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Development of phase change material for write once Blu-ray disc

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ABSTRACT

Phase change materials based on addition of ceramic material ($ZnS–SiO_2$) into antimony–indium–tin ($Sb_{100-x-y}Sn_xIn_y$) have been considered as possible candidates for high density optical data recording. Chemical compositions of the alloys have been optimized in order to develop a new high density Blu-ray Recordable Low to High optical data format. The evaluation of electrical parameters of resultant product shows that the jitter depends on the percentage of $ZnS–SiO_2$ and the chemical composition of the parent $Sb_{100-x-y}Sn_xIn_y$ phase change material.

1. Introduction

The proposed work relates to a method of developing a new phase change material for write-once optical recording medium that can support higher recording densities using a blue laser beam of wavelength 405 nm. Within write-once optical recording commonly known as Write Once Read Many times (WORM), many physical mechanisms have been developed. The most widely used mechanism on Compact Disc Recordable (CDR) and Digital Versatile Disc Recordable (DVDR) attributes the use of organic dye as the recording layer. A more desirable approach on Blu-ray disc recordable (BDR) technology is to use inorganic phase change materials that have so far been the very basis of all developments in DVD rewritable (DVD RW) technology because of their higher reliability, lower cost, better light resistance and longer life. It has been established [1] that by properly selecting the composition, the phase change materials can be made suitable for WORM application as well. In BDR discs, depending upon the composition of phase change materials, two types of recording conditions, namely Low to High (L2H) and High to Low (H2L) are possible. The L2H refers to transition of reflectivity from Low to High, whereas H2L refers to reflectivity transition from High to Low upon formation of the recording marks. As per the book specifications [2], the reflectivity range for L2H media is from 16% to 35% whereas that of H2L media is from 11% to 24%. For proper formation and detection of recording marks, it is necessary to have materials that can transform from amorphous phase to crystalline when exposed to laser pulse of suitable power and there should be sufficient difference in reflectivity between these two states. Materials that have been developed over the years for BDR application are Cu/Si [3,4], SbSnIn [5], InSb [5] and BiFeO [5]. A unique feature that distinguishes these alloys from the conventional phase change materials is their extremely high crystallization rate just below the melting point. Hence, it is practically impossible to reverse the material back into the amorphous state once crystallized. This makes these alloys suitable for WORM [1] application.

In $Sb_{100-x-y}Sn_xIn_y$ phase change alloys, it is reported [1] that the noise increases when the recorded crystalline marks becomes smaller. The mechanism for this increase in noise is not well understood but thought to be on account of availability of few crystalline grains and hence the lower density of nucleation sites. This low nucleation density perhaps is not an issue in low density recording, however, with increase in recording density, the probability of proper nucleation during the irradiation of laser pulse becomes lower as the marks become smaller. As a result of this, the non-uniformity in the size of recorded marks adversely affects the read back jitter. In the present work, we first developed BDR L2H using $Sb_{100-x-y}Sn_xIn_y$ phase change alloy in order to understand how this phenomenon manifests itself in high density data recording application.

It is also reported in the literature [1] that addition of Zn, S, Si and O_2 into the $Sb_{100-x-y}Sn_xIn_y$ alloys results in significant improvement in nucleation density and hence may overcome the problem of improper formation of smaller marks, 2T incase of BDR. In optical data storage, information is encoded in the length of the written marks. Therefore, to store data on a phase change disc, marks of certain lengths have to be formed in the recording layer. In the Blu-ray format, a specific data modulation scheme is prescribed

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that contains marks and intermediate spaces of length between 2T and 8T. The duration of these marks is specified with respect to clock frequency with basic time period $T = 15.15$ ns. Accordingly, the smallest mark, 2T, is of duration $2\times$ 15.15 ns = 30.3 ns and the largest one, 8T, is of 121.2 ns. As a comparison, the smallest mark size in DVDR is 99.75 ns. Antimony, tin and indium alloy when added with ceramics ZnS:SiO_2 (ZnS and SiO_2 at.% = 80:20) in a suitable amount significantly improves the smaller mark formation for low density formats like CDR [6] and DVDR [7]. It is expected that this challenge would increase manifold in case of BDR [2] wherein the mark sizes are far smaller.

In addition to the density of nucleation sites, the chemical composition of parent alloy also plays an important role in governing the size of the recorded marks [8]. Many workers [9,10] have reported that indium stabilizes the crystalline marks whereas tin increases the recording speed. Therefore, optimization of tin and indium concentration ratio in the alloy with a given density of nucleation sites is necessary in order to obtain marks with well-defined shapes and sizes, specially the smaller marks (2T). It is thus imperative to investigate this major technological challenge of forming smaller marks in order to realize proper recording density and speed.

In the present work, we made an attempt to replace the recording dye material by an inorganic alloy. $Sb_{100-x-y}Sn_xIn_y$ alloys were used as parent recording material along with addition of certain at.% of ZnS–SiO_2 to develop BDR L2H discs which show high speed recording performance and better sensitivity. It is also shown that the resultant BDR L2H discs exhibit improved corrosion resistance through the formation of stable marks and hence has a better archival life. The process and technology so developed could be commercially exploited to produce cheaper BDR L2H media.

2. Experimental details

Multi layer stack [11] of BDR was deposited on to a 1.1 mm grooved polycarbonate substrate using unaxis multi-chamber sputtering unit. Fig. 1 depicts the typical layer stack design. High purity targets of ZnS–SiO_2, different compositions of $Sb_{100-x-y}Sn_xIn_y$ (with and without the addition of ZnS–SiO_2) and silver were used for sputtering buffer layers, phase change layer and reflective layer, respectively. Argon was used as sputtering gas. The buffer layer 1 (BL1) between the phase change and the cover sheet protects the cover layer from thermal damages during writing operation and accordingly sputtered relatively thick. Buffer layer 2 (BL2) between the phase change and the metallic layer ensures retention of sufficient heat during the writing operation and its subsequent dissipation through metallic layer for proper mark formation. Silver metallic layer works as a heat sink medium apart from its reflectance characteristics. Thicknesses of BL1, BL2, phase change and silver layers were optimized to obtain considerably higher contrast between the crystalline and amorphous state of the phase change material for better electrical performance.

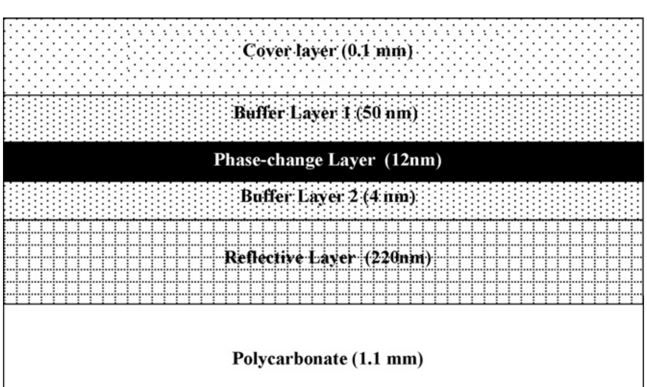

Fig. 1. Typical stack layer design (BDR L2H) [figure not to scale].

Table 1
Various compositions of phase change materials used for experimentations.

S. no.	Target	Composition $Sb_{100-x-y}Sn_xIn_y$	$ZnS–SiO_2$
1	Target 1	100%	0%
2	Target 2	70–73%	27–30%
3	Target 3	80–83%	17–20%
4	Target 4	90–93%	7–10%
5	Target 5	95–98%	2–5%

The reflectance of the sputtered discs at 405 nm, before bonding, was measured using ETA-RT (Model: Steag Eta-optik). A 100 μm thick polycarbonate film was bonded with sputtered disc with pressure sensitive adhesive using vacuum bonding equipment. The electrical parameters of finished BDR disc, namely Jitter & ISI pattern were evaluated on ODU (Model: Pulsetec, ODU 1000).

The 2T to 8T mark formation has been analyzed by Inter Symbol Interference (ISI) pattern measured through Time Interval Analyzer (TIA). It depicts the behavior of the mark with respect to the preceding space. The variation in the length of individual mark has to be minimum in order to get the least jitter value.

In the present work, we first used $Sb_{100-x-y}Sn_xIn_y$ alloy as the parent phase change recording material. Subsequently, ZnS–SiO_2 (ZnS and SiO_2 at.% = 80:20) was added to the alloy in different ratio. We experimented with various composition of "$Sb_{100-x-y}Sn_xIn_y$—ZnS:SiO_2" as the phase change layer to improve the mark formation during high density data recording in the BDR L2H media. These compositions are listed in Table 1.

Further, in order to improve mark formation and to bring down the jitter to meet book specifications [2], different chemical compositions of Target 5 with varying Sn/In ratio, as shown in Table 2, were tried.

3. Results and discussion

BDR has five times more storage capacity than a DVDR and hence, has smaller mark sizes. While this is an advantage for fast growth rewritable materials, it can be a serious drawback for write-once media. As the volume of material is heated for nucleation to take place, the formation of smaller marks becomes difficult due to reduction in available nucleation sites. Larger marks are formed due to the availability of more nuclei and smaller marks are difficult as there are only one or two nuclei. The choice of phase change material in high-sped recording is largely based on the ease of nucleation.

We observed that the mark formation in the recording material has been significantly hampered by arbitrary delays in BDR L2H developed with Target 1. The tremendous decrease in the density of 2T marks clearly suggests a lower density of nucleation sites in $Sb_{100-x-y}Sn_xIn_y$ alloy film as can be seen from Fig. 2(a). Hence, we established that $Sb_{100-x-y}Sn_xIn_y$ alloy as such cannot be used for designing media for high density recording. The problem seems to have been solved with the use of phase change material developed with addition of ceramic material into the basic write once $Sb_{100-x-y}Sn_xIn_y$ matrix. With the use of Target 2 as the sputtering material for phase change layer, we could get 2T mark formation as shown in Fig. 2(b).

Fig. 3 shows the ISI plot for Target 2. Blue dots in the picture show the mark length. If the spread of blue dots is more, it means mark length is varying a lot which results in high jitter values. Pink and yellow lines are just the pictorial representation of the mark formation in the TIA display. It is evident from this figure that 2T