Jpn. J. Appl. Phys. Vol. 42 (2003) pp. 1005–1009
Part 1, No. 2B, February 2003

Blue-Laser Readout Properties of Super Resolution Near Field Structure Disc with Inorganic Write-Once Recording Layer

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(Received August 14, 2002; revised manuscript received November 12, 2002; accepted for publication November 14, 2002)

A novel inorganic write-once recording material SbN_x (antimony nitride) was proposed for super resolution near field structure (super-RENS) discs. The layer structure is polycarbonate substrate (0.6 mm)/ZnS–SiO_2 (170 nm)/AgO_x (15 nm)/ZnS–SiO_2 (40 nm)/SbN_x (25 nm)/Ag (100 nm)/UV-curing resin/dummy PC substrate (0.6 mm). The recording layer with high-contrast characteristics enhanced the readout signal, which was compared with that of conventional phase-change materials. The carrier-to-noise ratio (CNR) of 150 nm mark length was about 44.2 dB at a readout power of 2.5 mW using blue laser. A below-diffraction-limited mark length as short as 60 nm can be readout using blue laser of 405 nm with a lens having a numerical aperture of 0.65. [DOI: 10.1143/JJAP.42.1005]

KEYWORDS: super-resolution, near-field technique, super-RENS, blue laser, below-diffraction-limited aperture

1. Introduction

In conventional optical storage and far-field recording, the theoretical limitation of diffraction is about 0.6λ/NA, where λ is the wavelength of the laser used and NA is the numerical aperture of the lens. A shorter wavelength with a higher numerical aperture lens can absolutely decrease spot size and significantly increase recording density. However, a higher NA lens implies stricter requirement for the media and drive system. Therefore, many methods have been developed to exceed the diffraction limit for various media such as magneto-optical, phase-change, write-once and read-only media. A super-resolution technique[1–6)] with a below-diffraction-limited aperture within the readout spot is one candidate method for increasing recording density by simply inserting a mask layer in the layer structure of a disc without changing laser diode and optical pick-up components. In 1998, Tominaga *et al.* proposed antimony (Sb)-type super resolution near field structure (super-RENS) disc, which integrated super-resolution with a near-field technique.[7)] In the layer structure of the Sb-type super-RENS disc, an optical near field is generated at a transparent aperture within the Sb mask layer and interacts with the recording marks. Therefore, the interface layer between the mask layer and the recording layer should be sufficiently thin within a near-field region (<50 nm) to detect signals of below-diffraction-limited mark length (∼60 nm) using a laser beam of 635 nm wavelength. Conceptually, the Sb-type super-RENS is also called a transparent-aperture-type super-RENS. Tsai and Lin[8)] and Liu *et al.*[9)] thought that the SiN_x/Sb/SiN_x sandwich layer works not only as an ‘‘aperture’’ for reducing spot size but also for enhancing other effects of electromagnetic intensity. Physically, the phenomena invole ‘‘surface plasmon resonance’’ (SPR) effects. In 2000, Fuji *et al.*[10)] demonstrated that the AgO_x-type super-RENS can further enhance near-field signals by using red laser of 635 nm wavelength. An optical near field is generated around a scattering center within the AgO_x mask layer. When a laser beam with high power is focused on a disc, the AgO_x layer is decomposed rapidly into Ag and O_2 at the central area of the focused spot. Conceptually, the decomposed nano-Ag clusters work as a metallic probe of a near-field scanning optical microscope (NSOM) and such a probe that exists in the disc can detect recording marks at high velocity. The AgO_x-type super-RENS is also called a light-scattering-center (LSC)-type super-RENS. Blue laser has also been utilized for recording and readout on LSC-type super-RENS discs with a GeSbTe recording layer.[11)] According to Fuji *et al.*,[11)] the scattering center could reproduce the minimum mark length of 60 nm. The carrier-to-noise ratios (CNRs) of 100 and 150 nm marks are about 20 dB and 32 dB, respectively. It was also found that blue laser could produce a smaller scattering center than red laser.[10)]

The key issues for the super-RENS disc are its low CNR and low thermal stability of small recording marks when the disc is readout at high reading power. Therefore, selecting an appropriate material, which possesses high-contrast reflectivity between the recorded and unrecorded areas and thermal stability for the recording layer, is a good method of solving these problems. We developed the novel inorganic write-once material SbN_x, which is suitable for conventional blue-laser recording with a high-data-transfer rate and also as a recording layer material of the LSC-type super-RENS.

2. Experimental

We designed the super-RENS blue disc as presented in Fig. 1. The layer structure is PC substrate (0.6 mm)/ZnS–SiO_2 (170 nm)/AgO_x (15 nm)/ZnS–SiO_2 (40 nm)/SbN_x (25 nm)/Ag (100 nm)/UV-curing resin/dummy PC substrate

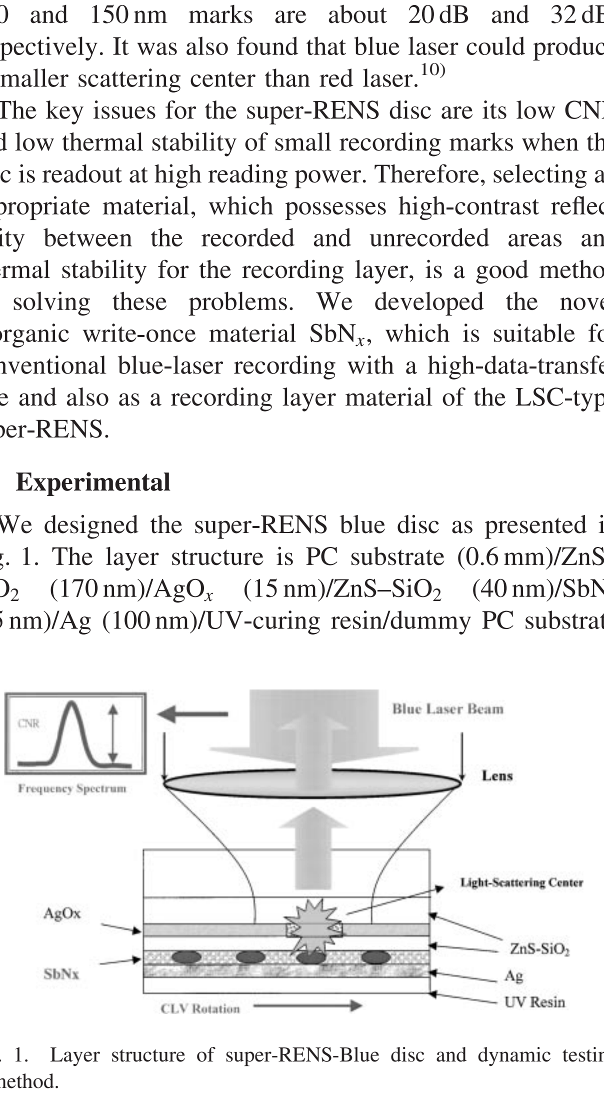
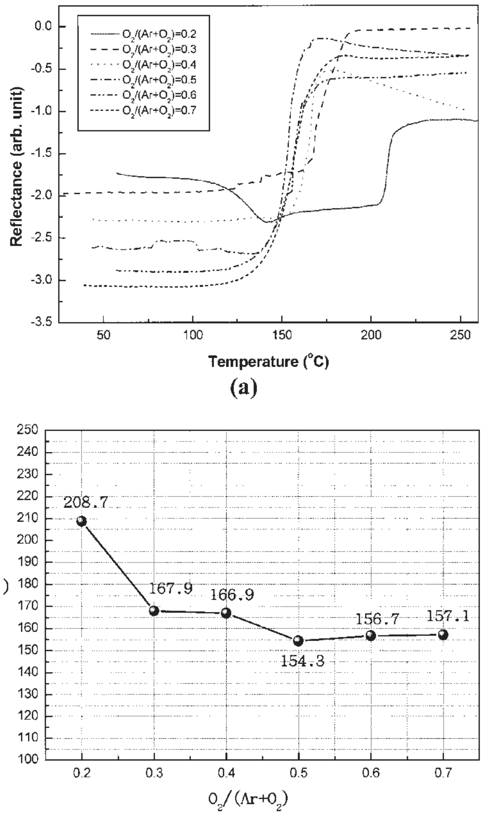


Fig. 1. Layer structure of super-RENS-Blue disc and dynamic testing method.

(0.6 mm). The films of all layers were deposited on a polycarbonate substrate by RF-magnetron sputtering at the background pressure of less than 5×10^{-6} torr and then at the argon pressure of 2–3 mtorr. The substrate was a conventional pre-grooved polycarbonate disc, 0.6 mm thick. We used silver oxide as the mask layer deposited by reactive sputtering. Since the light-scattering-center effect is dependent on the oxygen content in the AgO_x mask layer,[9] we optimized the partial-pressure ratio of oxygen in the sputtering chamber by controlling the mass-flow ratio of Ar to O_2. ZnS–SiO_2 was deposited as protective and interface layers, which served as spaced mask and recording layers, respectively. An inorganic write-once SbN_x film was used as the recording layer, which was deposited on the sandwich mask layers of ZnS–SiO_2/AgO_x/ZnS–SiO_2, as shown in Fig. 1. The thicknesses of all layers were controlled precisely, particularly those of the mask layer and interface layer. Silver was sputtered to form a reflective layer. Finally, UV-curing resin was coated on for protection and the dummy PC substrate was bound in order to increase substrate strength. Recording and readout testing of the super-RENS blue disc were performed using a conventional HD-DVD testing system (DDU-1000, Pulstec Co.) with a wavelength of 405 nm and an NA of 0.65. The writing marks were recorded on both land and groove areas. The recording mark length was controlled carefully by adjusting the recording power, pulse duration (writing strategy) and linear velocity in consideration of thermal expansion between marks in the recording layer. In detecting the signal of recording marks, the range of reading power was changed from 0.3 mW to 2.5 mW. The CNR of the readout signal could be measured using a frequency spectrum analyzer, which was connected with the read channel of the dynamic tester. The thermal properties of AgO_x were investigated using a self-designed transition temperature (T_x) tester, which can measure dependence of the reflectance and transmittance of films on heating temperature from 25°C to 650°C. The optical properties of AgO_x (15 nm) and ZnS–SiO_2 (170 nm)/AgO_x (15 nm)/ZnS–SiO_2 (40 nm) films sputtered on a glass substrate were investigated using a spectrophotometer (Hitachi Co.), which can measure the absorption and transmittance spectrum of the films at wavelengths from 200 nm to 1000 nm. The sensitivities of recording layers were examined using a commercial static tester (Mediatest, Toptica Co.) of blue laser with a recording wavelength of 399 nm and reading wavelength of 422 nm. The static tester can measure the reflective change *in situ* of media or films for the duration of recording pulses.

3. Results And Discussion

Figure 2 shows the thermal properties of AgO_x films with various partial-pressure ratios of oxygen to argon, where $O_2/(Ar+O_2)$ was varied from 0.2 to 0.7. As the temperature increased at a ramp of 50°C/min, the reflectance suddenly changed between 150°C and 170°C as shown in Fig. 2(a). The transition temperature (T_x) for each curve is defined as the corresponding temperature at maximum differential of the reflectance-temperature curve. Figure 2(b) shows T_x as a function of $O_2/(Ar+O_2)$, which was calculated from curves in Fig. 2(a). Variation of T_x implies variation in the composition of AgO_x and the composition may become Ag-rich, Ag_2O-rich or AgO-rich as oxygen content is increased gradually. Detail identification and analysis are necessary. T_x is almost between 150°C and 170°C, which agrees with the decomposition temperature (~160°C) of the reaction $AgO_x \rightarrow Ag + x/2\ O_2$. Figure 3 shows the absorption spectrum of single-layer AgO_x (15 nm) and sandwich-layer ZnS–SiO_2 (170 nm)/AgO_x (15 nm)/ZnS–SiO_2 (40 nm). Both films have adequate absorption at specific wavelengths of 405 nm and 650 nm. As the super-RENS disc is readout at high power, the heat source for decomposition into Ag nano clusters should come directly from the absorption of laser and partially from thermal diffusion of the recording layer, which is only 40 nm away from the AgO_x mask layer.



(a)

(b)

Fig. 2. Thermal properties of AgO_x mask layer. (a) reflectance as a function of temperature (b) T_x as a function of $O_2/(Ar+O_2)$.

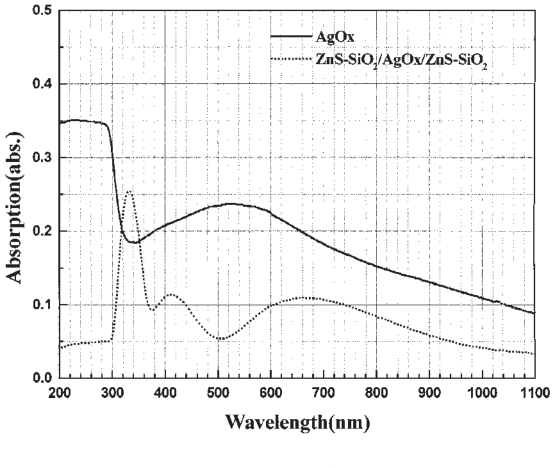


Fig. 3. Absorption spectra of AgO_x (15 nm) and ZnS–SiO_2 (170 nm)/AgO_x (15 nm)/ZnS–SiO_2 (40 nm) films.

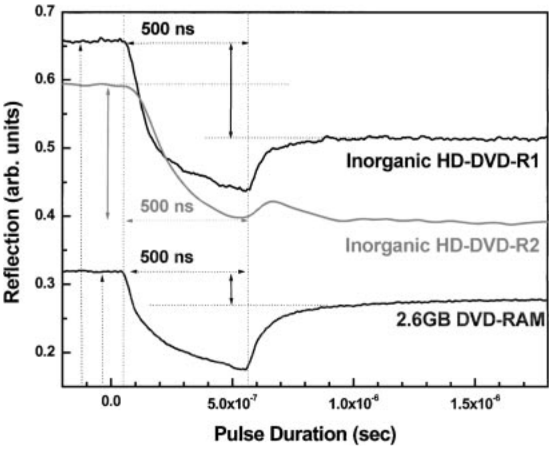
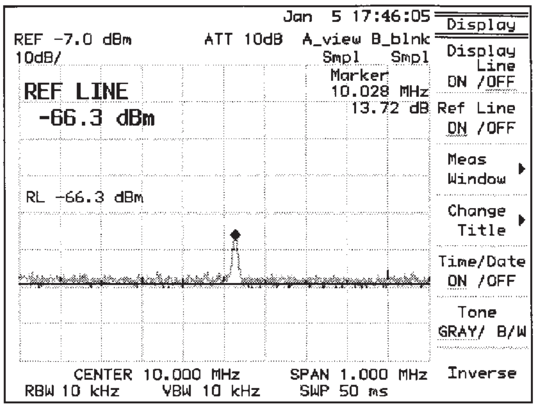


Fig. 4. Comparison of recording sensitivities between SbN_x and 2.6 GB DVD-RAM discs by static tester of blue laser.

Figure 4 shows the recording sensitivities of inorganic write-once material SbN_x and phase change material GeSbTe for commercial 2.6 GB DVD-RAM, which were examined using a static tester. The difference between inorganic HD-DVD-R1 and inorganic HD-DVD-R2 is the layer structure. The layer structure of the inorganic HD-DVD-R2 disc was modified for rapid cooling. At the end of the writing-power pulse, the cooling performance of the inorganic HD-DVD-R2 disc is more efficient than that of the inorganic HD-DVD-R1 disc and can increase the reflective contrast between before and after recording. Reflective contrasts of both inorganic HD-DVD-R discs are much higher than that of the commercial 2.6 GB DVD-RAM disc using blue laser.


Jan 5 17:46:05
REF -7.0 dBm ATT 10dB A_view B_blnk
10dB/ Smpl Smpl
Marker 10.028 MHz
13.72 dB
REF LINE
-66.3 dBm
RL -66.3 dBm
CENTER 10.000 MHz SPAN 1.000 MHz
RBW 10 kHz VBW 10 kHz SWP 50 ms

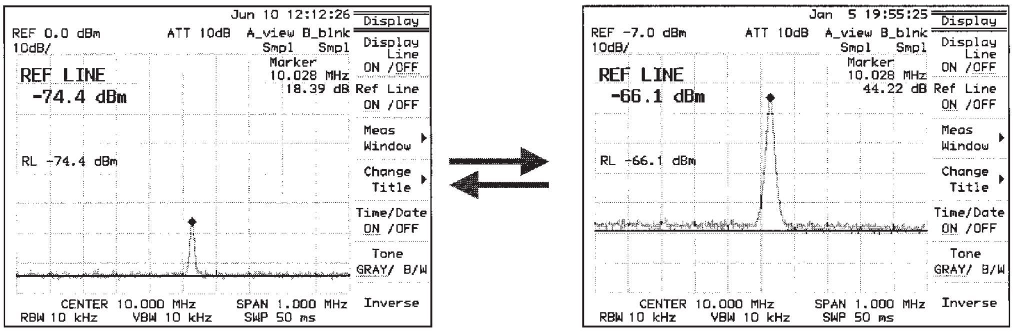
Mark length=75nm

Fig. 5. Frequency spectrum of 75 nm mark length, which was readout at $P_r = 2.5$ mW.

Theoretically, the resolution limit of recording marks is defined as half of the diffraction limit (~160 nm in this test system). A mark length as short as 75 nm can be readout by the super-RENS technique and the readout CNR of a 75 nm mark train is about 13.7 dB at a readout power of 2.5 mW, as shown in Fig. 5.

Figure 6(a) shows the frequency spectrum of the 150 nm

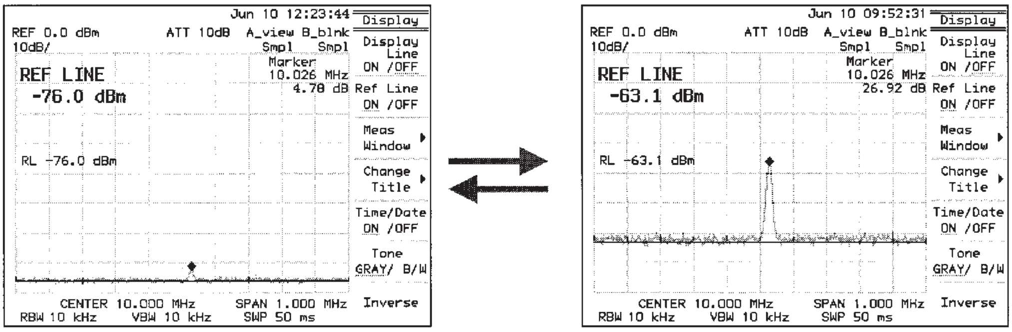
(a) Mark length = 150nm


Jun 10 12:12:26
REF 0.0 dBm ATT 10dB A_view B_blnk
10dB/ Smpl Smpl
Marker 10.028 MHz
18.39 dB
REF LINE
-74.4 dBm
RL -74.4 dBm
CENTER 10.000 MHz SPAN 1.000 MHz
RBW 10 kHz VBW 10 kHz SWP 50 ms

Jan 5 19:55:25
REF -7.0 dBm ATT 10dB A_view B_blnk
10dB/ Smpl Smpl
Marker 10.028 MHz
44.22 dB
REF LINE
-66.1 dBm
RL -66.1 dBm
CENTER 10.000 MHz SPAN 1.000 MHz
RBW 10 kHz VBW 10 kHz SWP 50 ms

Pr=0.4mW **Pr=2.5mW**

(b) Mark length = 100nm


Jun 10 12:23:44
REF 0.0 dBm ATT 10dB A_view B_blnk
10dB/ Smpl Smpl
Marker 10.026 MHz
4.78 dB
REF LINE
-76.0 dBm
RL -76.0 dBm
CENTER 10.000 MHz SPAN 1.000 MHz
RBW 10 kHz VBW 10 kHz SWP 50 ms

Jun 10 09:52:31
REF 0.0 dBm ATT 10dB A_view B_blnk
10dB/ Smpl Smpl
Marker 10.026 MHz
26.92 dB
REF LINE
-63.1 dBm
RL -63.1 dBm
CENTER 10.000 MHz SPAN 1.000 MHz
RBW 10 kHz VBW 10 kHz SWP 50 ms

Pr=0.4mW **Pr=2.5mW**

Fig. 6. Frequency spectra of (a) 150 nm mark length and (b) 100 nm mark length, which were readout at high ($P_r = 2.5$ mW) and low ($P_r = 0.4$ mW) powers.

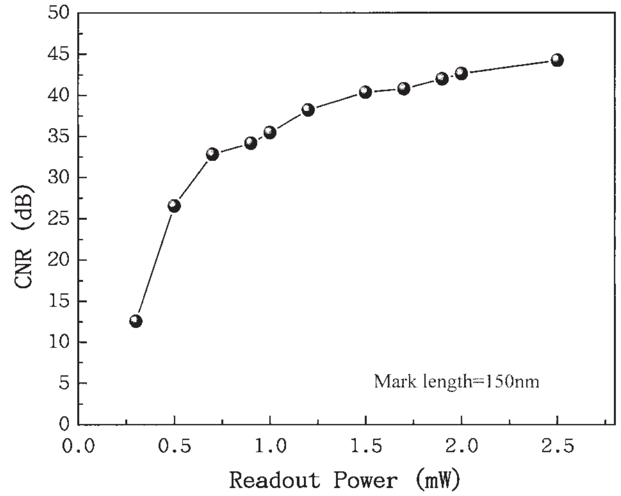


Fig. 7. Relationship between CNR of 150 nm mark train and readout power.

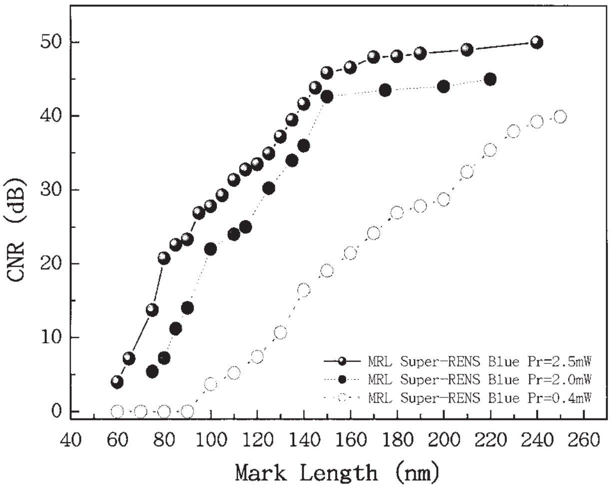


Fig. 8. Relationship between CNR and mark length of super-RENS-Blue Disc, which was readout at $P_r = 0.4$ mW, 2.0 mW and 2.5 mW.

mark train, which was readout at high ($P_r = 2.5$ mW) and low ($P_r = 0.4$ mW) reading powers. The readout CNR is as high as 44 dB at a readout power of 2.5 mW. Figure 6(b) shows the frequency spectrum of the 100 nm mark train, which was readout at high ($P_r = 2.5$ mW) and low ($P_r = 0.4$ mW) reading powers. The readout CNR is as high as 27 dB at a readout power of 2.5 mW. Figure 7 shows the relationship between CNR of the 150 nm mark train and readout power. Generally, higher CNR could be readout as the readout power is increased. The CNR would increase at a critical reading power of ~0.5 mW then would saturate with further increase in readout power, as shown in Fig. 7. Contrariwise, the CNR would be diminished at following decreasing readout power. Therefore, the characteristics of readout CNR depend on reading power and appropriate readout power is necessary for generating the surface plasmon resonance. However, much higher reading power may erase the recording mark and damage the mask layer because of a large amount of thermal accumulation. In consideration of thermal stability, an adequate material for the recording layer of the super-RENS blue disc should have high transition temperature (T_x).

Figure 8 shows the relationship between CNR and mark length of the super-RENS blue disc, which were readout at 0.4, 2.0 and 2.5 mW. Generally, the CNR signal would be reduced as decreasing recording mark length and higher readout power (>0.4 mW) is necessary for reading the mark length less than 100 nm. A mark length as short as 60 nm could be readout at $P_r = 2.5$ mW. The below-diffraction-limited mark lengths of 100 nm to 170 nm could be readout at a very low power of 0.4 mW.

Figure 9 shows the comparison between the super-RENS-blue discs with SbN_x and that with GeSbTe for recording-layer materials. Since the SbN_x has higher contrast between the recorded mark and the unrecorded area than GeSbTe, the CNR of the super-RENS disc with SbN_x is much higher than that of the super-RENS disc with GeSbTe when reading every mark length from 60 nm to 240 nm. Theoretically, surface plasmons are not only generated on a light-scattering center but also along single-tone mark trains below the diffraction limit and along period structures of metal films. As the light-scattering center is sufficiently close to the recording layer with small marks, the near-field electromagnetic interaction could be much more enhanced. Therefore, if the contrast in optics, morphology and composition of recording layer could be increased, the signal would be further enhanced.

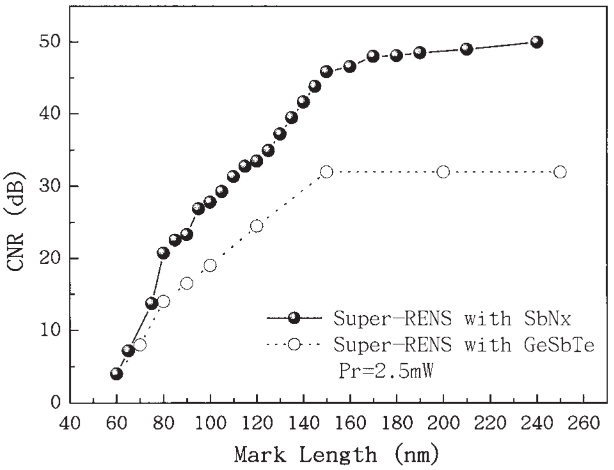


Fig. 9. Comparison between super-RENS blue disc with SbN_x and that with GeSbTe for recording-layer materials.

4. Conclusion

We have investigated the blue-laser readout properties of the super-RENS disc with the inorganic write-once recording layer SbN_x. Since the contrast of the recording layer is high, the CNR was as high as 44.2 dB at 150 nm mark length. The 60 nm mark length can be readout at a reading power of 2.5 mW, which exceeds the limitation of diffraction.

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