.

Fig. 4. TEM micrographs of the ZnO-type super-RENS structure are shown in Figs. 4(a) and 4(b), and Fig. 4(b) is a magnified image of Fig. 4(a).

nanostructures are the key factors for induction of the super-resolution function observed in our study.

Although the recorded bits were not observed at the Ge₂Sb₂Te₅ recording layer shown in Fig. 4(a), the readout of the 100 nm marks using 4 mW laser power at the same track was repeated many times with a very clear and stable CNR value. In comparison with the measured readout signals of the AgO_x-type super-RENS, we found the stability and reproducibility of the readout of the ZnO-type super-RENS much higher. This may imply that the ZnO nanostructured layer is stable during the reading process. The thermal stability of the sputter-deposited ZnO thin films has been reported by Song and coworkers,¹¹⁾ and the out-diffusion of zinc atoms from ZnO films at a high temperature was verified to be negligible. We believe that the excellent near-field effect comes from the nanostructure of the ZnO thin film.

In conclusion, a new super-RENS disk using ZnO as the near-field active layer has been developed. TEM micrographs show very interesting nanostructures of this ZnO nano thin film. An excellent readout CNR can be obtained with this novel super-RENS. The basic working mechanism of this ZnO-type super-RENS is closely related to the ZnO nanostructure fabricated in a reactive ion sputtering system.

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