Application of Simulation on the Design of Phase-Change Optical Recording Disks

Lih-Hsin Chou, Chun-Ping Jen, and Ching-Chang Chieng
National Tsing Hua University, Taiwan

Abstract — Optical absorption and thermal conduction are the two key factors affecting temperature distribution and, subsequently, the write, erase characteristics of a phase-change optical recording disk. Therefore, by using carefully measured film physical properties of each layer, this work simulates a transient temperature profile while simultaneously considering optical absorption and thermal conduction. Through the simulated transient temperature profile, cooling-rate and reflectivity, dependence of phase-changed spot size on the laser power and laser pulse duration was observed. The proper combination of the disk structure and the associated write, erase conditions are obtained as well. A disk structure can subsequently be designed on the basis of this information. In addition, a novel dielectric layer, i.e. hydrogenated amorphous carbon (α-C:H), is simulated and compared with the disk applying conventionally used ZnS-SiO₂ dielectric layers. The disk structures used herein are PC/ZnS-SiO₂/GeSbTe/ZnS-SiO₂/Al and PC/α-C:H/GeSbTe/α-C:H/Al. According to those results, α-C:H film is highly promising as a dielectric layer of the phase change optical recording disk for both wavelengths of 780 and 660 nm.

I. INTRODUCTION

The erasable optical recording disks can generally be classified as phase-change and magneto-optical types. The phase-change optical recording disks (PCORD) use a small-sized laser beam to heat a local area. A local heated area can cause a transformation between amorphous and crystalline phases (in which the optical information “1” and “0” can be stored) by properly selecting the laser pulse height and duration. A multilayered structure must therefore be designed to optimally use the applied laser power to heat the local area with a desirable phase-changed spot size, while still maintaining a reasonable amount of reflected light for both amorphous and crystalline spots as well as a certain reflected light contrast between amorphous and crystalline spots. In addition, the disk structure design requires the local transient temperature profile during laser heating. However, measuring the transient temperature is quite difficult owing to the small spot size (≤ 1µm) and a short heating period (≤ 0.1 µs). Consequently, optical absorption and thermal conduction must be simulated for disk structure design.

Heat mode optical recording disks have received increasing attention [1]-[6]. Earlier work [1], [2] applied Lambert-Beer’s law to calculate the heat absorbed by the recording layer which neglected the effect of multiple reflections and used physical properties of bulk materials. More recent works [3], [4] considered multiple reflections and extended the simulation to three-dimensions [5]. Koyanagi et al. [3] compared the simulated work with experimental results, estimating the thermal conductivity of the thin-film recording media to be 50% lower than that of the bulk.

In this work, carefully measured film physical properties, which were essential in the simulation, such as index of refraction, thermal conductivity, heat capacity, latent of heat as well as each layer’s film density, were used for the simulation. Considering multiple reflections, both optical absorption and thermal conduction are calculated to simulate the transient temperature profile of the local area under pulsed laser irradiation. According to the simulated transient temperature profile, cooling rate and reflectivity, dependence of the phase-changed spot size on the laser power and pulse duration was observed. In addition, the multilayered disk structure and the associated write, erase conditions were obtained. Moreover, a novel dielectric material, i.e. α-C:H, is examined as a protective layer using the previous method; it is also compared with results obtained by applying the conventionally used ZnS-SiO₂ protective layer.

II. THEORETICAL MODEL

Transient thermal conduction problem can be simulated by solving the general time-dependent energy equation, which can be expressed as

\[ \rho C_p \frac{\partial T}{\partial t} = k \nabla^2 T + Q \]

where \( \rho \) denotes the density, \( C_p \) represents the specific heat, and \( k \) is the material’s thermal conductivity. The heat source term \( Q \) is not only time-dependent, but also a function of position. Herein, the heat source attributed to energy absorption of laser beam in the films is calculated by considering multiple reflections. The intensity of incident laser beam is described by the Gaussian distribution

\[ I = I_0 \exp\left(-\frac{r^2}{r_0^2}\right) \]

where \( r_0 \) denotes the Gaussian radius of the incident beam. The two-dimensional finite difference method is employed to discretize the transient energy equation.

III. SIMULATION

Optical absorption and thermal conduction are the two key factors affecting temperature distribution and subsequently, the write, erase characteristics of a PCORD.
To ensure optimal use of the laser beam, the top and bottom dielectric layers are chosen to be transparent at the laser beam's wavelength. Incorporated with the total reflectance characteristics of the Al metal layer, the irradiated laser is either reflected or absorbed by the recording layer. Therefore, the more absorbed the light implies a less reflected light. It is highly desired to have a perceptible amount of reflected light for the crystalline phase and a large reflectivity contrast $[\Delta R/\text{Re} = (\text{Ra}-\text{Re})/\text{Re}]$, where Ra and Re denote reflectivities for amorphous and crystalline phases, respectively) for signal detection. Therefore, in this work, the disk structures are designed to compromise between reflectivity and optical absorption.

Table I lists each layer's physical parameters. This table reveals that the $\alpha$-C:H films used herein possess markedly different physical properties than ZnS-SiO$_2$ films. The extinction coefficients of $\alpha$-C:H at both 660 nm and 780 nm are non-zero, but are sufficiently low, only 0.08% - 0.26% of those of the recording layer. Consequently, nearly all of the unreflected incident laser light is absorbed by the recording film.

Simulation results indicate that thermal conduction heavily influences the transient temperature distribution. Next, the following two disk structures are compared: $\text{PC}/\alpha$-$\text{C:H}(1590\text{ Å})/\text{GeSbTe}(200\text{ Å})/\alpha$-$\text{C:H}(360\text{ Å})/\text{Al}(350\text{ Å})$ and $\text{PC}/\alpha$-$\text{C:H}(1590\text{ Å})/\text{GeSbTe}(200\text{ Å})/\alpha$-$\text{C:H}(210\text{ Å})/\text{Al}(350\text{ Å})$, designated as structures A and B, respectively. The two structures only differ in the thicknesses of upper dielectric layers. The light absorbed by the lower dielectric layer of both structures A and B is calculated to be 3% of that absorbed by the recording layer. For the crystalline phase, the light intensity absorbed by structure B is 97.5% of that absorbed by structure A at 660 nm as shown in Table II. For work reported [6] and a general belief in this field, a thinner upper dielectric layer will give a rapid cooling structure since Al metal layer is a heat sink. Therefore, the lower light absorption of structure B accompanied with structure B's thinner upper dielectric layer imply that the local heated temperature of structure B should be low, i.e. less than 97.5% of that of structure A. However, the local highest temperature of structure B (543 K) is 98% of that of structure A (554 K), which is higher than expected. The cross sectional isotherms of the two disk structures A and B right after irradiation of a 5 mW, 50 ns laser pulse of 660 nm are shown in Fig. 1. This phenomenon is thought to be due to the differences of the physical characteristics between $\alpha$-C:H films and ZnS-SiO$_2$ films. The thermal diffusivity, denoted by $k/\rho C_p$, of the $\alpha$-C:H film (~0.0192 cm$^2$/sec) is about 6.4 times higher than that of the ZnS-SiO$_2$ film (~0.0026 cm$^2$/sec). This implies that $\alpha$-C:H film can conduct heat much faster than ZnS-SiO$_2$ film. Therefore, a thicker upper $\alpha$-C:H layer may enhance the thermal conduction to the top Al metal layer and result in a lower temperature rise in the recording layer.

![Fig. 1. The cross sectional isotherms of (A) disk structure A and (B) disk structure B right after irradiation of a 5 mW, 50 ns laser pulse of 660 nm. The isotherms are in units of °C.](image-url)
The laser beam radii are 0.350 μm and 0.496 μm for 660 nm and 780 nm, respectively. Due to the square dependence of the irradiation area on laser beam radius, the beam intensity of 660 nm is two times higher than that of 780 nm. For a 2-D static test, both the write and erase powers needed for 660 nm is lower than those for 780 nm. For disk structure B with a thicker (~700 Å) Al layer is designated as structure B'. The write and erase conditions for structure B' are listed in Table III. An increase in Al film thickness from 350 Å to 700 Å doesn't change the light reflectivity. The disks employed ZnS-SiO₂ dielectric layers are used for comparison which are with disk structures of PC/ZnS-SiO₂(150 Å)/GeSbTe(200 Å)/ZnS-SiO₂(210 Å)/Al(700 Å) and PC/ZnS-SiO₂(1440 Å)/GeSbTe(200 Å)/ZnS-SiO₂(210 Å)/Al(700 Å) and are designated as disk structures C and D, respectively. Disk structures C and D are used for calculation at 660 nm and 780 nm, respectively. The write and erase powers needed for disk structures C and D are shown in Table III. The write laser power and pulse duration were chosen for a phase-change spot size equal to the laser beam diameter. If a phase-changed spot size equal to FWHM of the laser beam is chosen as conventionally used, both the write and erase laser powers will be lower than those reported in this work. From the time dependent transient temperature T(t), the cooling rate as the difference quotient [T(t)-T(t₀)]/(t-t₀), where t-t₀= 1 ns, is obtained. The cooling rate at the edge of the written spot size exceeds 3 x 10⁷ °C/s. According to Table II, both the erase and write powers deemed necessary for disks with α-C:H dielectric layers are higher than those for disks with ZnS-SiO₂ dielectric layers. The lower reflectances of disk structure D shown in Table II is also attributed to the lower powers deemed necessary for writing and erasing compared with disk structure B' at 780 nm. Furthermore, a higher thermal conductivity and lower volume specific heat of α-C:H dielectric layers primarily account for the higher erase and write powers needed for disk structure B' than those for the structures employed ZnS-SiO₂ protective dielectric layers. Notably, the GeSbTe recording film used in this work has a crystallization temperature of 182 °C and two melting temperatures of 490 °C and 675 °C, respectively. The higher melting temperature of the recording film used in this work causes the write and erase powers to be higher than those reported [6].

The physical properties of α-C:H films can be varied widely by applying different deposition techniques as well as varying the deposition parameters. The α-C:H films reported herein are deposited by plasma enhanced chemical vapor deposition with a DC bias voltage of ~300V applied to the electrode, which held substrate. Although the erase and write powers used for structure B' exceed those for both structures C and D, we believe that carefully selecting the α-C:H film with proper physical properties ensures not only that a better disk structure can be designed, but also that the α-C:H film is highly promising as the protective layer in PCORD.

### IV. CONCLUSION

**REFERENCES**


### TABLE III

<table>
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<tr>
<th>Structure</th>
<th>Erase condition</th>
<th>Write condition</th>
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<th>Write condition</th>
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<td>23.5mW, 50ns</td>
<td>10.0mW, 50ns</td>
<td>33.0mW, 50ns</td>
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<tr>
<td>C</td>
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<td>16.0mW, 50ns</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>7.0mW, 50ns</td>
<td>23.3mW, 50ns</td>
<td>-</td>
</tr>
</tbody>
</table>

For the crystalline phase, the light intensity absorbed by structure B is 97.9% of that absorbed by structure A at 660 nm. In contrast to the general belief that a thinner upper dielectric layer will give a rapid cooling structure, the local highest temperature of structure B (543 K) is 98% of that of structure A (554 K), which is higher than expected. The 6.4 times higher thermal diffusivity of the α-C:H film than that of the ZnS-SiO₂ film account for the reason that a thicker upper α-C:H layer may enhance the thermal conduction to the top Al metal layer and result in a lower temperature rise in the recording layer. These results demonstrate that thermal conduction primarily influences the transient temperature distribution. Optical absorption has only a minor influence. Moreover, the disk with α-C:H films used as protective layers can write and erase at both 660 and 780 nm as shown in Table III.

**ACKNOWLEDGMENT**

The authors would like to thank the assistance of Mr. W. Hsu, Dr. T. R. Jeng, Dr. D. Y. Chiang and Dr. D. Huang for preparing the GeSbTe and ZnS-SiO₂ films, as well as Mr. W. Hsu for measuring the physical properties of the previous films. Mr. T. S. Wu is also appreciated for preparing and measuring the physical properties of α-C:H films.