Phase Change Recording Media of 20GB/single and 36GB/dual by using Wavelength of 405nm, NA of 0.65, and Light Incidence on 0.6mm-thick Substrate

Katsutaro Ichihara
Storage Materials and Devices Lab., Research and Development Center, Toshiba Corp.,
1, Toshiba-cho, Komukai, Saiwai-ku, Kawasaki 212-8582, Japan

Phone: +81-44-549-2114, Fax: +81-44-520-1802, E-mail: katsutaro.ichihara@toshiba.co.jp

Keywords; Phase-Change Media, AOD, 0.65-NA, 0.6mm-thick substrate, 20GB/single, 36GB/dual

1. INTRODUCTION

Two prospective formats have been proposed for the next-generation optical disc systems using blue-violet lasers and both proposals have been in progress. The one proposal is so-called “Blu-ray Disc” which uses numerical aperture of an objective lens (NA) of 0.85 and a 0.1mm-thick cover sheet as a light incident layer [1-3]. The other is “AOD” which uses NA of 0.65 and light incidence on 0.6mm-thick polycarbonate substrate[4-7]. Although Blu-ray is superior for its higher capacity due to the use of higher NA, the author believes that AOD seems to be superior for the total cost-performance, since AOD is easier to be compatible to the current DVDs and CDs, it can use bare-discs, and it is easier to obtain mass-productivity for both drives/recorders and discs. The author and his colleagues in Toshiba have developed the advanced phase change recording media for AOD system. The single-sided user data capacity has been successfully demonstrated as 20GB/single-layer and 36GB/dual-layer with the maximum user data transfer rates of 36 Mbps.

In this paper, the comparison between the system, which uses NA of 0.85 and light incident on 0.1mm cover sheet, and AOD system is described in order to make the superiorities of AOD clear first, the main features of Toshiba’s AOD Re-Writable media are described second, the experimental procedures for the AOD media is explained third, the recording experimental results for both single-layer and dual-layer AODs are shown fourth, and finally the author summarize this paper. Here, AOD Re-Writable stands for all re-writable discs of AOD system. The author believes that the current DVD-RAM, DVD-RW, and +RW will be united to the single format in the near future AOD Re-Writable.

2. COMPARISON between TWO SYSTEMS

In this chapter, the results of the comparative study between the higher NA system and AOD system are described. Here, the higher NA system means the system using NA of 0.85 and the light incidence on 0.1mm-thick transparent cover sheet, which was investigated by Toshiba [8]. It is similar to Blu-ray, but it is not Blu-ray itself. And AOD is the abbreviation of “Advanced Optical Disc” and/or “AO (BLUE in Japanese word, pronounced as “ao”) Disc”. Although the official name of AOD has not been decided yet, it is called as “AOD” in this paper.

Table.1 shows the comparison between the higher NA system and AOD system. The higher NA system of Toshiba has demonstrated 30GB user data capacity when the format efficiency was assumed to be 83% [8]. On the other hand, AOD has demonstrated 20GB user data capacity with the same format efficiency [4]. The capacity of the higher NA system was 1.5 times higher than that of AOD. However, regarding to another important items, such as the affinity with the current DVDs and CDs, AOD seems to be superior to the higher NA system, as shown in Table.1. The usability of bare discs, which stands for the cartridge-less type, is indispensable for slim drives, which leads to slim personal computers. The compatibility with the current DVDs and CDs is one of most important requirements by users. AOD will be able to assure the compatibility much more easier than the higher NA system, since its NA (0.65) is nearly equal to the current DVDs, which leads to the usability of single pick-up head for operating all discs of AODs, the current DVDs and CDs. In addition, the mass productivity for both drives/recorders and discs is indispensable for building up the huge market. The mass productivity of AOD discs is expected to be similar to that of the current DVDs, since the mastering laser will be able to be the same and the production process of dual-layer discs will also be the same between AODs and the current DVDs. On the contrary, media for the higher NA system require deep ultra-violet (DUV) laser or electron beam (EB) in their mastering process. The production process of dual-layer discs in the higher NA system is also much different to the current DVD-9. Table.2 shows the example of comparison of the production process for dual-layer discs. In the case of AOD, the production process is simple as followings. L0, which stands for the first layer from the light incident side, and L1, which is the second layer from the light incident side, are prepared separately. The dual-layer AOD discs will completed by the bonding and the curing process after the depositions of films for L0 and L1. On the contrary, in the case of the higher NA system, the production process will be somewhat complicated as followings. The layer(s) of L1 is prepared on the formatted substrate, UV resin is coated on the L1, the format of L0 is made by the stamping and the curing, the stamper of L0 is removed, the layer(s) of L0 is prepared on the L0 format, and finally 0.1mm thick transparent cover sheet is attached on the L0.

As the consequence, one of the main concepts of AOD is the affinity with the current DVDs and CDs, although the user data capacity and tilt tolerance will be smaller than the higher NA system.

3. Features of Toshiba's AOD Re-Writable Disc (Single-Layer)

Table.3 summarizes the main features of our single-layer AOD Re-Writable disc, which is based on the phase change technology.

Regarding to the higher linear density issues, we adopted the following technologies.

(1) Bismuth substituted GeTe-rich pseudo binary alloy as the recording layer for obtaining both higher Carrier to Noise Ratio (CNR) and sufficient Erase Ratio (ER).

(2) The interface layer free structure, which means that no crystallization enhancement layer was attached to the phase change layer, for reducing the noise-level, which leads to higher CNR.

(3) L-H polarity, which defined so that the reflectivity of amorphous (Ra) is higher than that of crystal (Rc), for obtaining better overwriting ER. L-H polarity is also useful for obtaining lower cross-erase (XE).

Regarding to the higher track density issues, we adopted the following technologies.

(4) Land and Groove (L/G) recording method for obtaining lower cross-talk (XT), lower cross-erase (XE), and higher tracking signal (TS).

(5) Thermal Control Layer (TCL) for obtaining lower XE even when the track pitch is reduced much more.

The Toshiba's own technologies are (1), (2), and (5), although the novel interface layer is indispensable for the case of L0 of the dual-layer. In our recent results, the adoption of interface layer seems to be also useful for the single-layer case, since the interface layer will promise long life durability. The technology (3) has been the invention of NEC Corp. [9] and the technology (4) has been the invention of Matsushita Electric Industry [10].

The technologies of (1), (2), and (5) are described in detail in this paper including the novel interface layer technology for L0 of Toshiba's own.

3-1. Bismuth substituted GeTe-rich pseudo binary alloy as the recording layer

It has been found that the difference in the refractive indices (n,k) between amorphous and crystal increase with increasing GeTe content in the pseudo binary GeSbTe composition line, which connects two inter-metallic compounds, Sb_2Te_3 and GeTe, in blue wavelength region. The difference in the reflectivity, (Ra-Rc), was improved to about 23% from the value of about 16%, which was obtained when the typical $(GeTe)_2$-(Sb_2Te_3) composition was used. The Bismuth substitution has been found that ER was much improved even when we adopt the interface layer free structure. The improvement in ER was more than 10 dB when we adopted the Bismuth substitution and sufficient ER has been obtained.

3-2. Interface layer free structure

It has been reported that the interface layers, which attached to the recording layer directly, enhanced the nucleation probability at the interface between the phase change film, which leads to high ER [11]. However, we have found that the adoption of the interface layer tended to increase the noise-level in some cases. The author suppose that this phenomenon may be originated from the improper combination of phase change material and the interface material. But unfortunately, the noise level increased much when we adopted the interface layer to the GeTe-rich phase change film. The noise-level was improved about 3 dB when we removed the interface layer and CNR increased much. However, ER decreased more than 10 dB by removing the interface layer simply. Thus, we adopted the Bismuth substitution to the phase change film and it did worked well, as described in ***3-1***.

3-3. Thermal Control Layer (TCL)

Higher linear density was successfully obtained by using the Bismuth substituted GeTe-rich recording layer and the interface layer free structure. However, higher track density was not obtained at this stage, since XE was too high when the track pitch was made narrower. The origins of XE have been considered that (a) the direct heating of amorphous marks in the adjacent tracks by light irradiation and (b) the lateral heat diffusion from the track, on which the writing beam is irradiated, to the adjacent tracks. Since the absorption of amorphous (Aa) was made small as 50% through 60% due to the adoption of L-H polarity in our case, the direct heating was considered to be small. Therefore, we interpreted that the large XE was mainly originated from the lateral heat diffusion. We considered that the lateral heat diffusion would be suppressed by enhancing the heat diffusion perpendicular to the film plane, because of the nature of heat flow. The heat flow perpendicular to the film plane is dominated by the heat sink layer, which is the thick reflective layer, in the usual media. The one way to enhance the heat flow perpendicular to the film plane seemed to make thinner the interference layer between the recording layer and the heat sink layer. But this approach did not work well, since the balance between L/G degraded. Therefore, the novel approach has been adopted by using the Thermal Control Layer (TCL) at the light incident side of the recording layer. The film material has been chosen for TCL, which has both high thermal conductivity and high transmittance in blue light region. High thermal conductivity TCL has promised to enhance the heat flow perpendicular to the film plane toward the both sides of the recording layer. XE at track pitch of 0.34 um has been reduced to nearly equal to 0 dB for both L/G in accordance with the adoption of TCL.

3-4. Film Structure of Single-layer AOD Re-Writable

Figure.1 shows the cross-sectional view of Toshiba's single-layer AOD Re-Writable medium. The combination of the films with high refractive index, 1st Interference ZnS-SiO_2, TCL (AlN), and 3rd Interference ZnS-SiO_2, and the film with low refractive index, 2nd Interference SiO_2, makes this medium as L-H polarity.

AlN-TCL plays an important role to enhance the heat flow perpendicular to the film plane and suppress the latent heat flow , which leads to distinctly low XE characteristics even when the track pitch is made narrower. Figure 2 shows the results of thermal simulation for the medium without and with TCL. The arrows in this figure depict thermal flows. The arrows in the 3rd Interference ZnS-SiO_2 direct to lateral and short, which means small heat flow perpendicular to the film plane in the case of the medium without TCL. On the contrary, the arrows direct to perpendicular and long in the case of the medium with TCL.

Furthermore, the Bismuth substituted GeTe-rich recording layer and the interface layer free structure improve the linear bit density, as described in ***3-1*** and ***3-2***.

Figure.3 shows the contour maps of the optical design for the medium shown in Fig.1. The horizontal axis is the thickness of TCL and the vertical axis is the thickness of the 3rd Interference layer. High reflectivity change (Ra-Rc) and high Ac/Aa are consistent in a wide thicknesses range, as shown in Fig.3. Here, Ac stands for the absorption of crystal. Ac/Aa is the index of overwriting ER. Overwriting ER can be optimized when the appropriate value of Ac/Aa is chosen, since the heat of fusion of amorphous and crystal compensates in overwriting operation. Best thicknesses for TCL and the 3rd Interference layer were around 20nms or so.

The features of the dual-layer AOD Re-Writable disc are described briefly in chapter 5.

4. EXPERIMENTAL

The films were successively sputtered on 0.6 mm thick substrate with L/G format. The sputtering process has been mainly carried out by using OCTAVA proto-type machine, which was produced by Shibaura Mechatronics Corp. Then, the media were bonded to the counter substrates in the case of the single-layer discs. The fabrication process for the dual-layer discs has already been shown in Table.2. The phase change films were crystallized by the use of a commercially based bulk initializing equipment before the recording experiments.

Table.4 summarizes the conditions for the recording experiments. The data bit length was set to 0.13 um/bit in the case of the single-layer and it was set to 0.14 um/bit for the dual-layer's case. The track pitch was fixed at 0.34 um for both the single-layer and dual-layer cases, except the study of comparison. The maximum user data transfer rates were 36 Mbps for both single-layer and dual-layer cases. We have measured mainly 9T-CNR, ER, and XE for the analog characteristics. XE was defined as the decrease of 3T carrier level after 10 times 11T marks overwriting on both adjacent tracks. The CNR after 10 times random overwriting on a single track, and the CNR after 10 times overwriting on both adjacent tracks was defined as CNR-1 and CNR-2, respectively. The write strategy was optimized so that an asymmetry of 2T signals was balanced for the bER measurement.

Here, the track pitch of 0.34 um corresponds to 0.26 um and 20GB capacity corresponds to more than 34GB when NA of 0.85 is used.

5. RESULTS and DISCUSSION

5-1. Single-Layer AOD Re-Writable

Table.5 shows the results of comparison between two types of TCL. The track pitch was set to 0.37 um, corresponding to 18GB, in this case. The one TCL is ultra-thin Ag-alloy (about 8nm thick) and the other TCL is 20nm thick AlN. We used Ag-alloy in our previous study. We have demonstrated 18GB capacity in this case [12]. Therefore, we examined several kinds of the film materials, which could replace Ag-alloy, in order to obtain 20GB capacity. Finally, we have found that AlN is much better than Ag-alloy for TCL. CNR after initial writing has been improved much by replacing Ag-alloy to AlN, since the noise level has decreased much. The origin of the noise for the medium with Ag-alloy as TCL may be considered to be the island-like film structure of ultra-thin Ag-alloy. The verification of this consideration is now in progress. ER of the medium with AlN-TCL has been also much improved, as shown in Table.5. This is because Ac/Aa of the medium with AlN-TCL became to an appropriate value, since Ac/Aa of the medium with Ag-alloy TCL was nearly equal to the unity which had no compensation capability of the heat of fusion between amorphous and crystal. XE shows the similar values between two types of TCLs in the case of the track pitch of 0.37 um. XE of AlN-TCL seemed to be superior than Ag-alloy TCL when the track pitch is reduced to 0.34 um.

Table.6 shows the CNR-1 and CNR-2 of the medium with AlN-TCL in the case of track pitch of 0.34 um. The difference between CNR-1 and CNR-2 corresponds to XE. There is no substantial difference between CNR-1 and CNR-2, as shown in Table.6.

Figure.4 shows the bERs as a function of radial and tangential tilts. The bottom bER was less than 10^{-6} for both L/G. The system requirement of bER is 3 times 10^{-4}. Both the radial and the tangential tilt margins at a bER of 3 times 10^{-4} are sufficiently wide. Figure.5 shows the bottom bER as a function of overwriting cycle. The data was obtained by using the random shift recording. The bottom bER increases only slightly more than 100 times overwriting, but it keeps less than 10^{-5} even after overwriting 10,000 times.

As the consequence, we have successfully demonstrated 20GB/single-layer user data capacity with sufficient tilt margins and feasible overwriting cycle times by using our advanced phase change medium for AOD system.

5-2. Dual-layer AOD Re-Writable

L0 is mainly described in this section. The requirements for L0 are the large transmittance (about 50%) and the balance in transmittance between amorphous and crystal [13], which lead the issues of low contrast ratio, low cooling rate, and low ER. Regarding to these issues, we have adopted the following technologies for L0.

(1) H-L polarity for obtaining a large contrast ratio.
(2) Additional transparent heat sink layer for obtaining a rapid cooling rate.
(3) Novel interface layers for obtaining a sufficient ER even when the recording layer thickness is around 6 nm.

Figure 6 shows the cross-sectional view of the dual-layer AOD Re-Writable. The light is incident from the lower side of this figure. We examined various kinds of interface layers and finally we have found that TS-interface layer is quite effective to obtain a sufficient ER in L0. Here, TS-interface layer stand for the ultra-thin film, which was sputtered from Ta_2O_5 + X composite target supplied by Tosoh Corp. The promising candidate for the additional heat sink layer has been AlN at the present.

Figure 7 shows the example of the optical design. Transmittance of 50% and the contrast ratio of about 80% are consistent at the thickness of the recording layer of about 6 nm, when we combine Bismuth substituted GeTe-rich alloy as a recording layer, HfO_2 as interface layers, and 10nm thick Ag-alloy semi-reflective layer. The similar results were obtained in the case of TS-interface layers.

Figure 8 shows CNR-1s as a function of peak power during writing for the medium with HfO_2 (a) and TS (b) interface layers. The medium with TS-interface layers (b) shows both higher sensitivity and higher CNR. Therefore, we have chosen TS-interface layers for L0.

Table.9 shows the analog characteristics and bER performances for L0 and L1. All analog characteristics are sufficient for both L/G of both L0 and L1 so that all bottom bER are less than 4 times 10^{-5}. The bERs of L0 are 5 track performance and those of L1 is single track performances. The bER of L1 for the multi track operation are in progress now.

It can be said that the feasibility of 36GB/dual-layer AOD Re-Writable has been successfully demonstrated.

6. CONCLUSION

Two prospective formats, the higher NA system and AOD, have been compared. AOD is considered to be superior for its total cost-performance, such as the usability of bare discs, the easier compatibility to the current DVDs and CDs, and the easier mass productivity of both drives/recorders and discs, although the user data capacity and tilt margins of the higher NA system are superior than AOD due to the uses of higher objective lens and thinner light incident layer. The author and his colleagues have been focusing on the development of AOD Re-Writable discs, which are based on the phase change recording technology. The author and his colleagues in Toshiba have developed both single-layer and dual-layer disc technologies. The main features for the single-layer technologies are the adoptions of Bismuth substituted GeTe-rich alloy as a recording layer, interface layer free structure, and AlN thermal control layer. We have successfully demonstrated the user data capacity of 20 GB/single-layer and the maximum user data transfer rate of 36 Mbps by using our advanced phase change medium at bER performances, when the format efficiency is assumed to be 83%. 20GB capacity will be able to record about 4.5 hours of high-definition moving picture when the compression method is assumed to be H.264. Furthermore, we have been challenging the development of dual-layer AOD Re-Writable disc. The main features of our dual-layer technologies are the adoptions of the H-L polarity, the additional transparent heat sink layer, and the novel interface layers. We have successfully demonstrated the feasibility of the user data capacity of 36GB/dual-layer. The author believes that AOD will be the main stream in the future interchangeable disc storage devices in the consumer market and the professional archiving market as well.

[REFERENCES]

[1] K. Osato et al., Proc. SPIE,3401, 80 (1998)
[2] H. J. Borg et al., Jpn. J. Appl. Phys, 40, 1592 (2001)
[3] I. Ichimura et al., Tech. Digest of ODS'01, 139 (2001)
[4] N. Ohmachi et al., Proc. PCOS'02, 98 (2002)
[5] T. Tsukamoto et al., Proc. PCOS'02, 20 (2002)
[6] T. Sugaya et al., Proc. PCOS'02, 86 (2002)
[7] S. Ohkubo et al., Proc. PCOS'02, 92 (2002)
[8] K. Yusu et al., Tech. Digest of ODS'02, 413 (2002)
[9] S. Ohkubo, USP-6,064,642 (2002-5-16)
[10] K. Nishiuchi et al., USP-5,568,461 (1996-10-22)
[11] N.Yamada et al., Jpn. J. Appl. Phys., 37-1, 4B, 2104(1998)
[12] This was reported in WG-11 meeting of DVD-Forum on May(2002)
[13] N. Yamada et al., Tech. Digest of ISOM/ODS'02, 404(2002)

Acknowledgement

The author wishes to express his thanks to all colleagues of AOD in NEC and Toshiba for their cooperative studies. The author also expresses his great thanks all member companies of WG-11/TG-11-1 of DVD-Forum for their earnest support to our proposal of AOD. Finally, but not least, the author expresses his thanks to the committee members of EPCOS'03 for giving the occasion to discuss about the future optical recording system and media.

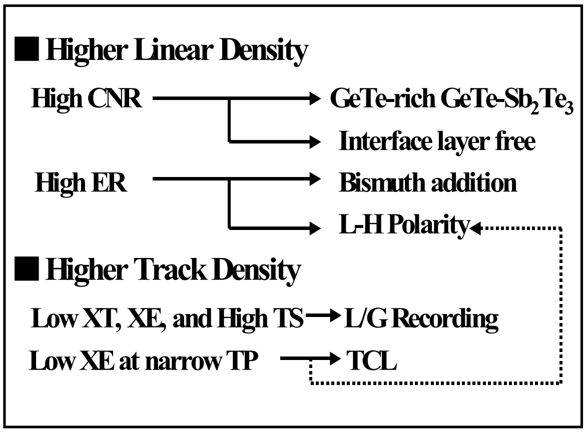
Table.1 Comparison of Two Optical Systems

System	AOD	Higher NA
Disc items	t0.6mm&NA0.65	t0.1mm&NA0.85
Capacity	20GB	30GB
Bare disc	Possible	Difficult
CD/DVD compatibility	Possible	Difficult
Mastering laser	UV (Same as DVD)	DUV or EB
Dual layer disc	Same as DVD	Difficult
Disc cost	Almost same as DVD	Expensive
Mass productivity	Almost same as DVD	New Process

Table.2 Comparison of Process for Dual-layer disc

AOD	Higher NA
1. Deposition of L0	1. Deposition of L1
2. Deposition of L1	2. UV resin coating
3. UV resin coating	3. stamping
4. bonding	4. Curing
5. Curing	5. Remove stamper
	6. Deposition of L0
	7. Forming cover layer

Table.3 Media Technologies of Toshiba's AOD



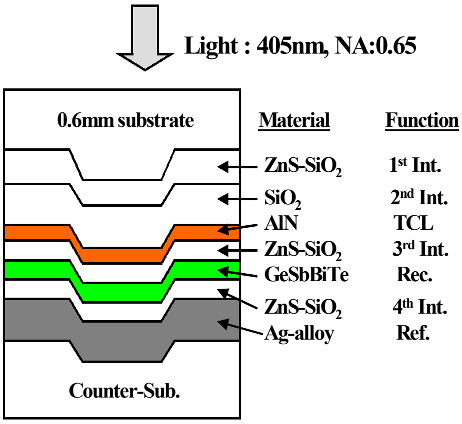


Fig.1 Cross-sectional View of AOD Medium

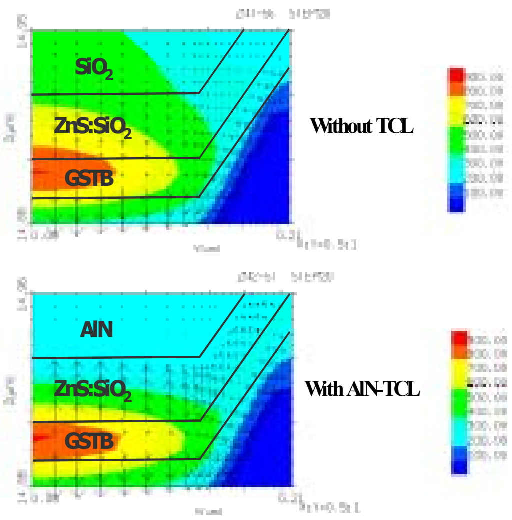


Fig.2 Results of Thermal Analysis

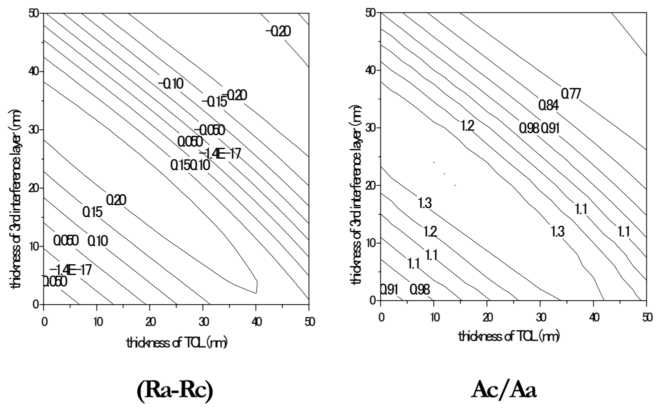


Fig.3 Contour maps of Optical Design

Table.4 Experimental condition

Capacity	18GB	20GB
Laser wavelength	405nm	
NA of objective lens	0.65	
Thickness of substrate	0.6mm	
Track pitch	0.34μm	
Data bit length	0.14μm	0.13μm
Channel clock frequency	64.8MHz	
Modulation code	RLL(1,7)	
Data detection method	PR(1,2,2,2,1)	

Table.5 Comparison between Ag-alloy and AlN as TCL

material of TCL	CNR (dB)		Noise (dB)		ER (dB)		XE (dB)	
	G	L	G	L	G	L	G	L
Ag-alloy	56.8	57.9	-67.8	-69.9	25.7	26.6	0.0	0.3
AlN	59.4	58.3	-72.2	-72.6	33.7	33.0	0.1	0.2

(Track pitch:0.37um)

Table.6 Overwrite and XE performances

CNR1 (dB)		CNR2 (dB)	
G	L	G	L
56.2	54.5	55.5	54.2

(Track pitch:0.34um)

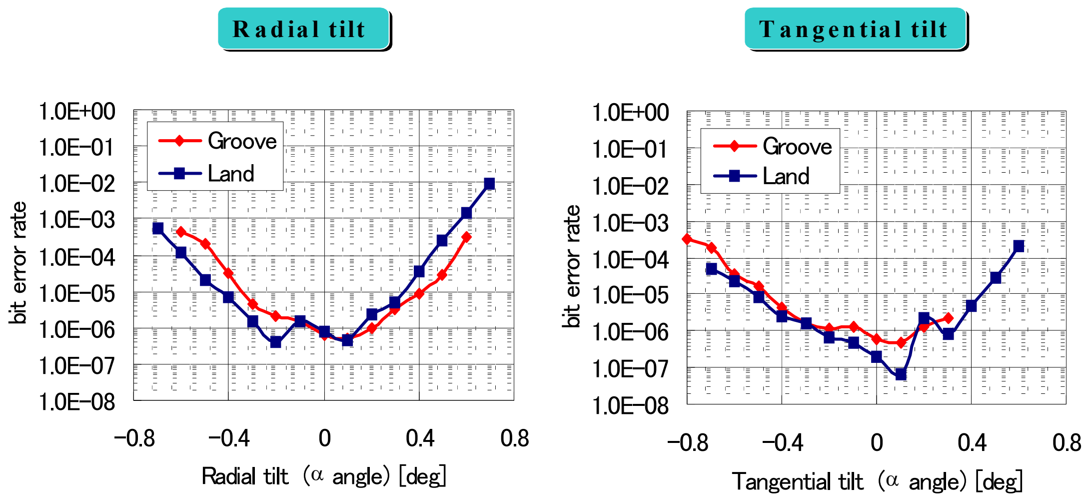


Fig.4 Bit error rate of 20GB/single-layer disc

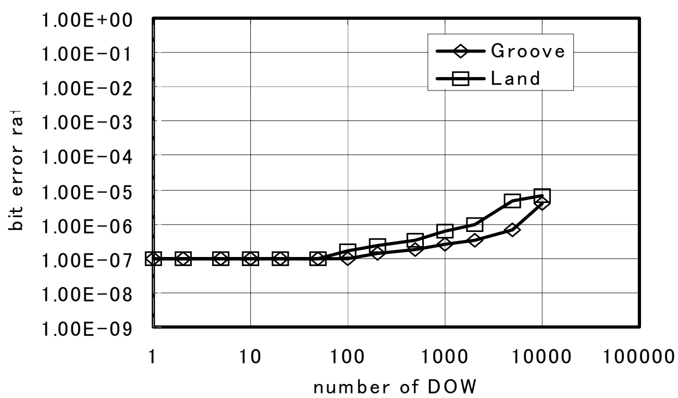
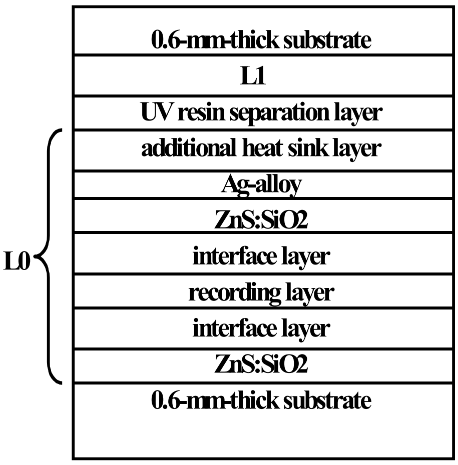


Fig.5 bER as a Function Overwriting Cycle



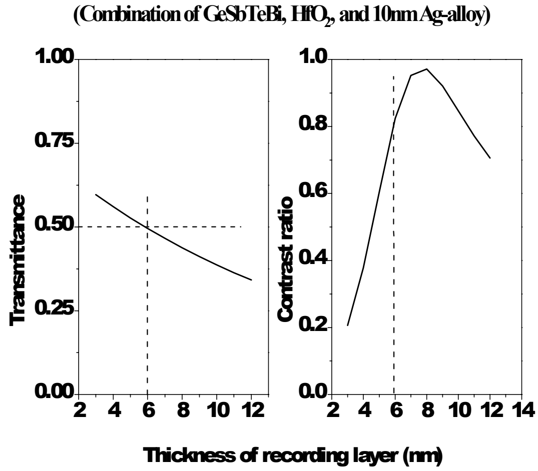


Fig.6 Cross-sectional View of Dual-layer AOD

Fig.7 Example of Optical Design for L0

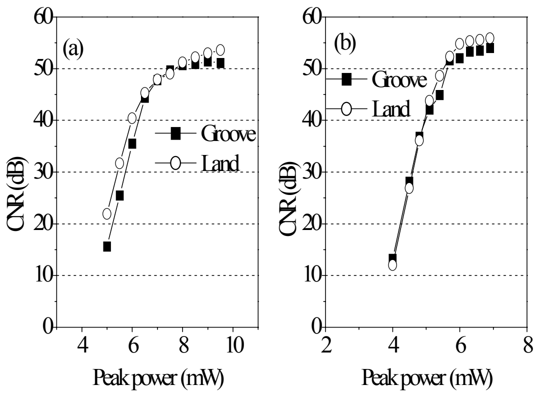


Fig.8 CNR as a function of Peak Power for L0

Table.9 Recording Characteristics of L0 and L1

Disc	track	CNR1	CNR2	ER	XE	Ch-bER
L0-TS	G	53.6	53.1	29.5	0.3	1.9×10^{-5}
	L	53.3	53.0	28.7	-0.2	3.7×10^{-5}
L1	G	52.0	52.0	32.7	0.1	8.9×10^{-6}
	L	52.2	52.0	27.7	0.1	3.3×10^{-5}