

Rewritable dual-layer recording with near-field coupled SIL system

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ABSTRACT

Dual-layer rewritable recording with a SIL (Solid Immersion Lens) system was first demonstrated. The refractive index of the SIL was 2.068 and the laser wavelength was 405 nm. Newly developed optical disk medium has two phase-change recording layers, L0 and L1, separated by an only 3 μm thick resin layer having the refractive index of 1.5. The disk surface was coated with the same resin of 1 μm in the thickness for protection. Two optical heads that were different in the SIL thickness and the distance between the objective lens and the SIL were used separately for L0 and L1 in order to minimize the spherical aberrations for each layer. Successive overwriting and read-out were successfully achieved for the both layers. Since the refractive index of the resin layer is still low (1.5), the achieved recording density is corresponding to 135GB. However, this work is just the promising first step willing to achieve a higher density optical disk, and the promising recording capacity will be 180 GB by increasing the refractive index to 1.8.

Key words: Near field recording, Dual-layer, SIL, Phase-change, Rewritable

1. INTRODUCTION

Near-field optical recording using a SIL (Solid Immersion Lens) system was proposed by Kino et al. in 1990¹⁾ as a high-density optical recording beyond the optical diffraction limit. These technologies have been advanced by various proposals such as super-sphere SIL²⁾, comparative study of hemi-sphere and super-sphere SILs on spherical aberration³⁾ and so on. Especially, read/write demonstration⁴⁾ applying gap servo technology with a cone shape SIL accelerated the development of SIL near-field surface recording; today, the SIL technology becomes a potential candidate for the next generation optical disks' aiming, for example, at 3D or 4K2K contents in the near future. By utilizing the large numerical aperture (NA) of the SIL, five times or more recording density as compared with the conventional Blu-ray Disc systems (25GB/ ϕ 120mm) is promising. Here, it is becoming important whether the SIL technology will be applicable to the multi-layer recording. Without the possibility, the recording capacity may remain as high as around one hundred and half GB. Reportedly, some simulation results suggested the possibility of multi-layer recording with SIL systems⁵⁾; however, no actual experimental demonstration has been reported yet in fact. In the present work, we first demonstrated the near-field dual-layer recording using the set of SIL and a rewritable phase-change optical disk. We newly developed a phase-change optical disk and SIL systems optimized for the disk structure. In this paper, we describe the structure of the optical disk, construction of the SIL system, discussion of key issues for dual-layer recording and overwrite experimental results using them.

2. KEYS ISSUES FOR SIL DUAL-LAYER RECORDING

The high recording density beyond the diffraction limit rule in the SIL surface recording is achieved by utilizing the evanescent light which occurs at the boundary surface with more than Brewster angle in incident light. Figure 1 (a) shows the FDTD simulation results of evanescent light incident on the boundary of substances with the refractive indexes of 1.5 and 1.0 in condition of total internal reflection. As seen in the figure, the incident beam is reflected completely although it is oozing through the boundary as a near-field light. However, it becomes a transmitted beam when the air gap is narrow enough for less than 100 nm as shown in Fig.1 (b). These results mean that the multi-layer recording is possible in near-field coupled SIL recording system, as similar to the Blu-ray system. Figure 2 shows the schematic diagram of the dual layer recording with the SIL system. Recording layers L1 and L0

are separated by spacer and the cover layer is provided as a top-coating as similarly to the dual-layer Blu-ray disk. Although the evanescent coupling in these experiments is operated at the air gap area, read/write is essentially achieved by a propagated beam for both L0 and L1. Of course, multi-layer recording will be possible for tri- or quadri-layer structure, if the transmittance of each recording layer is enough to read/write.

Here, the predicted keys issues for dual-layer recording in SIL system are discussed. According to BD Format of dual-layer Blu-ray disc, the thickness deviation of spacer Δt should be less than 2 μm , which is restricted by spherical aberration (SA). The relationship among SA, Δt and NA is;

$$SA \propto \Delta t \times NA^4 \quad \dots\dots\dots (1)$$

The SA due to thickness-deviations of cover or spacer is neglected for SIL surface recording because of $\Delta t=0$, but it becomes huge value for dual-layer SIL recording. Figure 3 shows the allowance of spacer thickness deviation Δt due to spherical aberration (a) and focal depth as a function NA (b). As shown in the Fig.3 (a), it is revealed that the Δt less than 100 nm will be required when NA is around 1.8. In the case of surface recording, a gap-servo has also focus-servo functions, but the SIL optical system in this experiment does not have a focus servo-mechanism. Therefore Δt should be far smaller than focal depth because Δt causes a focus offset directly. If the NA is around 1.8, Δt should be far smaller than 100 nm as seen in Fig. 3 (b).

3. EXPERIMENTS

The refractive index of the SIL was 2.068 (@405 nm in wavelength), and the optical head structure was similar to that in the previous paper.⁴⁾ However, the spherical aberration became a serious issue especially in the case of multi-layer recording using a high NA system. Since we were not ready for the spherical aberration compensation mechanism, yet; two optical heads were separately provided for the dual-layer optical disk, one for L0 and the other for L1, in this experiment. Each head was adjusted to minimize the spherical aberration by arranging the SIL thickness and the distance between the objective lens and the SIL. The schematic diagram and the measured results of the aberration for the dual layer disk are shown in Fig.4. As seen in the figure, the spherical aberrations are suppressed to be negligibly small.

Figure 5 shows the schematic diagram of the rewritable dual-layer phase-change optical disk that is optimized for the SIL recording. The film stacks of the two layers are designed basically after the Panasonic 50 GB BD-RE media.⁶⁻⁷⁾ As indicated in the figure, the substrate-side and the beam-incident-side (cover layer-side) recording layers are taken to be L0 and L1, respectively. Chief differences from the BD are in the thicknesses of the spacer and the cover layers. In order to reduce the spherical aberration, each layer was set as thin as possible: 3 μm and 1 μm , respectively. They were fabricated by spin coating method using the same UV-resin for the BD (refractive index $n=1.5$). The NA of the SIL system was limited by the refractive index of these layers and the NA in this system is estimated remaining around 1.4.

4. RESULTS & DISCUSSION

Two kinds of dual-layer discs are provided, one is ± 30 nm and the other is ± 11 nm in spacer thickness deviation Δt . In the Fig. 6, the top figure shows the spacer thickness along the tangential direction for each disc and the bottom figures show the corresponding envelopes of RF signal when long mark-and-space signal was written. As seen in the bottom figures, envelope deviation is remarkable for the case of $\Delta t = \pm 30$ nm which is less than 1/3 of the focal depth. However, a constant envelope is obtained when Δt is suppressed to ± 11 nm. It indicates that the thickness deviation of spacer should be less than 1/10 of focal depth if focusing operation is not employed. Since we were not ready yet for the focus servo mechanism separately from gap servo, the dual-layer disc with ± 11 nm in Δt of spacer is used for following overwriting demonstration.

The read/write test has been performed with the gap distance of 30 nm and at the linear velocity of 3.08 m/s. The channel clock frequency was fixed to 66 MHz and the modulation code of 1/7 RLL was adopted. The dependence of each C/N for L1 (a) and L0 (b) on recording power is shown in Fig. 7. In the figures, black circles indicate the

results of initially recording, and open circles shows the results after 10-cycle overwriting for both L1 and L0. The recording power defines the incident power on the SIL system in this case; therefore, the effective recording power is estimated to be half of the "recording power" indicated in the figure because of a loss at the air gap. Figure 8 shows the recording power dependence of long mark (9T) carrier level for both just after writing and after overwriting with short mark (2T) for L1 (a) and L0 (b). Enough erasability more than 30 dB is obtained for both L1 and L0. These results shown in Fig.7 and Fig.8 indicate that the overwriting was successfully achieved for both of L1 and L0.

Figure 9 shows the signal eye-patterns after tenth overwriting for L1 (a) and L0 (b). The recording, erasing and read-out powers were 18 mW, 6 mW and 0.4 mW for L1, and 15 mW, 5 mW and 0.5 mW for L0, respectively. The linear recording density is 70 nm/bit, which is an expected value when $NA=1.4$. As can be seen in the figure, clear eye-patterns are obtained for both recording layers. Here, the tenth overwrite jitter of L1 is 10.9%, and that of L0 is 10.7%. As shown here, overwriting and read-out have been demonstrated successfully for the both recording layers. These results tell us that the film stacks applied for the dual-layered BD structure are essentially applicable to the near field coupled SIL system. The recording capacity in this experiment corresponded to only 135GB since the effective NA remained around 1.4. But it is promising to increase the capacity just by increasing the refractive index of the resin for the intermediate and the cover layers.

Figure 10 shows the estimated capacity as a function of stacked number and refractive index of spacer and cover layer. For example, the capacity will increase to 180 GB for dual-layer and 360 GB for quadri-layer if the refractive index of material becomes 1.8, and 230 GB for dual-layer and 460 GB for quadri-layer when $n=2.0$. In fact, it was reported recently that there is no problem in robustness by adopting the high refractive index cover layer ($n>1.8$) and 90 GB in capacity was achieved with single layer.⁸⁾ Furthermore we have already succeeded to replicate the track guide groove for high refractive index spacer ($n>1.8$). Therefore the capacity of 180 GB in dual-layer recording in SIL will be highly expected to be realized in the near future.

5. CONCLUSION

Near-field recording combining the multi-layer technologies and the SIL system was first actually demonstrated using the BD-like phase-change optical disc and the two optical heads. Since the refractive index of the resin layer is still low (1.5), the achieved recording density is corresponding to only 135GB. However, this work is just the promising first step willing to achieve a higher density optical disc. By developing the new resin with higher refractive index, the expected capacity will be close to half terabyte/ $\phi 120$ mm. As a solution of the next generation optical disc, the multi-layer SIL recording will be a promising candidate that is available for all of ROM/R/RE systems.

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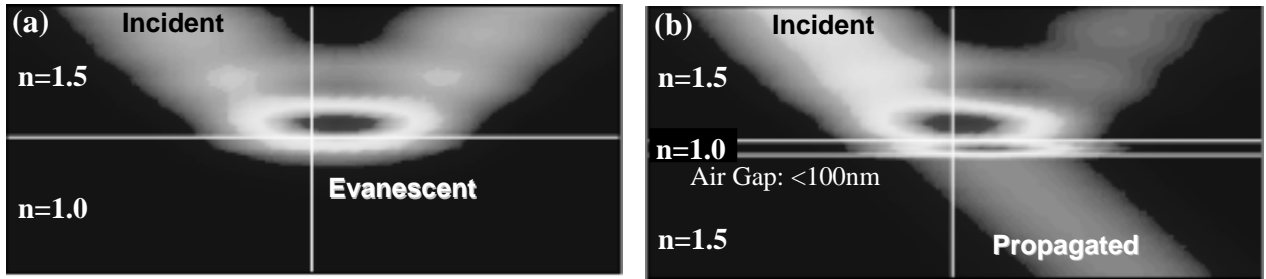


Fig.1 FDTD simulation results of evanescent wave for incident beam more than Brewster angle (a), and propagated wave for evanescent coupled at the gap area sandwiched between high index materials (b)

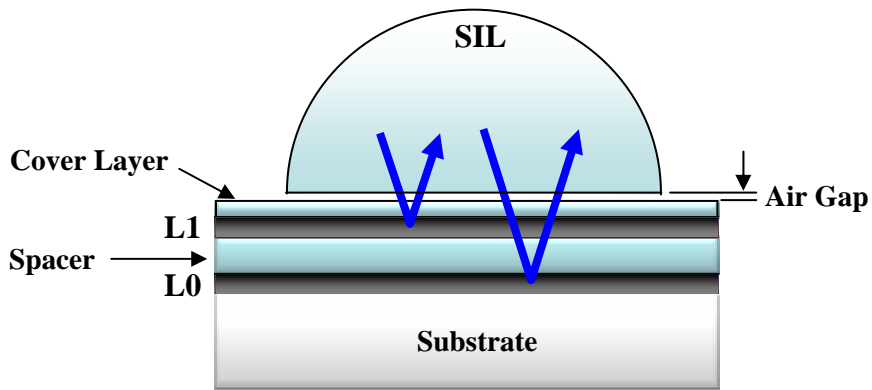


Fig.2 Schematic diagram of dual-layer recording with a SIL. Although evanescent coupling is operated at the air gap area, Read/Write operation is essentially achieved by propagated optical beam for both L0 and L1, as same as BD dual-layer disc.

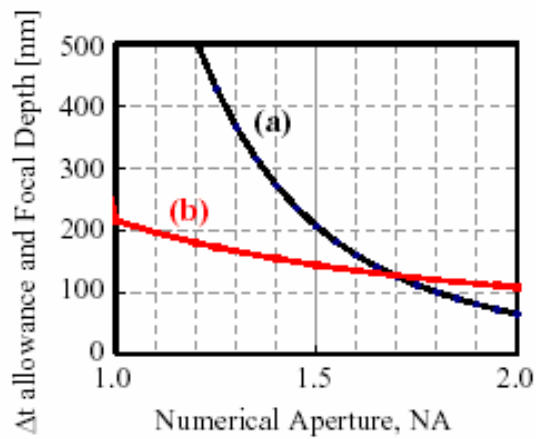


Fig.3 Allowance of spacer thickness deviation Δt due to spherical aberration (a), and focal depth (b).

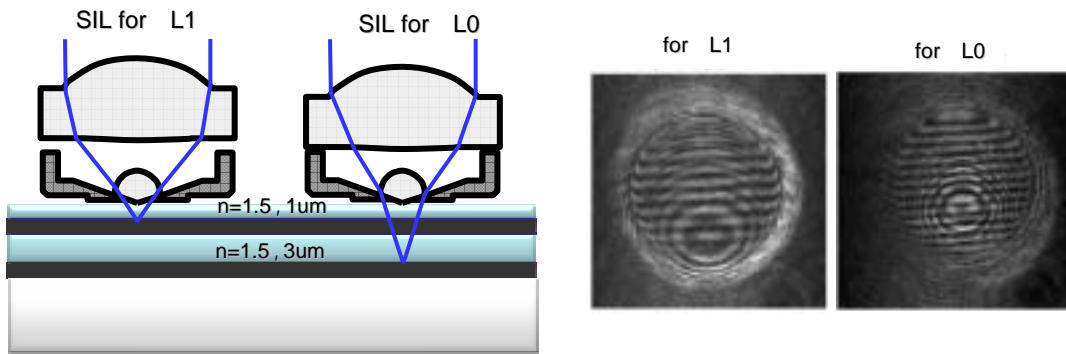


Fig.4 Schematic diagram of the arrangement of two optical heads and interference fringe patterns on the SIL for L1 and L0.

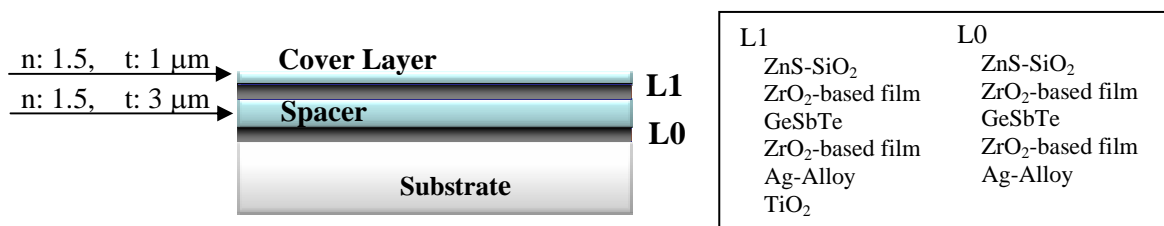


Fig.5 Schematic diagram and layer stacks of dual-layer disc for SIL near-field recording.

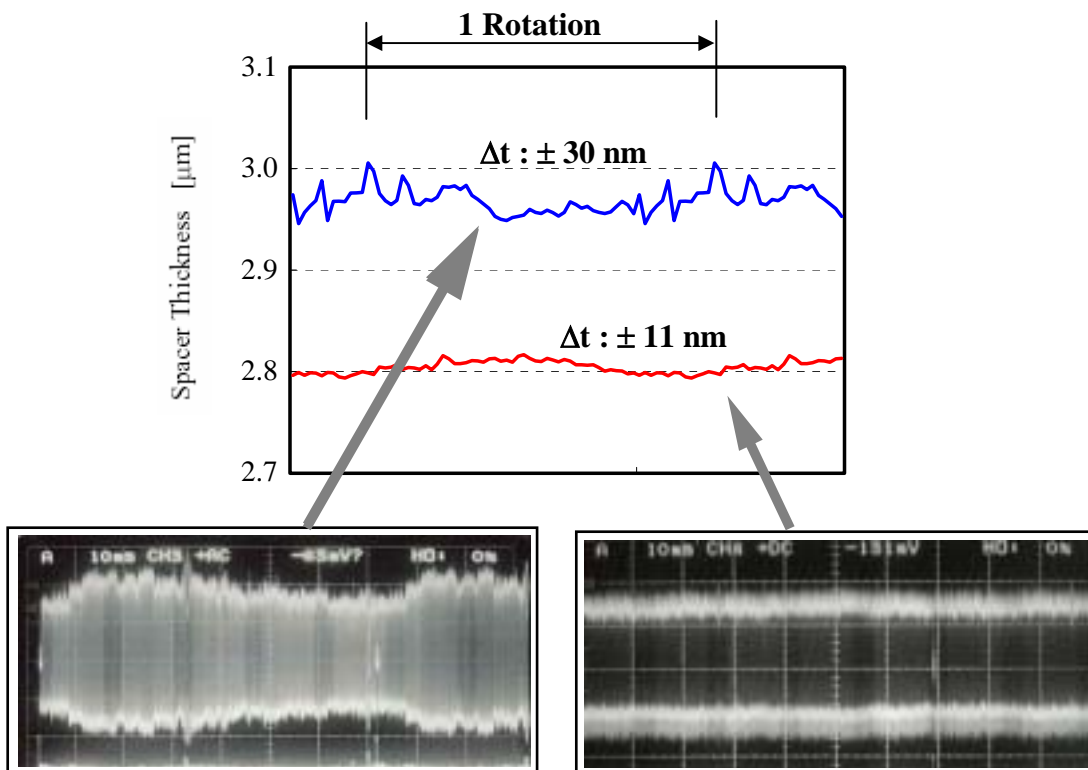


Fig.6 Influence of the spacer layer's uniformity on the produced RF signal envelope.

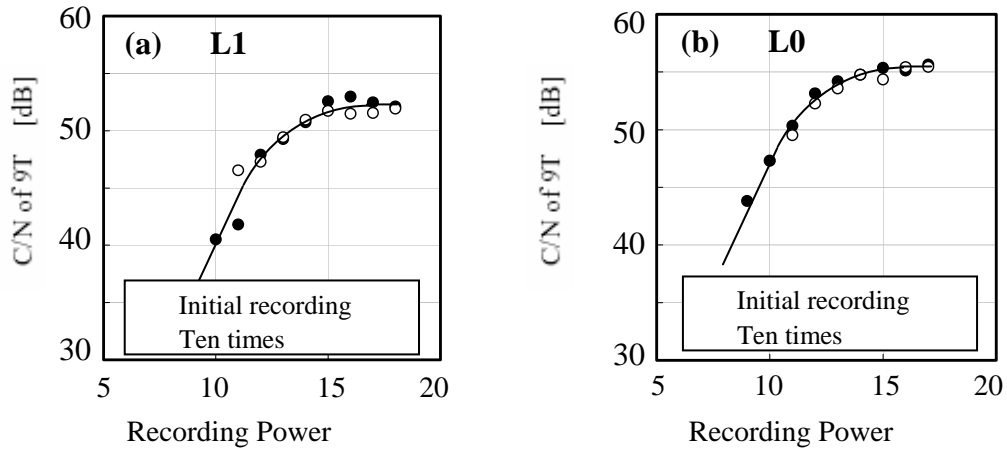


Fig.7 Recording power dependencies of C/N from long mark strings for L1 (a) and L0 (b)

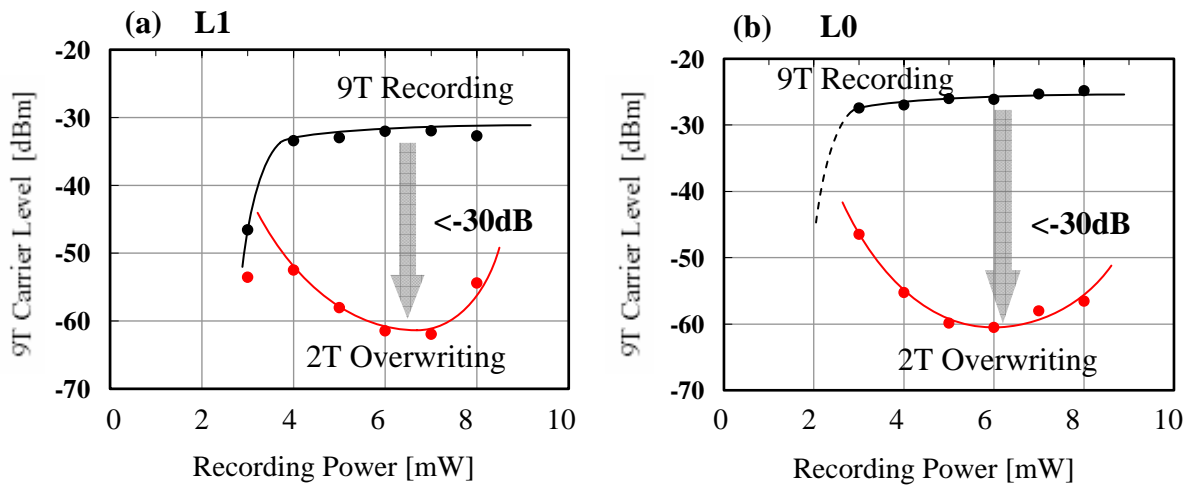


Fig.8 Recording power dependencies of long mark carrier for both just after writing and after overwriting with short mark, (a) for L1 and (b) for L0.

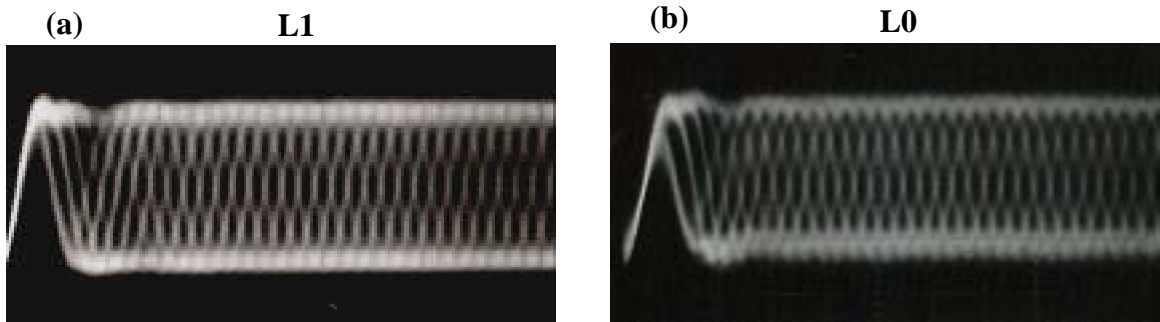


Fig.9 Eye-patterns after 10 times overwriting from L1 (a) and L0 (b), in the conditions of 1-7 random signal with channel clock of 66 MHz, liner velocity of 3.08 m/sec and 70 nm/bit in liner bit density

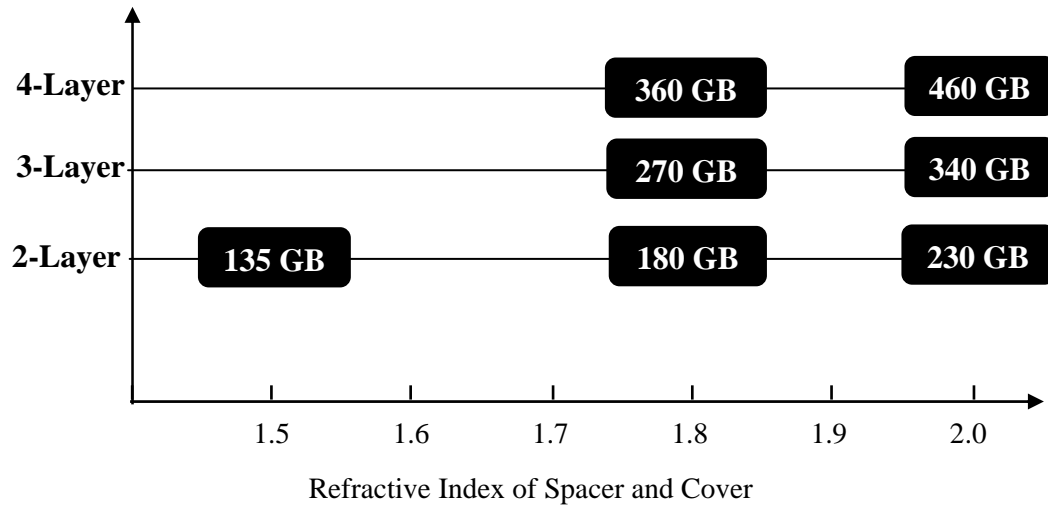


Fig.10 Estimation of expected recording capacities of multi-layer discs for SIL recording toward the development of higher refractive index material in spacer and cover layers