100 GB rewritable triple-layer optical disk having Ge-Sb-Te films

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Abstract
A rewritable phase-change optical disk with 100 GB capacity on ϕ120 mm was first demonstrated basically based on Blu-ray Disc format. The large capacity was achieved firstly by increasing the number of recording layers from two to three and secondary by increasing the recording density from 25 to 33.4 GB/layer, in other words, by reducing the minimum recording mark-length from 149 to 110 nm. For enabling the triple-layer structure, a very thin phase-change film around 6 nm was adopted to achieve a large transmittance of more than 50 %. Obviously, the optical contrast between in the amorphous and crystalline states tends to decrease as the thickness of the phase-change film becomes small and also the reproduced signal amplitude decrease as the recording mark size decreases. In order to overcome such double difficulties, we adopted a material film with rather large GeTe component in the GeTe-Sb_2Te_3 pseudo binary system with various optimizations of the film stacks.

Key words: rewritable optical disk, 100 GB, triple layer, 33.4GB/layer

1. INTRODUCTION

Rewritable optical disks have been the most successful results in this decade as the application of phase-change materials. Nowadays, the optical disk drives are normally mounted on almost all personal computers; in particular, the DVD/BD (Blu-ray Disc) video recorders steadily replaced VTR (video tape recorder) year-by-year. It is forecasted that the production numbers of rewritable optical disks in 2009 will be more than 230 millions for DVDs and 20 millions for BDs. On the recording capacity of the rewritable phase-change optical disk, it was continuously becoming large from 650 MB/ϕ120 of CD-RW in 1997, 4.7 GB/ϕ120 of DVD-RAM in 2000, 23.3 GB/ϕ120 of single layer BD in 2003 to 50 GB/ϕ120 of dual layer BD in 2004.

After then; however, the increasing speed of capacity became rather slow for the rewritable phase-change optical disks, while 100 GB or more capacity were reported for the write once type (R-type) optical disks utilizing the multi-layer technologies[1-2]. This is because providing for a highly transparent recording layer is indispensable for multi-layer optical disk and it is much difficult for a rewritable type than for a write-once type. It has been quite difficult for a rewritable type to realize i) a large transmittance of >50% with keeping ii) a high reflectivity of at least 5 % (especially for L1), iii) a high optical contrast of (Rc-Ra)/(Rc+Ra) >0.8, where Rc and Ra means reflectivity corresponding to the crystalline and amorphous states, respectively, and iv) a high recording data rate of 36 Mbps.

In this paper, R/D results to realize the rewritable triple layer optical disk establishing 100 GB capacity will be reported; i.e., the technologies for doubling the capacity of BD-RE from 50 to 100 GB by increasing not only the recording layer from two to three, but also increasing the recording density per layer from 25 to 33.4 GB. In the triple layer optical disk, we developed remarkable progress of the middle layer (L1) by adoption of GeTe-rich GeSbTe film and newly developed TiO_2-based dielectric film having a very high refractive index at 405 nm that works very effectively to increase the optical transmittance of the recording layer.

2. EXPERIMENTS

2. 1 Layer stacks of the triple layer optical disk

Figure 1 illustrates the layer stacks of the developed triple-layer optical disk. Three recording layers of L0, L1 and L2 are successively formed on a 1.1 mm thick disk substrate having continuous pre-grooved tracks on the surface. The track pitch of 0.32 μm equals to the previous BD. Three layers are separated by resin layer named "separation layer" whose thicknesses of 25 μm and 18 μm are chosen so as to minimize the stray light. After deposition of L2, the disk is sealed with a resin coat of about 0.5 mm thick on the top. L0 is required to have the highest reflectivity among three and a high signal contrast at once. Accordingly, the layer stack is characterized by the rather thick GeSbTe film of 10 nm and the very thick Ag-alloy film of 100 nm. On the contrary, either of L1 and L2 should be half-transparent. For satisfying the demands, very thin GeSbTe films (L1: 7.5 nm, L2: 6 nm) and also very thin Ag-alloy films (L1: 9 nm, L2: 7 nm) are provided for them. Additionally, a highly transparent TiO_2-based film having a very high refractive index about 2.7 or more is applied to the top film for enhancing optical transmittance.

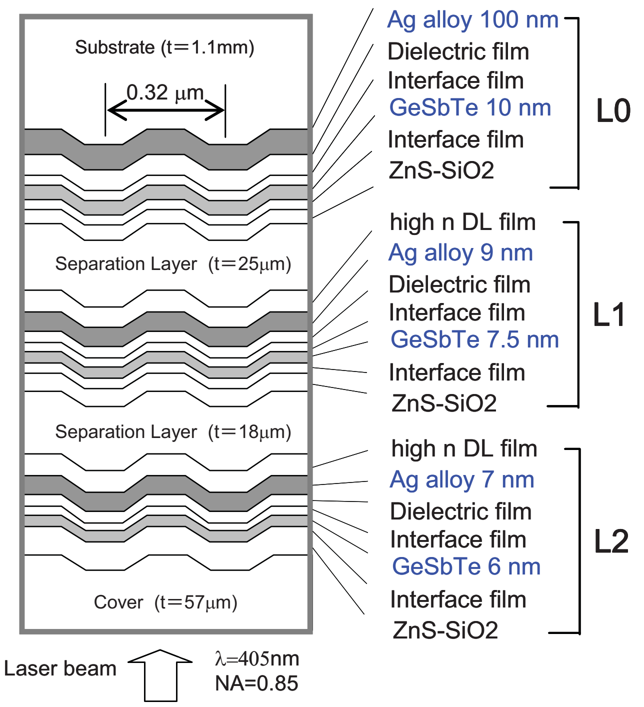

Fig. 1 Cross section of the triple layer optical disk

2.2 High contrast phase-change film

The first essential point for the 100 GB triple layer disk is realizing a high recording density corresponding to 33.4 GB per layer. For satisfying the requirement, we adopted a very GeTe-rich composition in the GeTe-Sb_2Te_3 material system. Figure 2 reveals compositional dependences of i) the crystallization temperatures, T_x ii) the crystallization time (without data) and iii) the variations of optical constants, |Δn|+|Δk|, between amorphous and crystalline states on the GeTe-Sb_2Te_3 tie line, where |Δn| and |Δk| respectively denote the variations of refractive indices and extinction coefficients at the wavelength of 405nm[3]. It is obvious in the figure that both of the T_x and the value of |Δn|+|Δk| increase with increased GeTe ratio; however, the crystallization time becomes a bit longer conversely. We optimized the material composition as maximizing T_x and |Δn|+|Δk| with keeping a

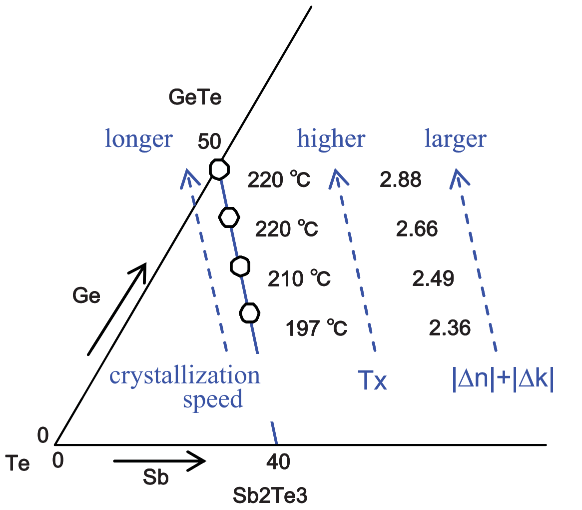

Fig. 2 Compositional dependence of phase-change properties along GeTe-Sb2Te3 tie line

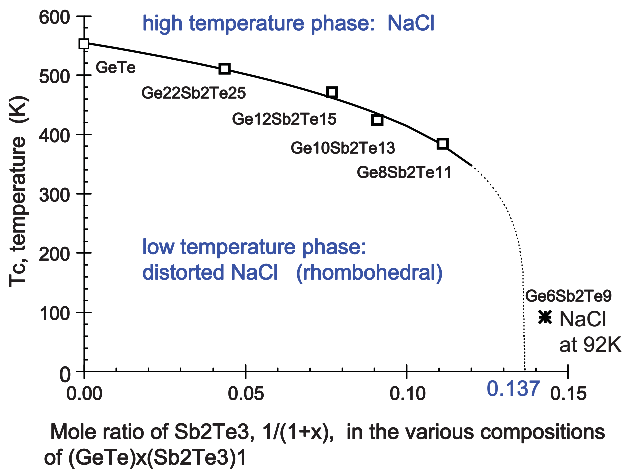

Fig. 3 Compositional dependence of crystal-crystal phase-transition temperature, Tc, on the increased Sb2Te3 concentration, 1/(1+x). (the original figure is from the reference[4].)

sufficiently short crystallization time enabling 2X speed overwrite at 7.36 m/s of linear velocity that corresponds to 72Mbps of the recording data rate.

Figure 3 shows the experimental results revealing the relations between the film composition and the transition temperature, Tc, from rhombohedral to NaCl structure. As shown in the figure, GeTe-rich compositions in the GeTe-Sb_2Te_3 tie line has a little bit distorted NaCl and change to cubic NaCl structure like GeTe above Tc[4].

2.3 New dielectric film with high refractive index

In the case of L1, the film stack is designed to have at once a high optical transmittance as high as 50% and at least 5 % reflectivity, with keeping a large reflectivity contrast, C_R, defined by the following equation of $C_R=(R_{cry}-R_{amo})/(R_{cry}+R_{amo})$, where R denotes the reflectivity. In the case of L2, the film stack is designed to have a further high transmittance of near 60% though the reflectivity is rather lower, around 2%.

The second essential point enabling 100 GB capacity is adoption of the high refractive index dielectric material for the top film on these L1 and L2 stacks. We have previously reported that TiO_2 (n=2.65) that is formed on the Ag-alloy film successfully worked to enhance the transmittance and to increase reflectivity contrast [5]. In the present triple layer disk, we adopted new composition film based on TiO_2 having a larger refractive index (n=2.75) as compared with TiO_2 and at once superior high transparency at λ=405 nm.

The effect of the above mentioned top film is apparent in the Fig. 4. This figure shows the optical calculation results revealing the relationship between the transmittance of L2 and the thickness of the dielectric film formed on the Ag-alloy film. As can be seen in the figure, transmittance first increases with the top layer thickness, takes a maximal at around λ/(8n), where n and λ denotes the values of refractive index and wavelength, respectively, and turns to decrease.

The obtained maximum transmittance becomes 1.5 % larger for the new TiO_2 based film as compared with for the conventional TiO_2. To put it reversely, these results mean that it is possible to increase the thickness of phase-change film with keeping the equivalent transmittance by adoption of the new dielectric film of n=2.75. In the present triple layer optical disk, 1 nm thicker GeSbTe film could be adopted by utilizing the new TiO_2-based dielectric film for both of L1 and L2.

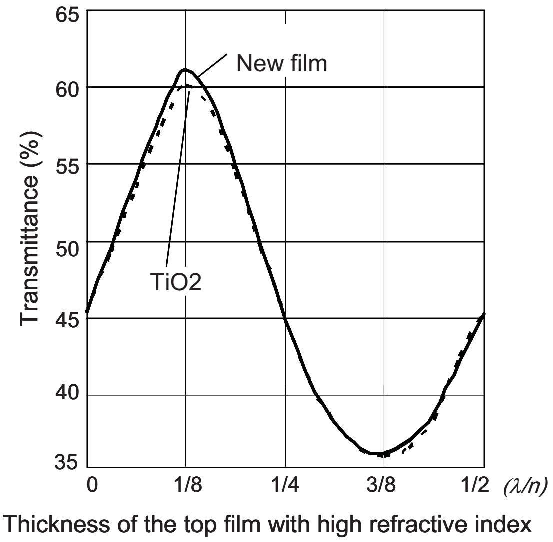

Fig.4 Relations between the transmittance of L2 stack and the thickness of the top dielectric film with high refractive index

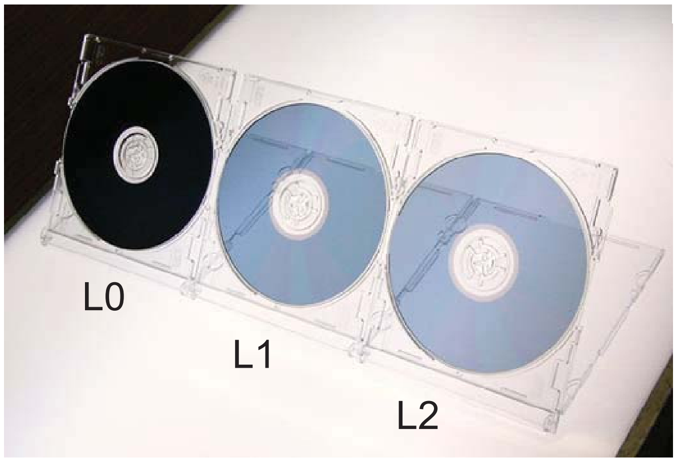

Fig.5 Aspects of L0, and half-transparent L1 and L2 that are made independently for the observation. The triple-layer sample disk was prepared by laminating these three layers.

3. RESULTS & DISCUSSIONS

3.1 Optical properties of the triple layer disk

The aspects of the layers, L0, L1 and L2 are shown in Fig.5. As can be seen in the figure, L0 is non transparent layer, while L1 and L2 are highly transparent though both of them are wholly pre-crystallized.

In table 1, the experimentally obtained optical properties of the triple layer sample disk are listed. It is seen that these results well coincide with the calculated values, for example, those shown in Fig. 4. The obtained transmittance is indeed around 50% (47-50) for L1 and further larger than 55% (58-60) for L2. It is also confirmed that quite large reflectivity contrast of more than 0.8 is achieved for every layer.

Table 1 Optical properties of each layer of the triple layer optical disk with 100 GB capacity

layer	(Rc-Ra)/(Rc+Ra)	Tc	Ta
L0	0.81	0	0
L1	0.86	47.3 %	49.8 %
L2	0.88	57.9 %	59.9 %

Here, it is very important that transmittance in the amorphous and crystalline parts are almost equivalent both for L1 and L2. It means that the transmittance of L1 and L2 is always and wholly constant between before and after recording. Thus, we can write a data on L0 (or L1) and to read out the written data on L0 (or L1) without significant distortion through L1 and L2 (or through L2). This effect was previously reported for the dual layer

Blu-ray Disc [6], and it was proved again that the "transmittance balanced structure" is possible for the rewritable triple-layer optical disk.

3.2 Dynamic properties of the triple layer disk

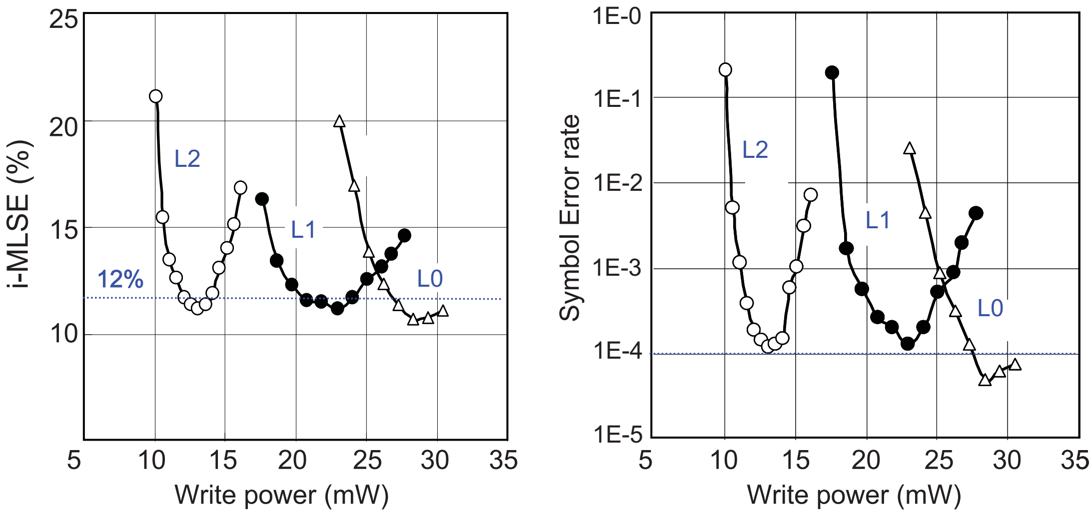

Fig.6 Dependences of i-MLSE (left) and Sybol Error Rate (right) on write power.

The triple-layer sample disk was evaluated using the conventional optical head for Blu-ray Disc (λ=405 nm, NA=0.85), though the minimum mark length of 2T was shortened to 112 nm. The recording linear velocity was 7.36m/s, and the data transfer rate was set to 72 Mbps. As the recording mark size is becoming small, it is getting difficult to evaluate the signal quality precisely using the previous index such as "jitter." In the present case, we used a new index called i-MLSE [7].

Very simply, i-MLSE is an evaluation index of recording signal quality utilizing a kind of signal processing method; i.e., i-MLSE is integrated deviation of reproduced signal waveforms from the ideal ones for a certain Euclidean distance. From the previously performed calculation, it is known that 12% of i-MLSE approximately corresponds to 1×10^{-4} of the symbol error rate (SER). As seen in the Fig. 6, good bottom i-MLSEs are observed for L0 (10.9%), L1 (11.2%) and L2 (11.2%).

The right hand side figure shows the experimentally obtained relation between the write power and SER. As expected from the right hand side figure, good SER about 1×10^{-4} or less are confirmed for each of L0, L1 and L2.

4. CONCLUSION

100 GB capacity /ϕ120 rewritable optical disk was first demonstrated with increasing of recording density (33.4 GB/layer) and stacking three recording layers. The key technologies were a very GeTe-rich GeSbTe film in the GeTe-Sb_2Te_3 system and a newly developed TiO_2-based dielectric film having a high refractive index of 2.75 at

405 nm wavelength. Every layer finely cleared the each criterion of i-MLSE value that corresponds to SER of $1x10^{-4}$. The developed triple layer optical disk will be very promising one as the next generation rewritable phase-change optical disk with 100 GB capacity.

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Biographies

Dr. Noboru Yamada is the general manager of the Digital & Network Development Centre at Panasonic Corporation. He has studied phase-change materials and their application to optical data storage since 1975. His principal achievements are discovery of GeSbTe phase-change materials in 1987, world-first products of DVD-RAM disk in 2000 and dual-layer Blu-ray Disc in 2004. His current research interests include multi-layer optical disk, near-field recording and nano-particle phase-change materials. Since 2005, he has been a co-chair of the EPCOS Program Committee.