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Short Note

Optical Switching Layer for Rewirtable Volumetric Optical Disks

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Owing to the presence of out-of-focus recording layers in volumetric optical disks, laser energy is decreased in reading/writing the targeted active layer. A non-linear optical material as an optical switch added to recording layers is proposed to modulate the optical characteristics of recording layers by diffraction limit laser spot impinged on it or not. The added optical switching structure can reduce laser energy and to increase recording sensitivity for reading and recording, respectively. Consequently, reading/recording on active layers of volumetric optical disks can be optimized. [DOI: 10.1143/JJAP.41.1683]

KEYWORDS: phase change, DVD, volumetric optical disk, dual layer optical disk, optical switching layer, thermo-chromatic material

The recording capacity of the phase-change optical disks has been increased by adopting high density recoding technologies, such as the mark-edge recording of using multiple laser-pulse trains and the land groove recording. However, to record more information or longer video, a significantly higher recording capacity is required. To realize a drastic increase of the recording capacity, a dual-layer recording method[1] aims to double the recording capacity by recording on two active layers from the same side of the disk. This method can realize dual layer digital versatile disk-random access memory (DVD-RAM) with 8.5 GB capacity on one side of optical disk using a conventional optical pick-up of lens $NA = 0.6$ and the laser wavelength of 650 nm.

The dual layer optical disk was comprised of data layers 1 and 2 of high transmittance (T) and high reflectance (R), respectively, where layer 1 is the first data layer impinged by laser beam and layer 2 is the second one. Therefore, low power absorption efficiency and lower reflected signal were obtained while writing and reading respectively on layer 1. In this paper, a thermo-control optical layer[1] attached to layer 1 is proposed to allow high absorption and high transmittance in layer 1 while laser beam focuses on layers 1 and 2, respectively.

The transmittance of layer 1 of a dual layer optical disk must be sufficiently large. Thus, a structure with no metallic reflector for the layer 1 of dual layer optical disk was adopted by Nagata *et al.*[2] A sample of 80 nm $ZnS–SiO_2$/15 nm GeTeSb/20 nm $ZnS–SiO_2$ disk structure for layer 1 met the condition mentioned above was selected and shown in Fig. 1(a),[3] whose reflectance/absorption/transmittance ($R/A/T$), calculated by thin film theory, are 10/45/45% and 21/57/22% in amorphous and crystalline states, respectively.

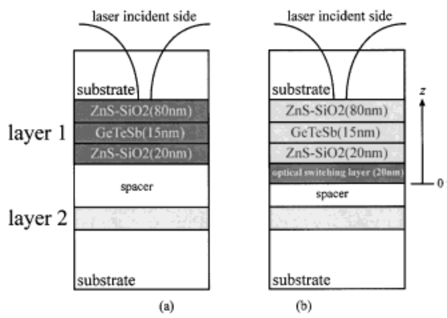

Fig. 1. Schematic of a dual layer optical disk with (a) no metallic reflector and (b) optical switching layer structure.

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Thermo-chromatic material[3] undergoes a remarkable thermally induced reversible semiconductor-to-metal phase transition, results in significant changes in its optical properties. Above the transition temperature (T_t), the material is metallic and highly reflective; below is dielectric, highly transparent and low absorption. For a dual layer optical disk, by attaching the material with layer 1, as shown in Fig. 1(b), so that layer 1 behaves as a thermo-induced optical switch. When the laser beam was focused on layer 1, the temperature of layer 1 was increased above T_t to be highly absorptive (i.e. optical switch is turn "on"), otherwise, highly transparent (i.e. optical switch was turn "off"). To examine optical switching effect, a dual layer optical disk with optical switching layer was modeled.

When laser beam was focused on layer 2 (optical switch is turn "off"), optical characteristics as a function of refractive index (n) of optical switching layer of 20 nm thick were calculated by thin film theory.[4] As illustrated in Fig. 2, the reflectance and transmittance increase with n in amorphous (amo) and crystalline (cry) state of layer 1. The disk with a switching layer of $n = 3.0$ thus was selected for quantitative analyses, whose $R/A/T$ are 16/28/56% and 26/43/31% in amorphous and crystalline states, respectively. When laser beam was impinged on layer 1 (optical switch was turn "on"), the optical switching layer was metallic, resulted in high extinction coefficient (k). $R/A/T$ as a function of k for an optical switching layer of $n = 3.0$ was selected and shown in Fig. 3. Absorption of layer 1 increases rapidly with k. $R/A/T$ were 3/70/27% and 17/71/12% in amorphous and crystalline states, respectively, when $k = 2$. The calculated results suggest that laser light can be modulated by the optical switching layer as k of thermo-chromatic material in "off" state is almost 0, and n, k in "on" state are larger than another state.

The state of the optical switching layer was controlled by

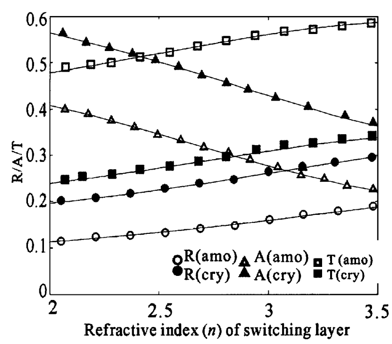
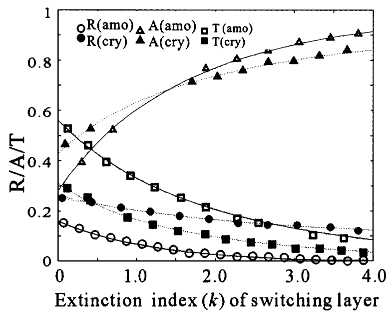
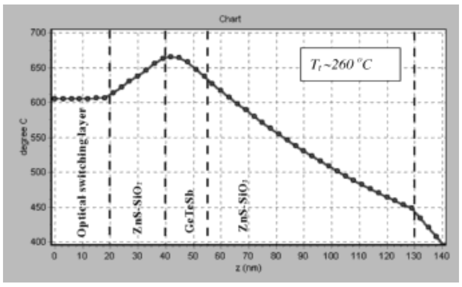


Fig. 2. $R/A/T$ of layer 1 as a function of refractive index (n) of switching layer, as optical switch is in "off" state.





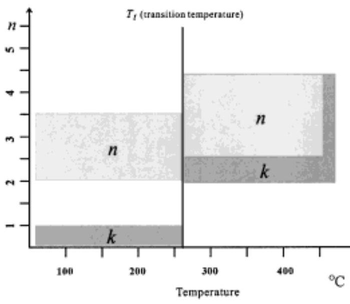


Fig. 3. $R/A/T$ of layer 1 as a function of extinction coefficient (k) of switching layer, as optical switch of layer of $n = 3.0$ is in "on" state.

Fig. 4. Numerical calculated temperature profile for cross section of layer 1 in the dual layer optical disk with optical switching layer, the temperature profile is depicted in the z direction (as shown in Fig. 1) form the bottom of layer 1.

Fig. 5. Estimated ranges of candidate material for optical switching film: $2 < n < 3.5$ and $k < 1$ as $T < T_t$; $2.5 < n < 4.5$ and $2 < k < 4.5$ as $T > T_t$.

temperature. To ensure that temperature was high enough to activate the optical switching layer, a Gaussian-distributed diffraction limited spot impinged normally on layer 1 of dual layer optical disk was then analyzed by thermal simulation program "Temprofile".[5)] To explore the maximum allowable transition temperature (T_t) of thermo-chromatic material for optical switching layer, temperature difference between an active layer and an optical switching layer during recording was calculated. The thermo-chromatic film (optical switching layer) was metallic as above the transition temperature, with chosen specific heat $C = 2$ (J/cm^3 °k) and thermo conductivity $K = 2$ (J/cm sec °k).[6)] Briefly, $n = 3$, $k = 2$ and $C = 2$, $K = 2$ were adopted to calculate the temperature profile of cross section in layer 1 of dual layer optical disk. As illustrated in Fig. 4, temperature on the optical switching layer could be raised over transition temperature (T_t) during recording. These calculated results reveal that optical switching layer could change optical characteristics of layer 1. Consequently, a thermo-chromatic material of low transition temperature and high thermo conductivity is applicable for an optical switching layer in dual layer optical disk.

Compared $R/A/T$ of layer 1 with those of a conventional dual layer optical disk, the simulated results reveal that layer 1 with an additional optical switching layer results in:

For recording on both layers: increase absorption of layer 1 by 30% when laser beam focuses on it. Hence, peak power to record on layer 1 can be reduced. Besides, transmittance of layer 1 is increased by 10% as laser beam focuses on layer 2. Thus the reflectance of layer 2 can be increased and peak power to record on layer 2 can be reduced.

For reading on layer 1: increase the contrast, defined as $(R_{top} - R_{bottom})/2(R_{top} + R_{bottom})$, of reflected beam from layer 1 by 20%, where R_{top} and R_{bottom} are the reflectance in crystalline and amorphous states, respectively.

The sharp temperature dependence of optical constants (n and k) of optical switching film in layer 1 at transition temperature results in similar change of $R/A/T$ in layer 1. Besides the sharp temperature dependence of optical constants, appropriate n, k value applicable for optical switching film is another essential criterion. According to the results shown in Figs. 2 and 3 for a thermo-chromatic film, $k < 1$ and $n > 2$ are needed to achieve high transmittance (∼50% at amorphous state) for accessing layer 2; and $2 < k < 4.5$, $n > 2.5$ to achieve adequate reflectance (∼5% at amorphous state) and high absorption for accessing layer 1. By taking temperature dependence into account, the range of n and k is further derived and shown in Fig. 5 where the candidate materials possess $k < 1$ at temperature below T_t, and n and k increase sharply above T_t, respectively. Many potential candidates meet these requirements exhibiting semiconductor to metallic phase transitions include:[7)]

- Vanadium oxides (VO_2).
- Superionic conductors: silver sulphide (Ag_2S) and silver selenide (Ag_2Se) and their alloys.

Moreover, candidates of optical switching layer do not limit to thermo-chromatic materials, organic materials[7)] and others, for example, whose temperature-dependence exhibit properties as illustrated is Fig. 5, are possible candidates as optical switching films.

The dual layer optical disk with optical switching layer was modeled and the following was obtained. Adding a thin thermo-induced semiconductor-to-metal phase transition optical switching layer to layer 1 results in increase of the absorption and transmittance by 10 and 30% when laser beam focuses on layer 1 and 2 of a dual layer optical disk, respectively. The study reveals that the efficiency of laser power for recording by adding an optical switching layer can be easily optimized. Moreover, the contrast of reflected signal is increased by 20%. The optical switching layer is being fabricated on a dual layer optical disk to evaluate its recording performance.

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