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THE OPTICAL RECORDING AND THERMAL ANALYSIS OF COMPACT DISC-RECORDABLE

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Abstract – Recently various types of optical discs have been developed and used. Compact Disc Recordable (CD-R) is a disc where enormous amounts of digital data can be recorded and played in currently used CD player or CD-ROM drive. The reflection and absorption rate of the laser beam in the layers of CD-R were numerically calculated. The laser beam energy absorbed in the recording layer is converted to heat, and this is transferred to the neighboring layers. The transient temperature distributions in the layers on recording were obtained numerically using ANSYS software. The written spot in the recording layer was heated far above its decomposition temperature and part of the polycarbonate substrate was heated above its glass transition temperature. After optical recording, the image of the recorded area was obtained by using an atomic forces microscope (AFM). The recording mechanism of CD-R was discussed with these numerical calculations and experimental observations.

Key words: CD-R, Optical Disk, Transient Temperature Distribution, Recording Mechanism, ANSYS Software, AFM

INTRODUCTION

The fast development of so called information society accompanies enormous amounts of data in various types, and this requires the research and development of the proper way to store and distribute the information. The optical recording, which uses the intensity of the light for data storage and reproduction, have become the most popular way for this purpose due to its characteristics such as high density, fast accessibility, and high capacity with low price [Marchant, 1990; Mansuripur, 1995]. Since Compact Disc Digital Audio was developed by Phillips and Sony, various optical discs have been developed [Kim, 1996]. Now a single disc can store more than giga bytes of data such as simple texts, pictures, sounds, and moving pictures.

CD-R is a kind of blank optical disc where any data can be recorded in compact disc format, and after recording this disc can be played in CD-player or CD-ROM drive [Pahwa, 1994]. The disc consists of transparent polycarbonate substrate, organic dye recording layer, metallic reflective layer and polymer protecting layer. The reflection change induced by high power laser beam is detected by low power laser beam, and this is used for optical recording and reading in CD-R. In the previous paper [Kim et al., 1997] the optimal layer design of the disc and optical characteristics in the layers of CD-R were discussed. In this paper the recording mechanism of CD-R was studied.

The energy absorption rate in the layers of CD-R has been used to calculate total heat generation in the recording layer, and the transient temperature distributions due to the heat conduction was obtained by using a well known package, ANSYS, which uses finite element method for transient thermal analysis. The modeling for the heat generation and the following heat conduction will be described. A sample disc was prepared using polycarbonate disc and organic dyes. After optical recording, the shape deformation on the surface of the substrate and dye was observed using AFM. The recording mechanism of the CD-R was discussed based on the temperature profiles over the layers and the experimental observations.

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SAMPLE DISC PREPARATION AND OPTICAL RECORDING

The disc structure of CD-R and properties of organic dyes are well described in the previous paper [Kim et al., 1997]. Fig. 1 shows the general procedure for the preparation of CD-R. After laser beam recording on photoresist coated optical glass, developing, and nickel plating, a stamper is made. From this stamper, polycarbonate substrate which has a spiral groove is produced by injection molding. The spiral groove structure of the substrate which contains wobble signal is used for tracking and positioning for optical recording. After spin coating of organic dyes [Matsuoka, 1990] on the substrate, reflective layer which is usually gold is sputtered and on top of the reflective layer a resin is spin coated and cured by ultraviolet lamp. The sample discs were prepared using flat polycarbonate substrates for AFM observation.

The optical recording on the sample discs was done by using APEX OHMT5 optical disc evaluation system. The 780 nm diode laser is used as the recording and reading light source.

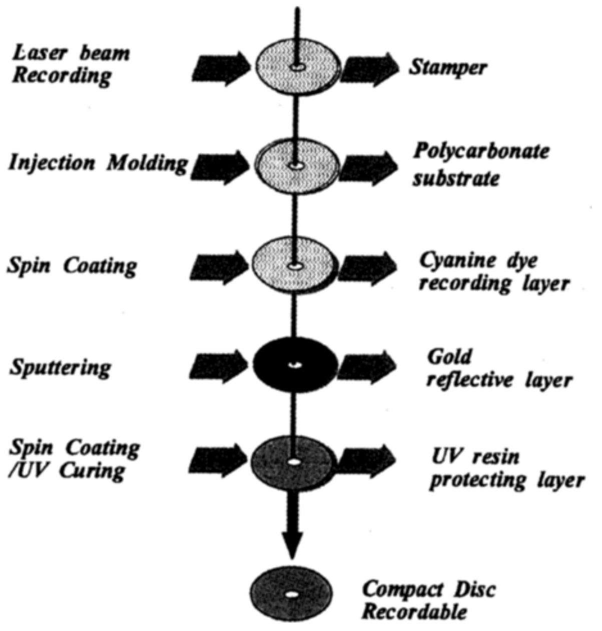

Fig. 1. The preparation of compact disc recordable.

The writing and reading power of the laser, focusing, tracking and disc spin speed are controlled through the control board with personal computer and signals can be recorded through the disc drive on the disc, and the recorded signals are analyzed by spectrum analyzer.

Fig. 2 shows the incident laser beam with Gaussian profile and the power variation of the laser beam during 3T recording for this experiment. In Compact Disc, 9 different length of pits (I_3 to I_{11}) are existed, and each I_n pit is recorded by applying (n−1)T write pulse. And during "3T recording", the laser is turned on for 2T and off for 4T. The laser is turned on for 2T which corresponds to 460 ns, and off for 4T. After optical recording, the reflective layer was peeled off by plastic tapes and the written spot was observed by AFM. The written spot of the polycarbonate was again observed after washing the organic dyes.

THERMAL ANALYSIS

The reflection and absorption rate of the laser beam were

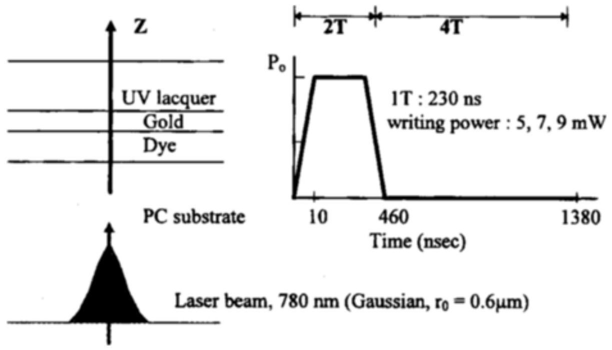

Fig. 2. The incident laser beam with Gaussian profile and power variation of the laser beam during 3T recording.

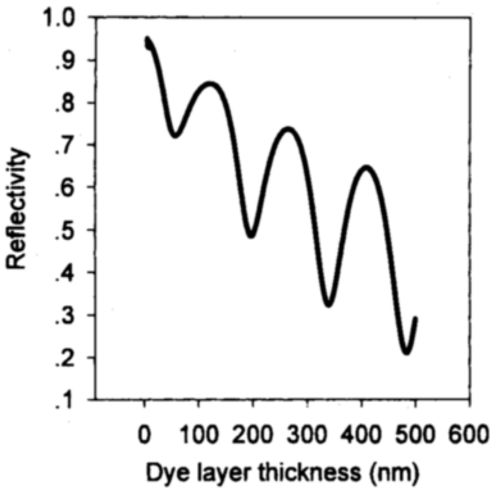

Fig. 3. The reflection of CD-R with the variation of dye layer thickness.

Table 1. The physical properties of the layers of CD-R

Layer	Refractive index	Thermal conductivity (W/mK)	Specific heat (J/kgK)	Density (kg/m^3)	Thickness
Substrate	1.57	0.2	1260	1200	1.2 nm
Dye	2.7+0.05i	0.2	1500	1500	240 nm
Gold	0.18+4.7i	31.5	129	19300	70 nm
UV lac.	1.5	0.2	1260	1200	500 nm

calculated based on the matrix method [Bell et al., 1978; Mansuripur, 1982] described in the previous paper [Kim et al., 1995, 1997]. Fig. 3 shows the reflection of CD-R with the variation of dye layer thickness. The reflection of the blank area of the disc should be over 70 % to compatible with compact disc drive. In the figure the recording layer thickness corresponding 70 % of reflection is 240 nm, so this thickness is used for thermal analysis. Table 1 shows the physical properties for thermal analysis.

The transient temperature distribution in the layers of CD-R was obtained by using a FEM package, ANSYS. For the laser beam induced optical recording, the governing heat equation can be expressed as follows.

$$\rho C_p \frac{\partial T}{\partial t} - \frac{1}{r}\frac{\partial}{\partial r}\left(Kr\frac{\partial T}{\partial r}\right) - \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right) = Q \qquad (1)$$

where T is the temperature, t is the time, C_p is the specific heat, K is the thermal conductivity of the layer, Q is the heat generation due to the energy absorption and r and z is the lateral and thickness direction, respectively.

Fig. 4 shows the geometry and boundary conditions used in the calculations and the followings were assumed. The laser beam has a wavelength of 780 nm with a Gaussian radial profile and an exp(−1) power radius of 0.6 μm. The laser was operated for a total time of 460 ns with initial and shut down ramp of 10 ns and the writing power of 7 mW. The laser beam energy absorbed in the recording layer is completely converted into heat energy and this induces temperature rise. The temperature distribution is axisymmetric and in-

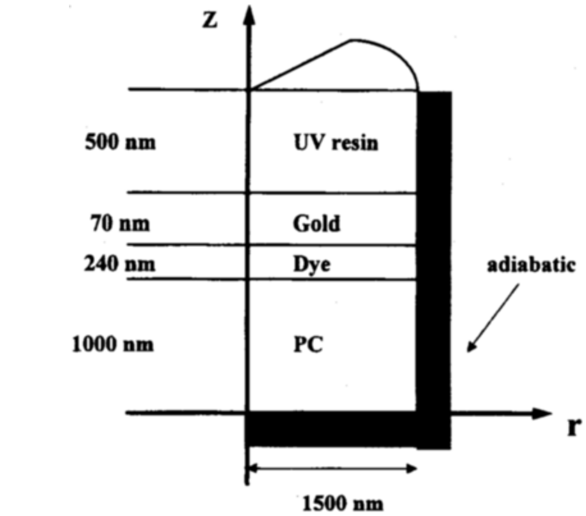

Fig. 4. The geometry and boundary condition used for thermal analysis of CD-R.

dependent of θ direction. As the boundaries are far away from the spot of laser beam absorption, it is assumed that no heat is transferred at the boundaries. The following boundary and initial conditions can be used in this case.

$$T(r, z, t=0) = T_\infty \quad (2)$$

$$\frac{\partial T}{\partial z}(r, z=0, t) = 0 \quad (3)$$

$$\frac{\partial T}{\partial z}(r=r_b, z, t) = 0 \quad (4)$$

$$K\frac{\partial T}{\partial z}(r, z=z_b, t) = h[T(z=z_b) - T_\infty \quad (5)$$

where T_∞ is the ambient temperature (25 °C), r_b is the radial distance from z-axis at the boundary and z_b is the distance from r-axis to the disc surface, and h is the convection heat transfer coefficient of air. Here h=12 W/m^{2}K was used assuming forced convection by air flow over a square plate [Holman, 1981]. The incident laser beam intensity distribution can be written as [Mansuripur et al., 1982]:

$$I(r, t) = [P_0(t)/(\pi r_o^2)]\exp[-(r/r_o)^2] \quad (6)$$

where r_o is the exp(−1) radius of the Gaussian beam and $P_0(t)$ is the instantaneous output power of the laser, and the total heat generation is:

$$Q(r, z, t) = 0.95 \times I(r, t) \times q(z) \quad (7)$$

where q(z) is the rate of energy absorption per unit volume in each layer [Kim et al., 1997]. 0.95 was multiplied to compensate for the energy loss by the reflection at the air-PC substrate interface.

Finite element grids were setup based on the above geometry, and material properties for each layers were defined. The heat generation calculated from above equations were used as the heat source for each elements. The average heat input for each elements were then calculated based on the above heat equations with initial and boundary conditions, and the temperature distributions in the layers were obtained at each time step. Latent heat effects were not included and calculations were done for total of 1380 ns. As the disc spins with 1.4 m/s of linear velocity, 60 % of input power were used in the calculation.

TEMPERATURE DISTRIBUTION AND RECORDING MECHANISM

Fig. 5 shows the temperature distributions in the layers at 20 ns and 450 ns. The laser energy absorbed in the dye layer is converted to heat, and this heat is transferred to PC layer and gold reflective layer. The figure shows that heat is transferred rapidly both in radial and lateral directions, and the temperatures in dye and PC are higher than that in gold layer. This is because gold is much more conductive than any other layers, so heat is quickly transferred in radial directions, and its temperature is relatively low even though its energy absorption rate is considerable. Fig. 6 shows the transient temperature profiles in dye recording layer in radial direction during and after recording. The figure shows that the temperature profile becomes Gaussian like incident laser beam profile during recording and the temperature at the center of laser beam spot in dye layer rises up to 330 °C, which is

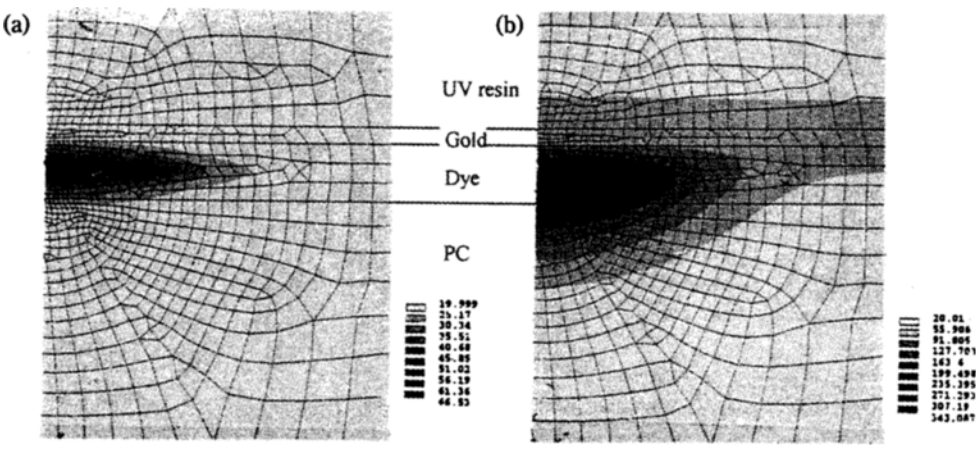

Fig. 5. The temperature distribution in the layers of CD-R at (a) 20 and (b) 450 ns of optical recording.

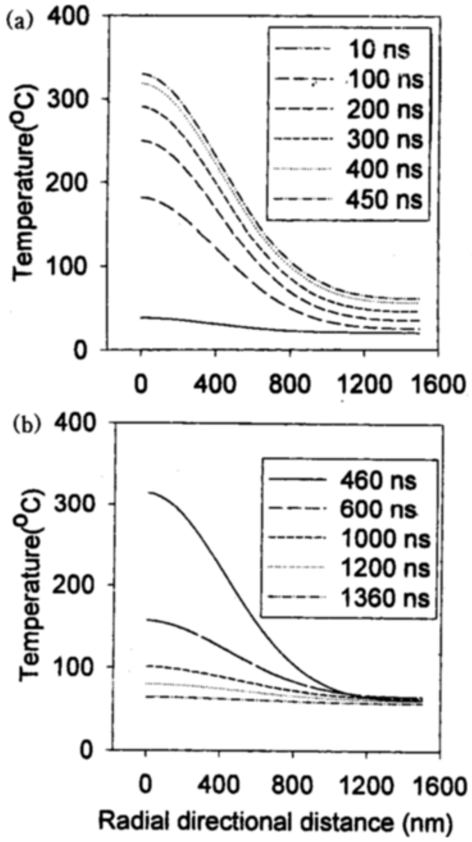

Fig. 6. The transient temperature profiles in dye recording layer in radial direction with (a) laser power on and (b) laser power off.

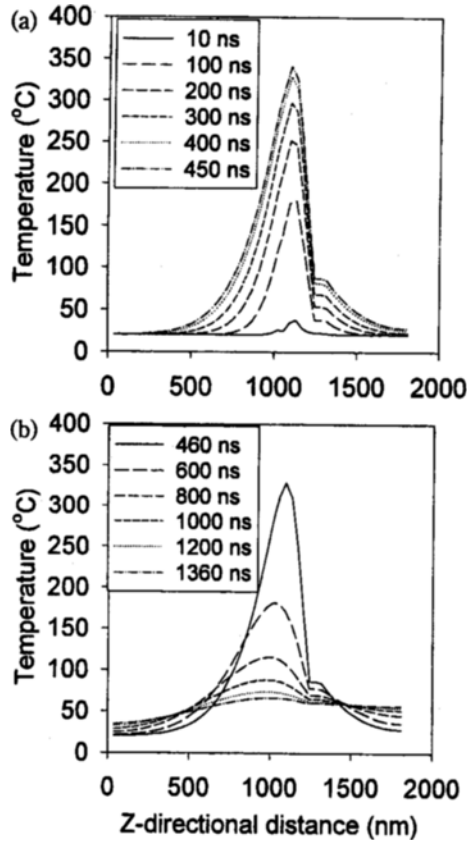

Fig. 7. The transient temperature profiles at the center of beam spot in z-direction with (a) laser power on and (b) laser power off. z=1000 represents the boundary between PC and dye layer.

far above the decomposition temperature (-240 °C) of dye. The figure also show that the temperature decreases very quickly when laser beam is off mainly due to the thermal conduction to other layers and heat convection by the spinning of the disc.

Fig. 7 shows the transient temperature profiles at the center of beam spot in z-direction. After 200 ns of laser beam irradiation, part of the PC substrate is heated above its glass transition temperature (-140 °C). The highest temperature can be observed at the center of dye layer and the temperature in gold layer is relatively uniform and low due to its high thermal conductivity. Fig. 8 shows the temperature variation in dye and PC layer at the center of written spot as a function of time. The figure also shows the melting and decomposition temperature of dye and glass transition temperature of polycarbonate. As the temperature of dye rises far above its decomposition temperature, partial decomposition of organic dye is involved in optical recording. The figure also shows that part of polycarbonate is heated above its glass transition temperature, which tells that the recording area in PC substrate would expand due to the heat energy transferred from dye layer.

Fig. 9 shows the AFM images of the written spot in dye layer and substrate. The figure shows that organic dye is decomposed to make a small hole, and the written spot of PC substrate was expanded, which are consistent with our theoretical results. It can be speculated that the decomposition of dye together with PC expansion induces the reflection change in the written spot of CD-R.

CONCLUSIONS

The temperature distributions in the layers of CD-R during optical recording were obtained by numerical calculation and

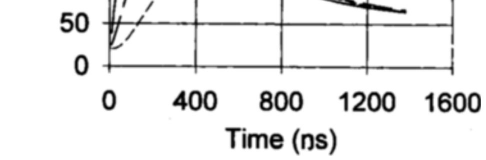

Fig. 8. The temperature variation in dye and PC layer at the center of written spot as a function of time.

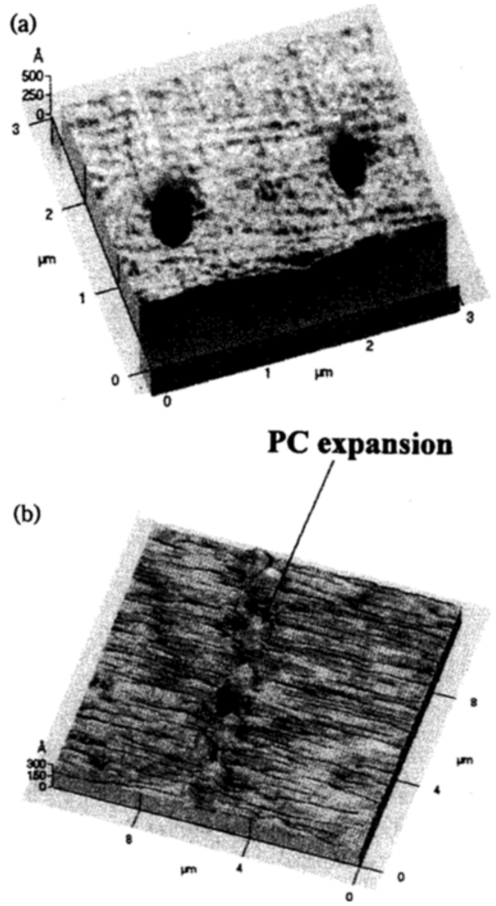

Fig. 9. AFM images of the written spot in (a) dye layer and (b) substrate of CD-R.

the real image of the written spot was observed by atomic forces microscope to study the recording mechanism of CD-R. When CD-R is recorded, the temperature at the center of written spot in dye layer rises above its decomposition temperature and the part of PC substrate is also heated to above its glass transition temperature, while the temperature rise in gold layer was not so high compare to that in recording layer. This shows that optical recording in CD-R involves thermal decomposition of dye induced by the local absorption of the laser beam energy and thermal expansion of PC substrate due to the heat transfer from dye layer. These change the optical properties of the written area so that digital data can be recorded and reproduced.

NOMENCLATURE

C_p : specific heat
h : the convection heat transfer coefficient
I(r,t) : the laser beam intensity distribution
K : thermal conductivity
$P_o(t)$: instantaneous output power of laser beam
q(z) : the rate of absorption of energy per unit volume at point z
Q(r,z,t) : the heat generation rate per unit volume at point (r,z) and time t
r : radial distance in the direction of r-axis
r_b : the radial distance from z-axis at the boundary
t : time
T : temperature
T_∞ : the ambient temperature
K : thermal conductivity
z : thickness distance in the direction of z-axis
z_b : the distance from r-axis to the disc surface

REFERENCES

Bell, A. E. and Spong, F. W., "Antireflection Structure for Optical Recording", *IEEE J. Quantum Electron.*, **QE-14**, 487 (1978).

Kim, J. S., Nam, T. Y. and Huh, Y. J., "The Optical Characteristics in the Layers of Compact Disc-Recordable", *KJChE*, **14**, 88 (1997).

Kim, J. S., "Optical Disc and Optical Recording Materials", *Poly. Sci. Tech.*, **7**, 646 (1996).

Kim, J. S. and Park, K. Y., "Layer Design for Optical Recording Media", Proc '95ME&D, 211 (1995).

Mansuripur, M., "The Physical Principles of Magneto-optical Recording", Cambridge University Press, New York, 1995.

Mansuripur, M., Connell, G. A. and Goodman, J. W., "Laser-induced Local Heating of Multilayers", *Appl. Opt.*, **21**, 1106 (1982).

Marchant, A. B., "Optical Recording", Addison-Wesley, New York, 1990.

Matsuoka, M., "Infrared Absorbing Dyes", Plenum Press, New York, 1990.

Pahwa, A., "The CD-Recordable Bible", Eight Bit Books, Wilton, 1994.