Super-resolution recordable disc with organic dye for recording layer

Wei-Chih Hsu [*, a, b], Song-Yeu Tsai[a], Po-Cheng Kuo[b], Mei-Rurng Tseng[a], Shih-Peng Hsu[a],
Tien-Tsan Hung[a], Chin-Jung Chang[a]

a. Materials Research Laboratories, Industrial Technology Research Institute
Bldg. 77, 195-5 Chung Hsing Rd., Section 4 Chutung, Hsinchu, Taiwan 31015, R.O.C.
b. Institute of Material Science and Engineering, National Taiwan University
No. 1, Roosevelt Rd., Sec. 4, Taipei 106, Taiwan, R.O.C.

ABSTRACT

A new structure of super resolution optical disk with organic dye for recording layer was proposed. By utilizing of Sb thin film for the mask layer, below-diffraction-limited marks on organic recording layer could be recorded and retrieved. The mark size as small as 120nm could be read out on the current dynamic tester of digital versatile recordable disc (DVD-R). The conditions of optical pickup head are 635nm of laser wavelength (λ) and 0.6 of lens numerical aperture (NA). The carrier-to-noise ratio (CNR) from recorded marks of 200nm was more than 28.5dB at low readout power of 2mW and at a constant linear velocity (CLV) = 3.5 m/s. The recording layer with modified composition owned high thermal stability and the readout durability was more than 6×10^4 cycles without any decreasing of CNR.

Keywords: super resolution, near field, Super-RENS, mask layer, below-diffraction-limit, recordable disc, and organic dye

1. INTRODUCTION

In optical data storage, the theoretical diffraction limit of spot size is about 0.6λ/NA, where λ is laser wavelength and NA is lens numerical aperture. Shorter wavelength with higher numerical aperture (NA) lens can decrease spot size absolutely and increase the recording density significantly. Recently, blue laser diode of 405nm and high NA lens of 0.85 are ready. However, the reliable blue laser with high power of more than 30mW and lifetime of more than 10000 hours are still expensive and hardly available. Otherwise, the higher NA of lens implies higher criterion for disks and drives. Thus, the super-resolution technique [1~6] with a below-diffraction-limited aperture within readout spot is a suitable and economical method to improve recording density by simply inserting the mask layers on disk without changing the laser diode and the optical device.

In 1998, J. Tominaga [1] proposed a new disk structure of polycarbonate substrate (PC)/SiNx/Sb/SiNx/$Ge_2Sb_2Te_5$/SiNx, which was named super-resolution near-field structure (Super-RENS). The interface layer of SiNx between the mask layer of Sb and the recording layer of $Ge_2Sb_2Te_5$ should be thin enough to detect near-field signal [1] and the reflective layer is unnecessary. The concept of Super-RENS comes from the combination of super-resolution technique and near-field

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scanning optical microscope (NSOM). A near-field aperture within optical disk can be opened and closed by changing the laser intensity and the non-linear optical layers of SiNx(170nm)/Sb(15nm)/SiNx(20nm) can produce surface plasmon effects to enhance near-field detection.[7] The thin solid SiNx film of interface layer acts as a near-field spacer over a wide area, which keeps fixed distance of 20nm precisely between the mask layer and the recording layer. For the thin interface layer, one of the key issues of the Super-RENS disk is low thermal stability of recording mark when the small marks are read out at high reading power. Therefore, selecting a stable material for recording layer is one way to solve this problem. In T.A. (transmitted aperture) type Super-RENS, the requirement of recording layer should have capability to resist thermal diffusion transferred from mask layer and to prevent the recorded marks from being erased. In LSC (light scattering center) type Super-RENS, the recording layer should absorb light of laser to produce heat and the heat transferred to mask layer to decompose AgOx and produce a light scattering center to enhance near-field detection.[8,9,10] Therefore, the phase-change recording layer should have higher crystalline temperature than decomposition temperature (~160^{o}C) of AgOx. L. Men et al. [10] proposed element-doped phase change material of $Ge_2Sb_2Te_5$-M (where M = Fe, Zn) for recording layer of LSC type Super-RENS and its readout durability can be improved obviously by doping effect.

In the Super-RENS disk, the phase change materials (i.e. $Ge_2Sb_2Te_5$) [1] or magneto-optical materials (i.e. TbFeCo) [11] have ever been used for the recording layer. In this work, we proposed new super-resolution disk structure with organic dye for recoding layer. Thermal stability of organic dye with modified composition, which own higher decomposition temperature (Td) and has lower absorbability at specific wavelength of 635nm, is suitable for recording layer to resist thermal diffusion from mask layer.

2. DISK STRUCTURE AND EXPERIMENTAL CONDITIONS

We designed two types of super-resolution disks as shown in Figure 1 (A) and (B). The substrate was a conventional pre-grooved polycarbonate (PC) disk, which is 120mm diameter, 0.6 mm thick and 0.74μm track pitch. The disk structure of type I is PC/SiNx/Sb/SiNx/Dye/Au and the type II is PC/SiNx/Sb/SiNx/Dye/SiNx. The difference between two types of disks is the reflective layer. The films except recording layer were deposited on a polycarbonate substrate by RF magnetron sputtering at the base pressure below 5×10^{-6} torr and were carried out at the argon pressure of 3 mtorr.We used antimony for the mask layer and SiNx for protective layers and interface layer. An organic dye was used as the recording film, which was deposited by spin coating on the sandwich layers of SiNx/Sb/SiNx and the optical density (O.D.) of dye was controlled carefully. The gold was sputtered as reflective layer. Finally, the UV-curing resin was coated for protection. The experimental conditions of Dynamic Testing were listed in Table I. Recording and readout properties were performed by DVD test system (DDU-1000, Pulstec Co.), in which the optical pickup head is 635nm of wavelength and 0.6 of N.A. The recording mark size was controlled carefully by recording power, pulse duration and linear velocity of disk rotation in consideration of thermal effect on recording marks in the organic layer. The super-resolution readout characteristics were investigated by measuring the carrier-to-noise ratio (CNR) of small mark size below the optical diffraction limit. The thermal stability of disk was characterized from measuring the readout durability (i.e. retrieved signal of CNR against the readout cycles).

3. RESULTS AND DISCUSSIONS

We selected two kinds of organic dyes abbreviated as PC1 and PC2 with different decomposition temperature (Td, weight loss measured by TGA) for recording layer. The Td of PC1 Dye measured by TGA is higher than PC2 dye. Both materials are cyanine dye. Figure 2 shows the absorbed spectrum of PC1 and PC2 thin film. The absorbed spectrum of PC1 dye is similar to PC2 dye, but the λ max of PC1 dye is lesser than PC2 dye, i.e. the absorbance of PC1 dye at wavelength 635nm is lower than PC2 dye.

The readout durability for 200nm-mark trains at Pr=2 mW and CLV=3.5m/s of super-resolution disk (Type I) is shown on Figure 3. The carrier-to-noise ratio (CNR) of PC2 disk rapidly dropped after about 10000 cycles and no signal could be retrieved after about 24000 cycles. The readout durability of PC1 disk is almost no change and no decline after 6×10^4 cycles, i.e. the PC1 dye owns better thermal stability than PC2 dye. For the consideration of thermal distribution from mask layer to recording layer and the recording sensitivity, the PC1 dye is an adequate material for recording layer of super-resolution disk.

Figure 4 shows pictures of readout signal intensity measured by frequency spectrum and the variation of CNR between different readout powers of super-resolution recordable disk with PC1-dye. The pictures reveal that the readout process between high and low reading powers is reversible. The phenomena show that at specific higher reading power (Fig. 4B) the transmitted aperture is opened because of optically nonlinear properties induced by thermal effect or surface-plasmon enhancement [7] and that at lower power (Fig. 4A) the aperture is closed because of antimony reverse to original crystalline state of high reflectivity. Antimony owns good thermal properties (i.e. high critical cooling rate) [12] and suitable reflectivity for focusing and tracking by servo-system (i.e. the as-deposited state is crystalline). Furthermore, because of antimony is a pure element, the mask layer has no segregation as reading at higher power.

Figure 5 shows the relationships between CNR and readout power of Type I and Type II super-resolution disk on the condition of recorded mark size of 200nm. As the readout power increased, the CNR of Type I disk suddenly increased to 28.5dB at readout power of 2.0mW. The CNR was not observed at readout power less than 1.5 mW and slightly increased to 30.5dB from 2.0mW to 3.0 mW. At readout power more than 3.0 mW, the CNR dropped below 15 dB or even disappeared for the thermal damage of high reading power erased the unrecorded area between marks. In the Type II super-resolution disk, the readout power should be increased, but the readout signal intensity is inferior to Type I super-resolution disk. Therefore, the reflective layer could assist the super-resolution disk in enhancing the readout intensity and reducing the readout power.

Figure 6 reveals the relationship between CNR and mark size of Type I and Type II disk on the condition of various readout powers of 3mW, 2mW and 3.5mW respectively. As the mark size was reduced, the readout signal was decreased. The readout signal intensity of Type II super-resolution disk is inferior to Type I super-resolution disk in all rang of mark size and the readout power should be higher, as described in figure 5. Theoretically, the mark resolution limit is defined half of the diffraction limit (λ/4NA ~265nm). The mark size as small as 120nm and 150nm can be readout in Type I and Type II disk respectively by the assistance of super-resolution technique.

4. CONCLUSIONS

We have investigated the super-resolution properties of organic recordable disks. The PC1 dye is adequate for the recording layer optically and thermally. The mark size below 150nm, which is beyond the limitation of diffraction, can be read out at reading power of 2 mW. The readout durability is more than 6×10^4 cycles and without any decline of CNR, which has good thermal stability. About the super-resolution recordable disk with organic dye for recording layer, there are still many issues to overcome. The further modification of optimizing disk structure, inserting the contrast-enhanced layer and modifying mask layer material could enhance the signal intensity.

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Table I The experimental conditions of Dynamic Testing

Laser Wavelength (nm)	**635**
Lens numerical aperture (N.A.)	**0.6**
Disk thickness (mm)	**0.6**
Track pitch (μm)	**0.74**
Linear velocity (m/s)	**2.5~3.5**
Recording area	**Groove**
Pw (mW)	**8~12**
Pr (mW)	**0.7~4**

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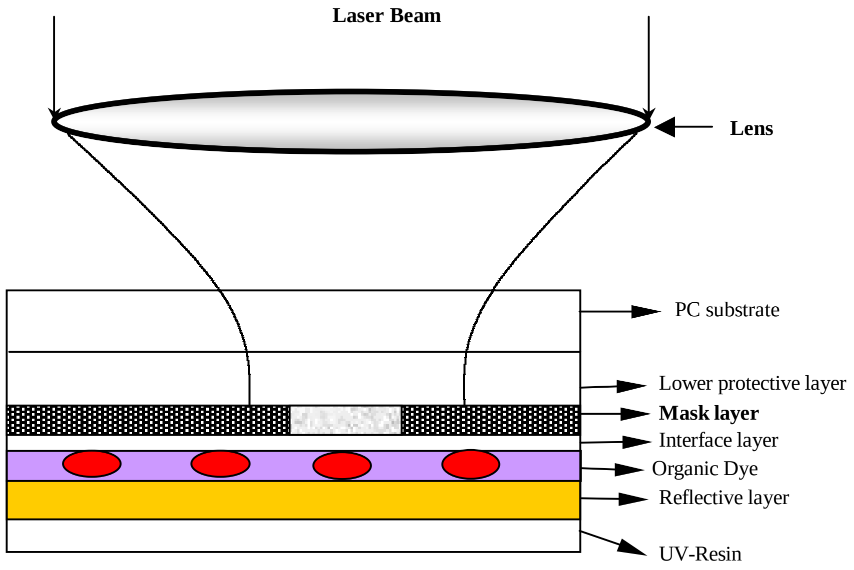
* Correspondence: TEL: 886-3-5916913; FAX: 886-3-5820442; E-mail: 880664@itri.org.tw

(A) Type I



(B) Type II

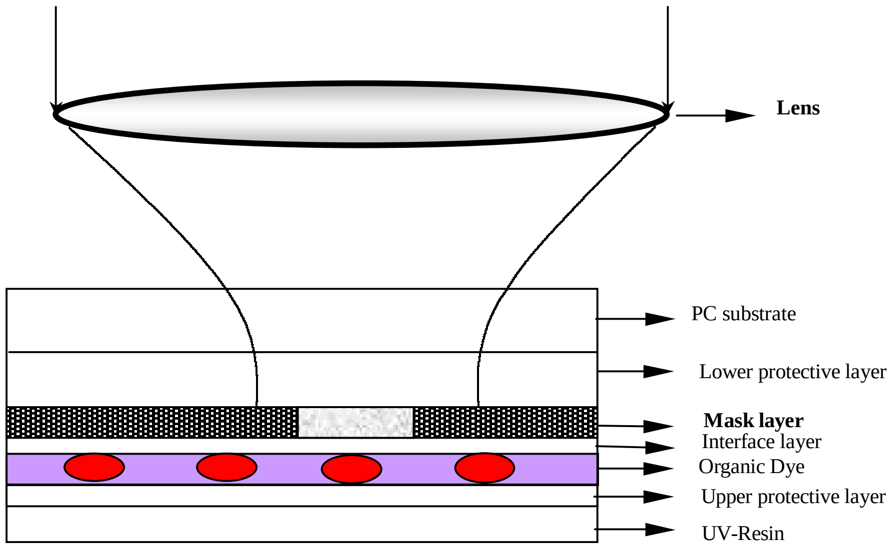


Figure 1 Disk structures of (A)Type I and (B)Type II

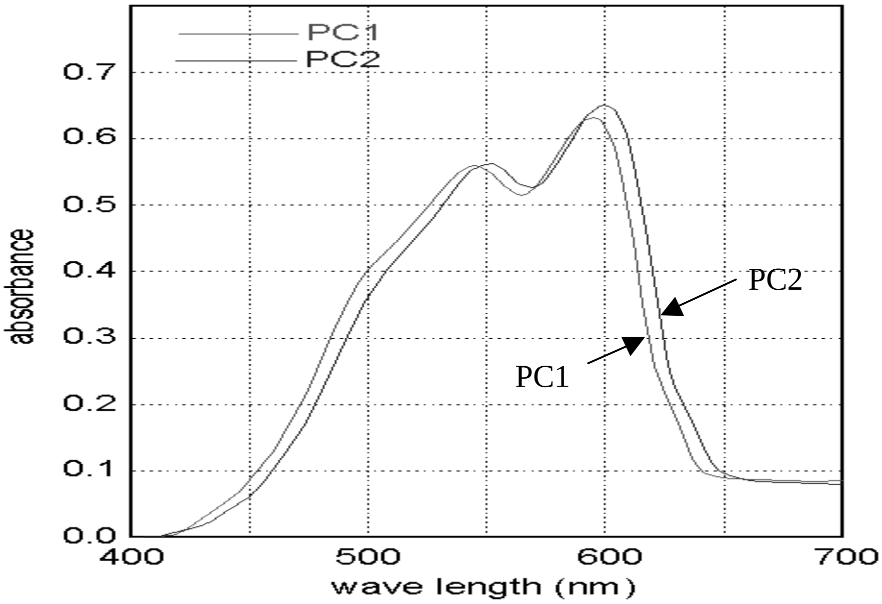


Figure 2 The absorbed spectrum of PC1 and PC2 thin film

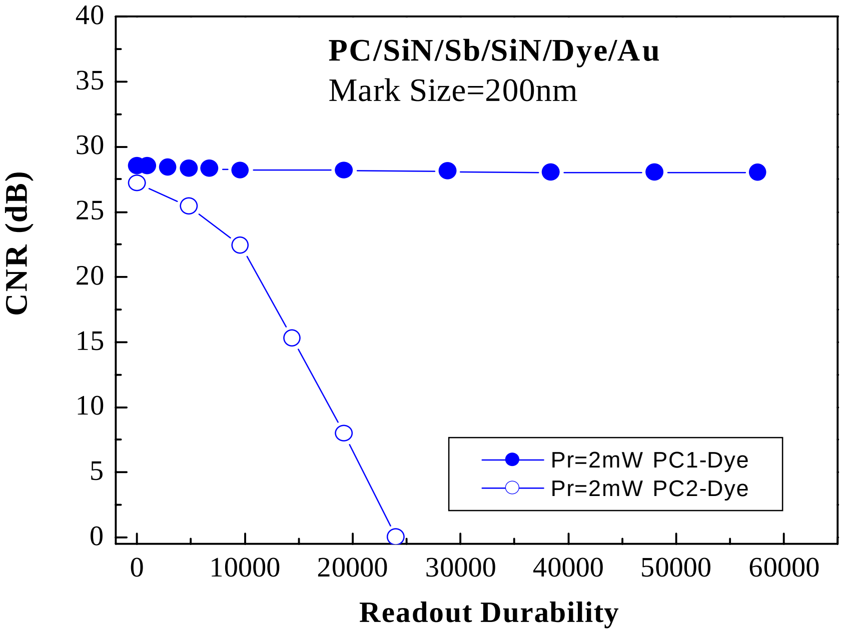
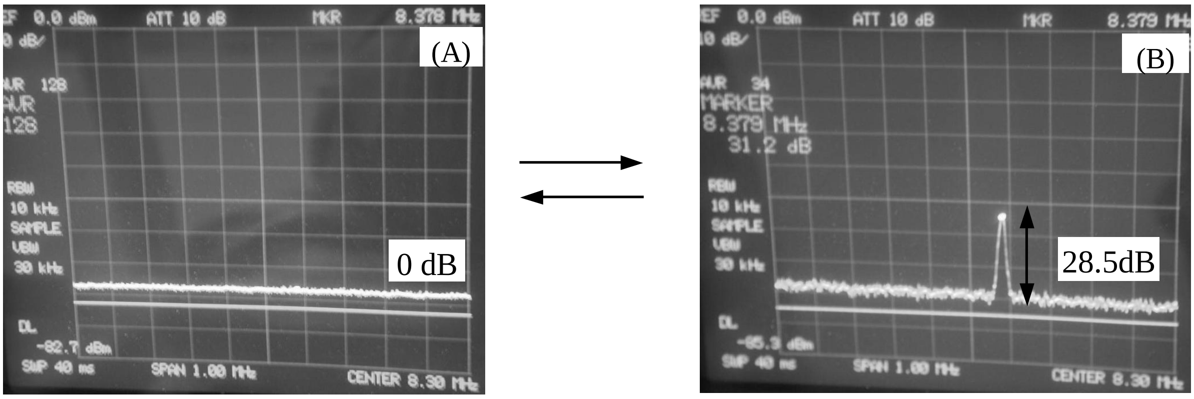


Figure 3 The readout durability of sample disks with PC1 dye and PC2 dye for recording layer



Pr=1mW

Pr=2mW

Figure 4 The variation of CNR between different readout powers

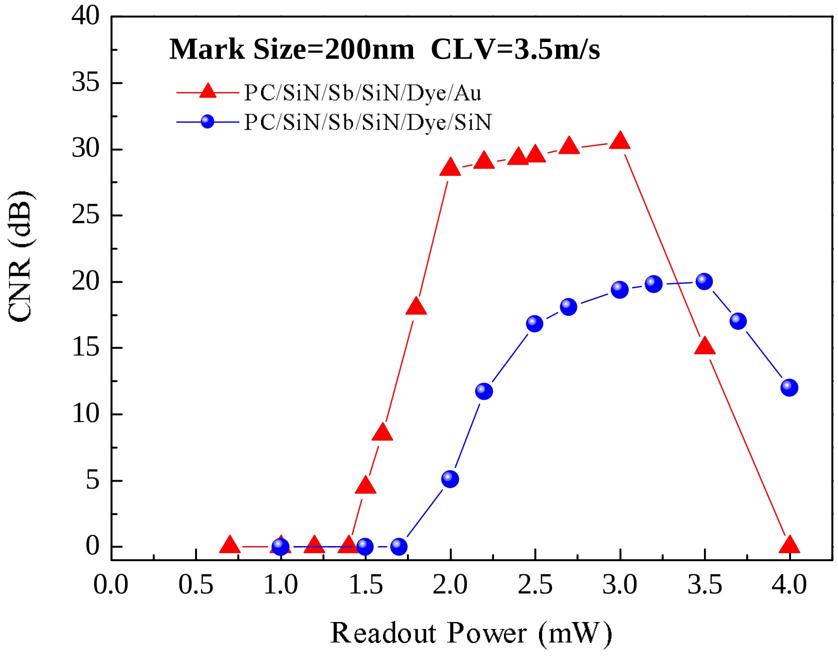


Figure 5 The relationship between CNR and readout power of sample disks with PC1-dye for recording layer

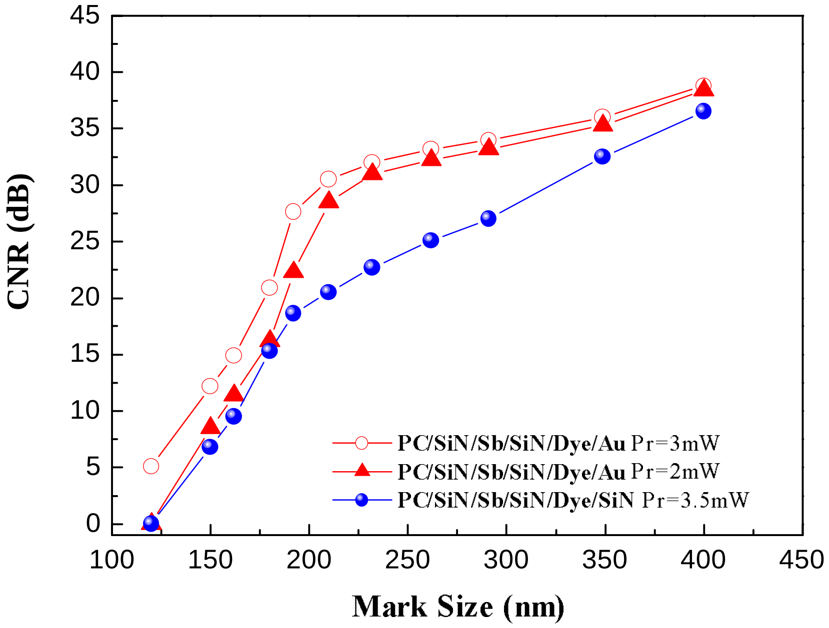


Figure 6 CNR and mark size characteristics of sample disks with PC1-dye for recording layer