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Short Note

Mask Films for Thermally Induced Superresolution Readout in Rewritable Phase-Change Optical Disks

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Tellurium was studied as a mask film in a thermally induced superresolution rewritable optical disk for detecting below-diffraction-limit marks. Mark trains of 0.15 μm could be retrieved with 9 dB in carrier-to-noise (CNR) using an optical system with the laser wavelength of 780 nm and an objective lens of 0.55 numerical aperture. Readout cyclability was examined and methods to further improve readout cyclability were proposed.

KEYWORDS: Gerasable phase change, mask films, thermally induced superresolution readout, cyclability, tellurium

The recording density of optical disks is restricted by the optical diffraction limit. Without using a short-wavelength laser and a high-NA lens, the superresolution technique is one potential approach for detecting below-diffraction-limit marks. Recently, the superresolution technique has been successfully demonstrated in several types of optical disks, such as magnetically induced superresolution (MSR),[1)] premastered optical disk by superresolution (PSR),[2)] super-resolution near-field structure (Super-RENS)[3,4)] and thermally induced superresolution rewritable optical disks.[5,6)] However, superresolution techniques in nonmagnetic media have a particularly critical problem: readout cycle is limited.

The mechanism of the thermally induced superresolution effect in rewritable optical disks is ascribed to the refractive index of the mask layer as a function of temperature, as depicted in Fig. 1. The amorphous marks and crystalline area of the recording layer correspond to two different refractive indices. Due to the spinning of the optical disk, the temperatures of the rear and front parts of the mask layer inside the laser spot are above and below the melting point T_m, respectively, which also correspond to two different refractive indices (melting region: n_m-i*k_m; solid region: n_s-i*k_s). Therefore, four types of reflectance (R_{ma}, R_{mx}, R_{sa} and R_{sx}) exist within a light spot. In the melting region of the mask layer, R_{ma} and R_{mx} denote the reflectance when the recording layer is in an amorphous state and a crystalline state, respectively; in the solid region of the mask layer, R_{sa} and R_{sx} denote the reflectance when the recording layer is in an amorphous state and a crystalline state, respectively. In rear aperture detection (RAD), the melting region and the solid region of the mask layer are designed to be the readout aperture and mask region, respectively. When RAD is adopted, the reflectance R_{sa} is equal to R_{sx} by adjusting the thickness of upper dielectric layer and spacer. The readout signal modulation is proportional to the value of $|R_{ma} - R_{mx}|$.

Suitable candidates for the mask layer should have several properties: (1) a "poor" recording medium which remains in a crystalline state even before and after readout and recording, (2) low melting point to easily generate the thermally induced superresolution effect, and (3) sharp nonlinearity in transmittance or reflectance at the threshold read power. Owing to the instability of the amorphous Te at room temperature, it crystallizes spontaneously seconds after pulse laser irradiation.[7)] Compared to Sb, Te has a lower melting point (450°C), specific heat and thermal conductivity. Moreover, a sharp nonlinear transmittance of the Te film is observed at a linear speed of 5 m/s when the read power increased to 5 mW, as shown in Fig. 2. Thus, Te is a suitable candidate for a mask layer.

In order to provide adequate laser energy for recording, the thickness of the Te film was thinner than 40 nm. $Ge_2Sb_2Te_5$ and ZnS–SiO_2 were used as the recording film and spacer, respectively. The optical properties of the thin-film layers used for the calculations are listed in Table I. Because the crystallization temperature of the $Ge_2Sb_2Te_5$ recording film is approximately 180°C, the spacer thickness should be thicker than 80 nm to prevent recorded marks from being erased during superresolution readout. To further reduce thermal damage of the recorded marks, it is essential to make the absorption of the mask layer (A_{Te}) higher than that of the recording layer (A_{GST}) during disk design. In this study, $A_{Te} \geq 1.5 A_{GST}$. A thermally induced superresolution optical

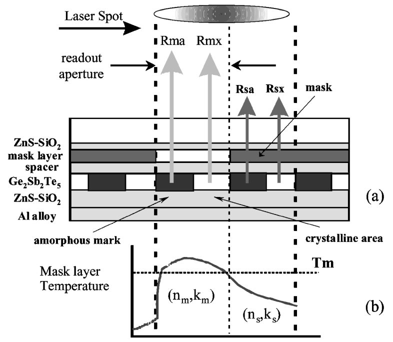

Fig. 1. Principle of thermally induced superresolution rewritable optical disks. The melting region of the mask layer is called the readout aperture. (a) Four types of reflectance R_{ma}, R_{mx}, R_{sa} and R_{sx} within a light spot. (b) Temperature profile of mask layer.

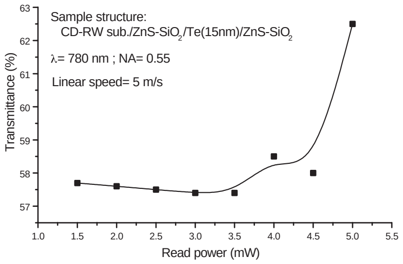

Fig. 2. Transmittance as a function of read power.

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Table I. Optical properties of thermally induced superresolution rewritable optical disk used for calculations.

Thin-film material	Refractive index (λ = 780 nm)
ZnS–SiO_2	2.15
Te	6.0-i*2.0
$Ge_2Sb_2Te_5$ (crystalline)	4.8-i*4.0
$Ge_2Sb_2Te_5$ (amorphous)	4.1-i*1.8
Al	2.1-i*7.2

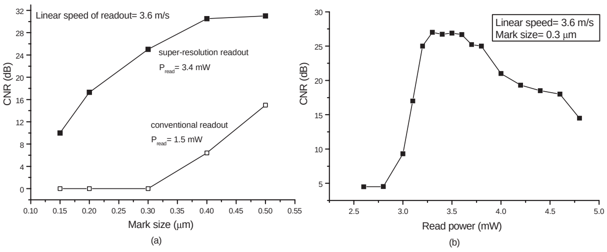

Fig. 3. (a) Comparison of CNR with conventional and superresolution readout for below-diffraction-limit marks. (b) CNR as a function of read power for 0.3 μm mark trains.

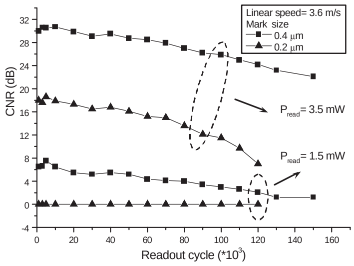

Fig. 4. CNR as a function of readout cycle.

disk consists of a compact disk rewritable (CD-RW) substrate / ZnS–SiO_2/ Te/ZnS–SiO_2 (105 nm) / $Ge_2Sb_2Te_5$ (45 nm) / ZnS–SiO_2 (19 nm) / Al alloy (80 nm). The laser wavelength was 780 nm and numerical aperture (NA) of the objective lens was 0.55 in recording. The write power P_w and the bias power P_b were 15 and 5 mW, respectively; the linear speed of recording was 5 m/s and the duty cycle of the write pulse was maintained at 30%. When the read power increased from 1.5 mW to 3.4 mW, the improvements in the carrier-to-noise (CNR) at a linear speed of 3.6 m/s were observed and the minimum resolvable mark size was 0.15 μm with 9 dB in CNR, as depicted in Fig. 3(a). CNR for superresolution readout was primarily limited by increase in the noise level due to control of the thermally induced aperture formation process.

The measured CNR was a strong function of read power. Due to the formation of an appropriate readout aperture, the CNR for 0.3 μm mark trains abruptly increased at the read power of 3.2 mW, as shown in Fig. 3(b). When the read power was above 3.6 mW, the readout signal contrast degraded by the formation of an oversize aperture resulting from excessive laser energy. CNR of superresolution rewritable optical disks was more sensitive to read power than that of conventional optical disks because the size of the readout aperture was based on the laser power instead of the focused laser spot.

Thermally induced superresolution readout cyclability was then examined. Results on continuous readout on the mark sizes of 0.2 and 0.4 μm are shown in Fig. 4. The accidental erasures of recorded marks during readout may degrade the performance of the readout signal. Two methods are being developed to improve readout cyclability. To obtain an adequate temperature difference between the mask and recording layers, the increment of temperature in each layer is assumed to be proportional to the individual absorption. The parameter of $A_{\mathrm{ratio}} = T_{\mathrm{m}}/T_{\mathrm{c}}$ was determined using disk media and used as a criterion of disk design for improving readout cyclability (T_{m}: melting point of mask layer; T_{c}: crystallization temperature of recording layer). T_{m} of Te is 450°C and T_{c} of $Ge_2Sb_2Te_5$ is 180°C. To prevent accidental erasures of the recording layer, $A_{\mathrm{Te}}/A_{\mathrm{GST}}$ is suggested to be A_{ratio} ($A_{\mathrm{ratio}} = 2.5$) for the disk media. Moreover, doping nitrogen of 3 at.% into the Ge–Sb–Te film was reported to increase T_{c} from 180°C to 230°C, without obviously changing the properties of recording layer. Thus, Ge–Sb–Te–N is being considered as a recording layer for increasing readout cyclability.[8)]

Sb and AgO_x were proposed as mask layers in the Super-RENS.[3, 4)] The readout cyclability of Super-RENS with a Sb mask layer has not been reported. The readout cyclability of a thermally induced superresolution rewritable optical disk with a Te mask film was higher than that of Super-RENS with an AgO_x film, however, CNR was slightly lower. Further research to understand the degradation of cyclability and to increase CNR using new materials or new disk configurations are being investigated.

Te film was investigated as a mask layer, which can yield CNR of 9 dB for a minimum resolvable mark size of 0.15 μm. Due to the size of the readout aperture being strongly dependent on laser power, the measured CNR of the superresolution disks was sensitive to read power. Accidental erasures of the recorded marks during readout cause degradation of the readout signal. Further increase in the readout cyclability of disks may require the increase in $A_{\mathrm{Te}}/A_{\mathrm{GST}}$ and T_{c} by optimizing the optical disk structure and applying recording media with a higher crystallization temperature, such as Ge–Sb–Te–N.

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