The Effect of Boundary Thermal Resistance on HD DVD-ARW Optical Recording Media

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ABSTRACT

Thermal conductivities and boundary thermal resistances of thin films having the thickness of the order of ten nanometers were measured by using the thermo-reflectance method at room temperature. A thermal simulation of HD DVD-ARW (the next-generation advanced rewritable DVD) media was carried out to clarify the effect of boundary thermal resistance at the interface of those films. The thermal conductivity of thin films greatly depends on film thickness. The result of the thermal simulation depends significantly on whether the boundary thermal resistance is considered or not. Thus it is important to consider the boundary thermal resistances and using thermal properties of thin films to perform more accurate calculation for the phase change recording media. The results of the thermal simulation also suggested that the boundary thermal resistances dominate the thermal diffusion and response of the medium.

Keywords: boundary thermal resistance, thermal conductivity, thermal diffusivity, thermo-reflectance method, thermal simulation, HD DVD-ARW

1. INTRODUCTION

In the phase-change recording media, information is recorded and erased by heating and cooling very small area using laser irradiation. For the most up-to-date recording media, it is more and more important to understand and to control the heat flow properly in order to maximize the recording density for a given laser spot size. The design of the media based on thermal simulation technology[1] is useful because the simulation gives us insights of the heat flow within very short time range as well as within very small area. However, thermal properties of such thin films having the thickness of several tens of nanometers as used for optical recording media cannot be measured by conventional methods.

One of the examples of such media is HD DVD-ARW, which utilizes a laser with the wavelength of 405 nm, an objective lens with the numerical aperture (NA) of 0.65, and a 0.6 mm-thick substrate formatted to record both on land and in groove. The main features of HD DVD are easier compatibility with the current DVDs and CDs, better mass-productivity, and usability of cartridge-free discs.[2] Figure 1 shows a structure of thin film stack of HD DVD-ARW medium. The media consists of ZnS-SiO_2, SiO_2, AlN, GeSbTeBi and Ag alloy films on a polycarbonate substrate. The user data capacity of as high as 20 GB has been demonstrated with this structure.[2] The disc has the track pitch of 0.34 μm, which is small compared to the beam spot size ($1/e^2$ diameter = 0.55 μm). Therefore it is important to minimize the deterioration of the recorded marks upon writing new records on adjacent tracks (cross-erase).

In this paper, we describe the first attempt to measure thermal conductivities and boundary thermal resistances of such thin films having the thickness of the order of ten nanometers by the pico-second thermo-reflectance method. Both the thermal conductivity and the boundary thermal resistance are measured. The results are used for the thermal simulation and the importance of the measurement technique is discussed.

2. EXPERIMENT

Figures 2 and 3 show the block diagrams and the schematic sketch of the pico-second thermo-reflectance measurement system.[3, 4] The system is based on the pump-probe configuration. A titanium (Ti) sapphire "pump" laser beam pulse is incident on the specimen to heat the backside of the film on a glass substrate, while another Ti sapphire laser beam pulse is incident as a "probe" beam to measure the surface temperature. Both beams have the wavelength of

776 nm and the pulse width of 2 picoseconds, varying the phase difference between the two beams. The measurement utilizes the thermo-reflectance effect, *i.e.*, the reflectance of sample surface depends on the temperature. The temperature as a function of time is obtained as a curve which we call the temperature history curve. Thus the thermal diffusion perpendicular to the film plane is measured. Table 1 summarizes experimental conditions used in the measurement. The power density of the pump beam on the sample is much weaker than that of the writing/erasing beams during recording in order to avoid unnecessary temperature rise of the specimen.

In this study, thermal properties of GeSbTeBi (GSTB) and ZnS-SiO_2 (ZS) films are examined. In order to complete the measurement, we took three steps as follows:

(i) 1-layer sample measurement:
Using the sample structure of Fig. 4 (a), the thermal diffusivity α of single layer molybdenum (Mo) with 70 nm-thick is measured. Mo is used as the reflective film of the specimen for the following two steps. $\alpha = \lambda/\rho/C_p$, where λ is the thermal conductivity [W/m/K], ρ is the density [g/m^3] and C_p [J/g/K] is the specific heat.

(ii) 3-layer sample measurement:
Either GSTB or ZS with various thicknesses sandwiched by two 70 nm-thick Mo films are measured in order to analyze α of each individual film as a function of film thickness and the boundary thermal resistance (R_B) between GSTB and Mo or ZS and Mo film.

(iii) 4-layer sample measurement:
Both GSTB and ZS films are sandwiched by 70 nm-thick Mo films and R_B between GSTB and ZS films is measured.

Mo films are chosen as the reflective film to obtain sufficient thermo-reflectance effect and good stability. In step (ii), two samples having different but similar thicknesses are used to derive α and R_B between the individual film and Mo film simultaneously, because single measurement yields one equation that includes two independent unknown variables. On the other hand, only one sample is necessary in step (iii). In each step, α and R_B are determined by analyzing temperature history curve using the method published elsewhere.[5] The specific heat (C_p) and the density (ρ) values of bulk materials are used for the derivation of thermal conductivity (λ).

3. CONDITIONS OF THERMAL SIMULATION

The thermal response and temperature distribution of a phase-change medium was simulated using thermal properties obtained by the technique shown above. The thermal simulation is based on the finite volume method. In the simulation, a Gaussian intensity distribution of the laser spot is assumed. The linear velocity of 5.6 m/s and the initial and boundary temperatures of 300 K are assumed. Laser powers are chosen so that the temperature at the beam center in the recording film becomes 1000 °C by a preliminary steady-state simulation assuming continuous laser beam application. This assumption gives a reasonable mark size for write operation for all cases. The write laser beam runs on the land track in this study.

4. RESULTS AND DISCUSSIONS

4.1. THERMAL PROPERTIES OF THIN FILMS

Figures 5 (a) and (b) show the normalized thermo-reflectance signal, *i.e.*, temperature history curves for 3-layer samples, which consist of a GSTB or a ZS film sandwiched by two Mo films. It requires only less than 13 nanoseconds for the heat generated by a 2-picosecond pulse to diffuse across the thin film stack. The differences caused by the thickness difference by a few tens of nanometers are clearly shown. The response is slower for thicker films. This demonstrates the sensitivity of the measurement method. Similar curves are obtained for a single-layer Mo film and Mo/GSTB/ZS/Mo 4-layer samples as well. These curves are analyzed to calculate α of each film and R_B between the ZS and Mo, GSTB and Mo and ZS and GSTB films.

Figure 6 shows α as a function of film thickness (d) for GSTB and ZS films. α of GSTB monotonically increases with increasing film thickness. The same tendency has been reported for aluminum film.[6] On the other hand, α of ZS showed only weak dependence on the thickness. Figure 7 shows R_B between GSTB and Mo and ZS and Mo films. It is reasonable that R_B between those films is independent of film thickness, implying that the atomic structure at the interfaces is similar regardless of the thickness as long as the same materials are used. R_B between GSTB and ZS films was measured to be 4.1×10^{-8} m^2K/W. This value is larger than the R_B between Mo and GSTB or Mo and ZS films. The thermo-reflectance method detects sensitively R_B between films having the thickness of the order of ten nanometers.

4.2. THERMAL SIMULATION OF RECORDING MEDIA

The thermal response of a phase-change recording medium was simulated using thermal properties obtained by the technique shown above. The simulation was done for two cases. In the first case R_B was considered, and the other case did not consider the effect of R_B, as is shown in figures 8 (a) and (b), respectively. The moving direction of the medium is perpendicular to the text plane. For this simulation, a short single write pulse of 9.3 ns which corresponds to the shortest (2T) mark of HD DVD-ARW is applied. The spatial temperature distribution at the instant the write pulse turns off is shown in the figure. At this time, the recording film at the center of irradiated laser reaches the highest temperature. It is clear that the thermal diffusion perpendicular to the film plane is suppressed whereas the lateral thermal diffusion is enhanced when considering R_B. This implies that the cross-erase, which is caused partly by undesired heat diffusion toward the neighboring track, may be more accurately simulated considering R_B.

In order to demonstrate the effect of R_B for cross-erase, the temperature evolution at the edge of the next track when a multi-pulse is applied to create a longer (8T) mark is calculated. The result is shown in the Fig. 9. If R_B is not considered, the maximum temperature is lower than when R_B is considered by more than 50 °C. For commonly used phase-change recording films, crystallization starts at around 170 °C. The difference of 50 °C around this temperature range may cause significant difference in the crystallization behavior. Thus, this result suggests that, for an accurate characterization of the cross-erase, which is one of the most critical issues when achieving higher densities, it is desired to use more realistic conditions, *i.e.*, the inclusion of the boundary thermal resistance.

5. CONCLUSIONS

Thermal conductivities and boundary thermal resistances of thin films of the order of ten nanometers have been measured by using the pico-second thermo-reflectance method. The measured films include GeSbTeBi and ZnS-SiO_2 which are used for HD DVD-ARW optical recording media. The thermal conductivity of GeSbTeBi thin films greatly depended on the film thickness. A thermal simulation was carried out to show the effect of boundary thermal resistance. The result depended significantly on whether the boundary thermal resistance is considered or not, especially for the temperature response at the track edge of the neighboring track. This suggests that the importance of the boundary thermal resistance to predict the cross-erase, which is critical issue for a high-density media.

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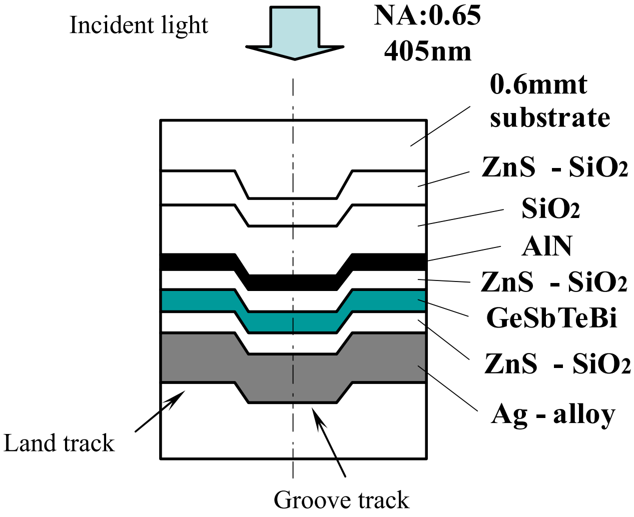

Figure 1. Film structure of rewritable HD DVD medium (HD DVD-ARW) used in this study.

Table 1. Experimental conditions of the thermo-reflectance method.

Laser	Two Ti / Sapphire Lasers
Wavelength	776 nm
Pulse Width	2 psec
Repetition Frequency	76 MHz
Pulse Energy of Pump Beam	0.67 nJ / pulse
Pump light (rear surface)	100 μm-diameter
Probe light (front surface)	50 μm-diameter
Temperature	Room temperature

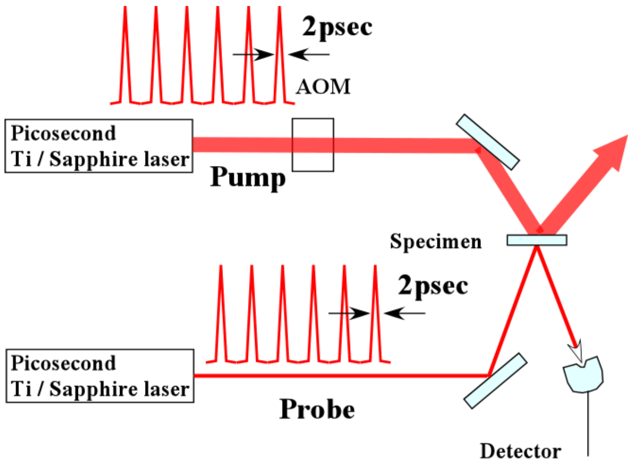

Figure 2. Block diagram of the pico-second thermo-reflectance measurement system. AOM stands for acoustic optic modulator.

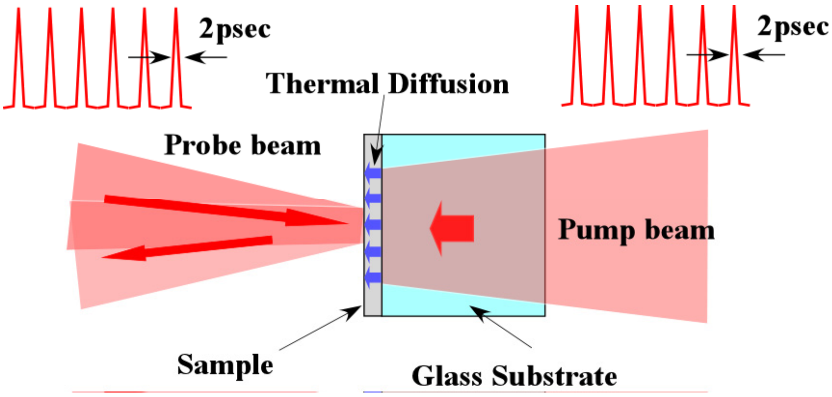

Figure 3. Schematic sketch of the thermo-reflectance measurement.

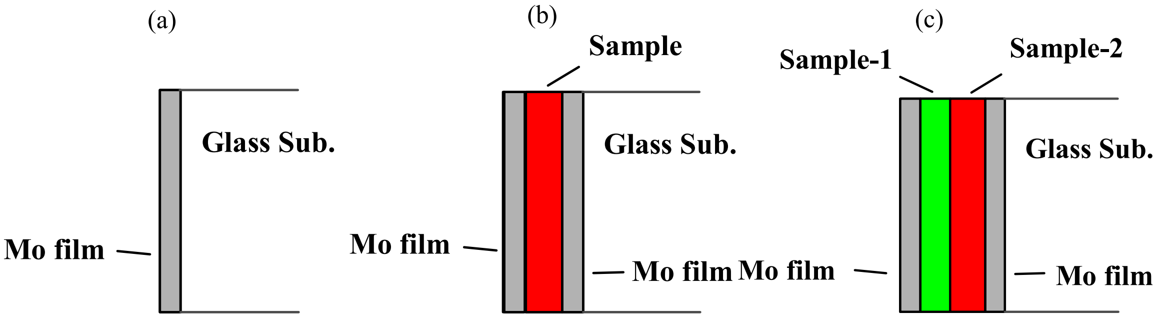

Figure 4. Sample structures for the thermo-reflectance measurement. **(a)** single-layer Mo, **(b)** a ZS or GSTB film sandwiched by two Mo films, and **(c)** Mo/ZS/GSTB/Mo films.

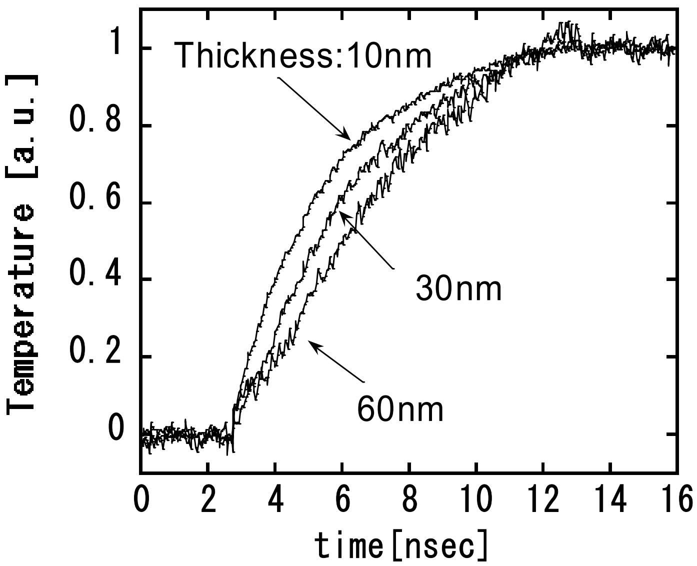

Figure 5-(a). Temperature history curves of three-layer samples of Mo/GeSbTeBi/Mo thin films for three different GeSbTeBi film thicknesses.

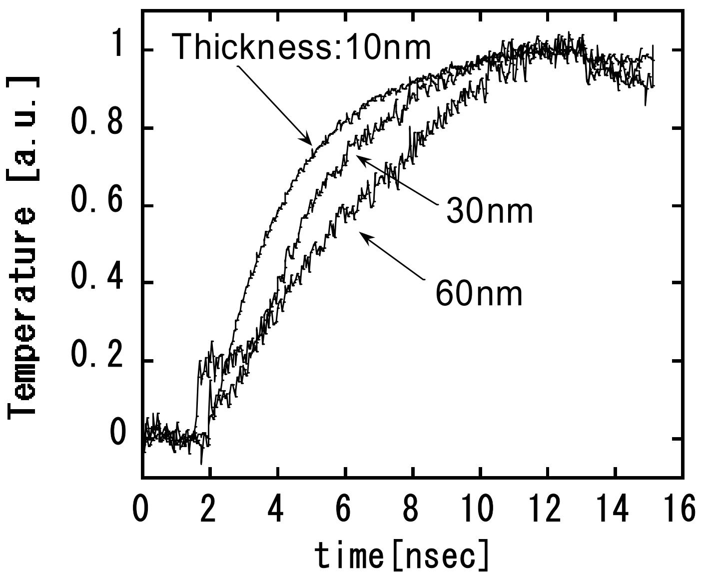

Figure 5-(b). Temperature history curves of three-layer samples of Mo/ZnS-SiO_2/Mo thin films.

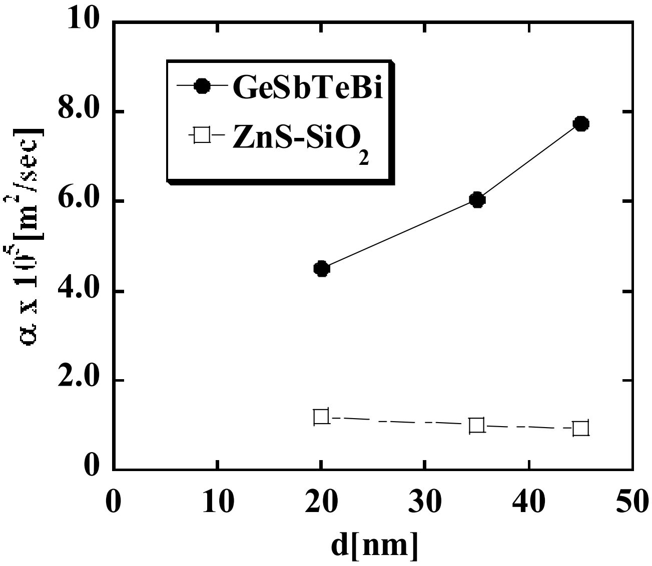

Figure 6. Thermal diffusivity of GeSbTeBi and $ZnS\text{-}SiO_2$ films as a function of film thickness.

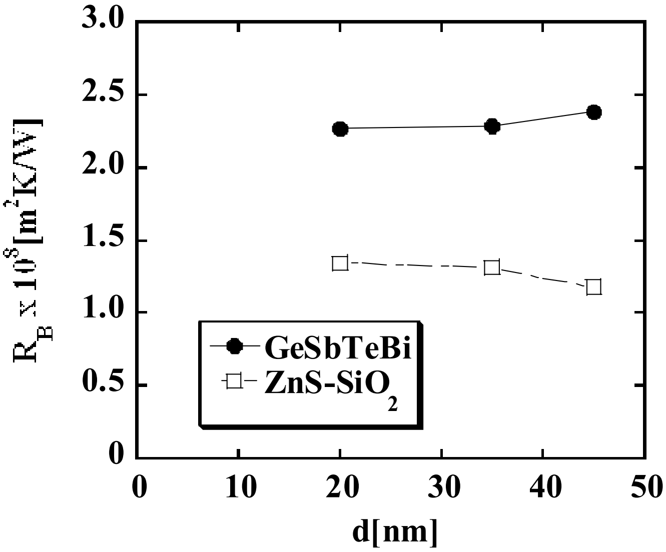

Figure 7. Boundary thermal resistance between GeSbTeBi and Mo films and $ZnS\text{-}SiO_2$ and Mo films.

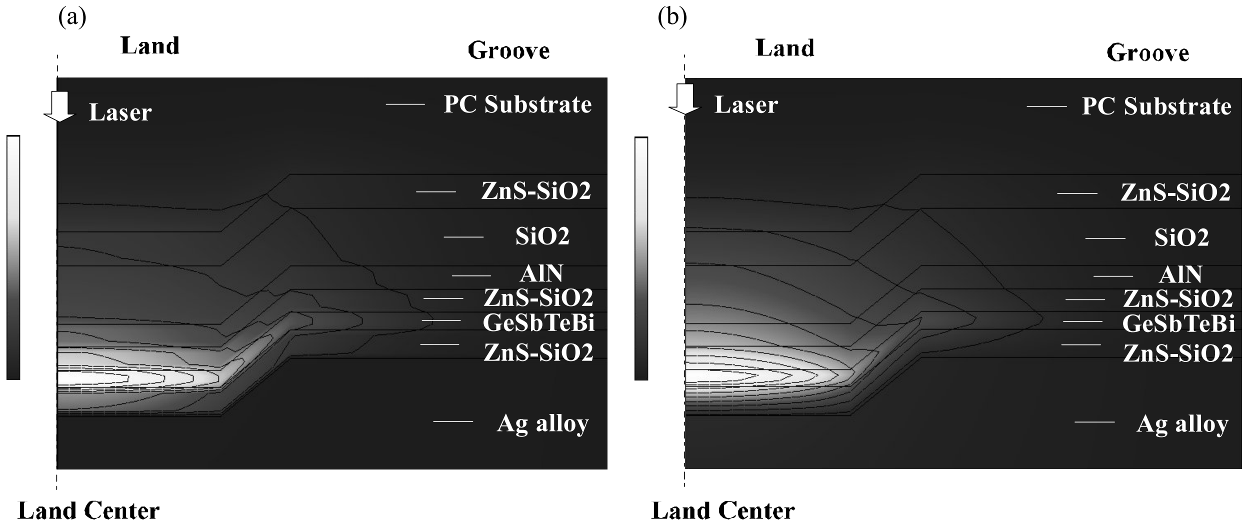

Figure 8. Temperature distribution in the medium. **(a)** considering R_B, **(b)** without considering $R_{B.}$

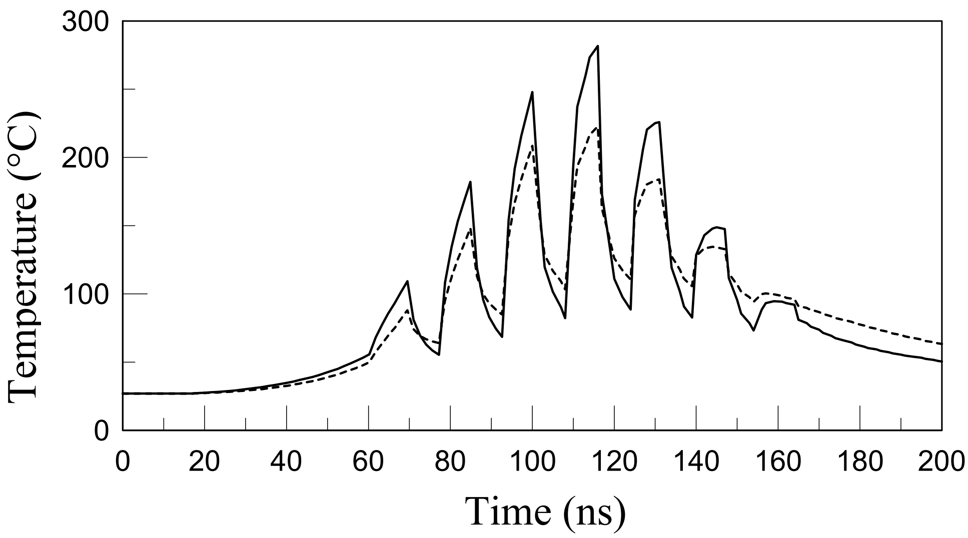

Figure 9. Temperature evolution during multi-pulse application on the neighboring track. Solid line: R_B considered, dotted line: without R_B..