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Investigation of pit formation in multilayer optical storage disks using optical coherence tomography

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ABSTRACT

We propose a novel application of optical coherence tomography (OCT) to monitor pit formation in laser irradiated optical storage materials. A multilayer optical storage recordable compact disk, is composed of multiple layers, each of different structure. Disks were irradiated with a Q-Switched Nd:YAG laser with an energy of 373 mJ. Post-irradiated disks were evaluated by OCT and those images were compared with optical microscopy. Our results indicate that OCT is a useful instrument to investigate pit formation in multilayer optical storage disks and might also provide information to optimize optical memory technology.

Keywords: Multilayer optical storage, Optical coherence tomography (OCT), Q-switched Nd:YAG laser, Pit formation, Spot marking

1. INTRODUCTION

Optical coherence tomography (OCT) is a new modality to perform cross sectional imaging.[1,2] OCT is very attractive because it offers advantages such as high-resolution imaging, non-invasive method, and real time measurement. OCT has been extensively used for high-resolution imaging in the fields of medicine and biophotonics.[1-3] Non-medical applications of OCT such as optical data storage, materials investigation, and microfluidic devices have also been reported.[4-6] Usually, it is difficult to acquire OCT images of highly scattering or reflecting materials due to the limited penetration depth (2-3 mm) of the probe beam. Many material defects, however, originate at the surface or at subsurface boundaries between different substances, making OCT an ideal instrument for surface inspection and quality control. For transparent or translucent materials such as plastic or polymer composites, defect imaging using OCT at greater depths is feasible.[4,5]

Recently, as compact semiconductor lasers have been developed, optical memory technology such as optical disks and holography have attracted great attention. Many studies have evaluated several optical materials such as photo-polymers, photo-resisters, and synthetic materials containing inorganic substances and metals.[7,8] Thus, method to investigate the optical characteristics of these new materials is essential. Moreover, non-invasive imaging might also be helpful in determining the optimal laser parameters including wavelength, energy, and pulse duration. Although significant efforts have been devoted to optimize the pit formation process, to date an optimal method has not been developed.

In this paper, we used OCT to monitor pit formation in laser irradiated multilayer optical storage disks. After Q-Switched Nd:YAG laser irradiation, structural changes in the disks were examined by OCT. Results were used to explain the mechanism on pit formation correlated with optical microscopy.

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2. THEORY AND SAMPLE PREPARATION

Figure 1 shows the structure of a conventional multilayered optical storage recordable compact disk which is usually composed of 4 ~ 5 layers. The bottom layer is the substrate layer, which is composed of polycarbonate with a thickness of ~ 1.2 mm. The second layer is the recording dye layer, which is an organic layer coated by dye with a thickness of 100 ~ 300 nm. This layer is removed after laser irradiation for recording. The third layer is the reflective layer which contains metals such as Ag, Au, Al which reflect the laser beam. The top layer is the protective layer which contains an UV cured resin. The semiconductor laser beam passes through the substrate layer and is focused onto the "groove" of the substrate/dye layer interface of the rotating CD-R. Depending on the input laser energy, thermal deformation of dye layer is created at the groove, thus generating binary signals on the dye layer from the difference between 'pit' (thermally deformed groove) and 'land" of the substrate/dye layer interface.[9,10] Laser spot marking generally involves three physical processes, optical absorption of the irradiated laser beam, heat flow and mass motion.[11-13] The interaction of these processes initiated by the high intensity beam results in the formation of small pits. Absorbed optical energy melts the dye and induces heat flow. As a result, the center of irradiated spot collapses and a "pit" and "rim" are created on the material surface.

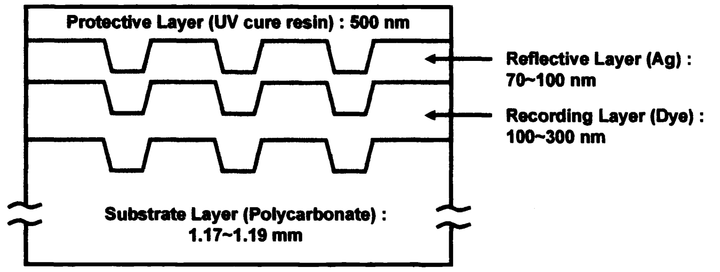

Figure 1. Structure of multilayer optical storage

Our objective is to evaluate laser marking of a recordable compact disk that contains a recording layer with dye. The individual layers of a recordable compact disk were separated in order to study the optical characteristics of each substance. All layers except for the protective layer, were produced by separate fabrication. The method to fabricate multilayered disks follows the typical manufacturing process of a CD/CD-ROM. First, the substrate polycarbonate layer is made by injection molding after engraving the groove and land, and a vacuum oven is then used to dry the Cyanine(Cyanine solution 14 + Quencher 2.5) or Cu-Pthalocyanine(Cl^- replacement) after spin coating. Then, Ag is vacuum-deposited during 25 seconds by a sputtering method Sputter (BPS Swire 12.5). Figure 2 shows the surface images of a fabricated multilayered disk imaged by SEM (scanning electron microscopy). In Figure 2, groove and land are clearly distinguished by different materials and structures as wave shapes in Figure 1 with very uniform distribution.

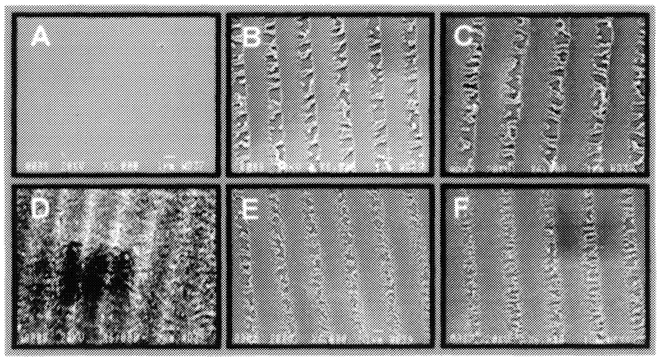

Figure 2. Surface images of samples using the SEM (× 6,000): (A) Polycarbonate, (B) Polycarbonate + Pthalocyanine, (C) Polycarbonate + Cyanine, (D) Polycarbonate + Ag, (E) Polycarbonate + Pthalocyanine + Ag, (F) Polycarbonate + Cyanine + Ag.

3. EXPERIMENTAL SET-UP

In our experiment, a Nd:YAG laser was used to irradiate the fabricated disks. The Nd:YAG laser, which is linear polarized beam with a 3 mm diameter is magnified and changed to a circular polarized beam by $\lambda/4$ plate. The laser beam is launched into a beam splitter and separated into two paths. One path is directed toward the photo detector to monitor intensity, the other towards the targeted disk. Direction of irradiation beam is controlled by a x-y position controllable mirror coated with ZeSe in order to keep the focal point on the surface of the disk. The irradiated beam is collimated and its focal distance is fixed at 225 mm. To monitor the energy of the irradiated beam into the sample, an power meter was used.

After laser irradiation, disks were imaged by OCT. A schematic of the OCT system is shown in Figure 3. A low coherent light source was coupled into the 2 × 2 fiber coupler and split into two paths. One beam was directed toward the disk and the other to a reference mirror. The light source has an output power of 10 mW at a central wavelength of 1310 nm with a bandwidth of 70 nm. A visible (633 nm) aiming beam was used to find and locate the exact imaging position on the disk. In the reference arm, a rapid-scanning optical delay line was used that employs a grating to control the phase and group delays separately so that no phase modulation is generated when the group delay was scanned.[14,15] The phase modulation was generated through an electro-optic phase modulator that produces a carrier frequency. The axial line-scanning rate was 400 Hz, and the modulation frequency of the phase modulator was 500 kHz. Reflected beams from the two arms of the interferometer were recombined in the fiber coupler and detected on a photodetector. The detected optical interference fringe intensity signals were band-pass filtered at the carrier frequency. Resultant signals were then digitized with an analog-digital converter and transferred to a computer where the structural image was generated. The lateral and axial resolutions of the reconstructed image were both 10 μm.

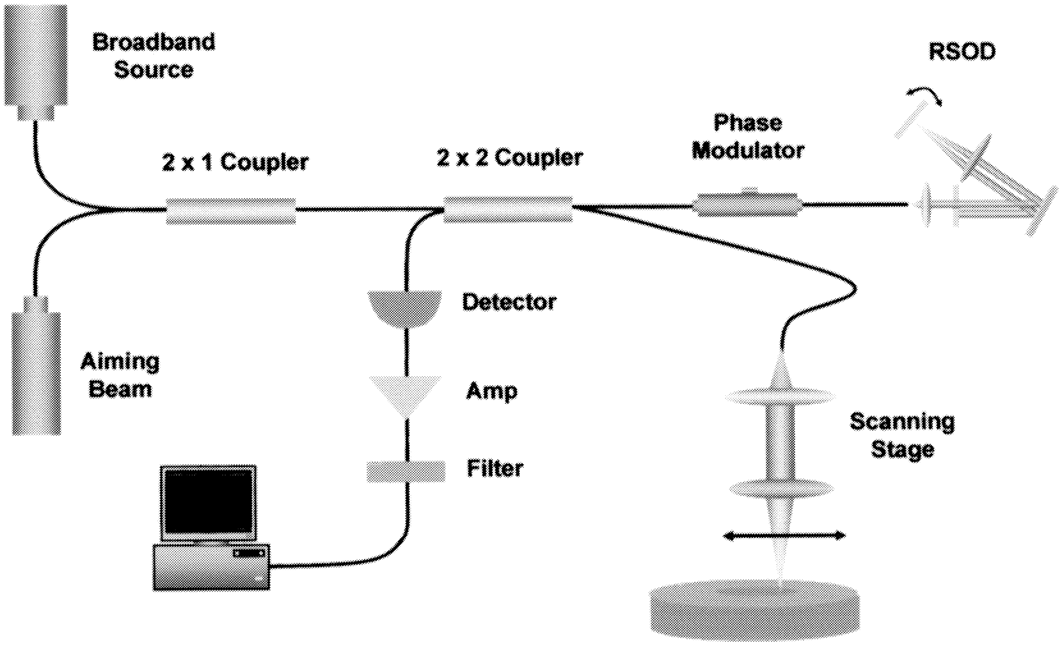

Figure 3. Schematic of OCT imaging system: RSOD, rapid-scanning optical delay.

4. RESULTS AND DISCUSSION

Figure 4 presents OCT images of a recordable compact disk. Images were obtained after scanning from the inside to the outside of the compact disk. In the images, the upper line represents reflection from the substrate layer and the bottom lines represent reflection from the reflective layer. In the area of the substrate layer without any coated material, the line is clear, otherwise with the protective layer, the substrate layer is not. In the reflective layer coated with Ag, high reflection is imaged and a thick line is shown in the recording layer coated dye, albeit clearer than reflection layer. The reason the image changes by layer is because the reflection coefficient is different for each layer and thickness.

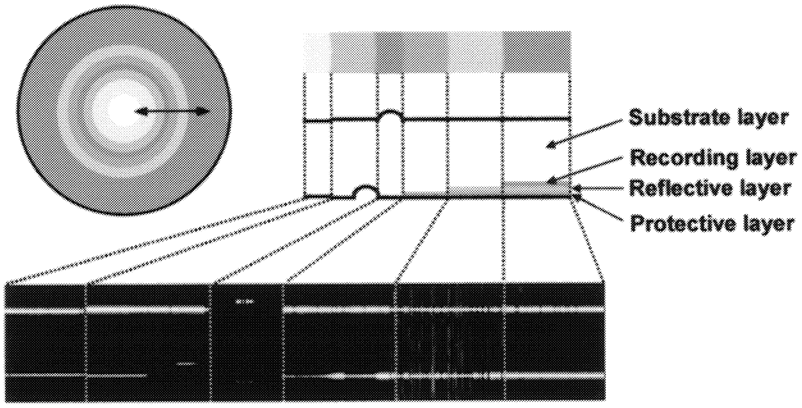

Figure 4. OCT Images of multilayer optical storage (recordable compact disk). The OCT image size is 6.0×1.5 mm with 10 μm/pixel.

In Figure 5, images from OCT and optical microscopy showing pit formation are presented. Prepared disk with different layers were irradiated using a Q-switched Nd:YAG laser with an energy of 373 mJ, on 80-μm spot sizes. Spot marking images on the substrate layer are shown in Figure 5. (A). Polycarbonate melted out in the microscopy image and the black area between two white lines is clearly apparent in the OCT image due to less reflection. Compared with the lower white line of the other OCT images, it appears thinner than other disks. This is because that reflection coefficient of the substrate layer is much less than the other dye layers such as the recording and reflective layers. Figure 5 (B) and (C) presents spot marking on the substrate layer coated with dye. Dye in the recording layer and polycarbonate of substrate layer are melted out and separated at the same time. The small spot, which appears in the center of the upper line, is caused by chemical changes and thermal transformation of the dye. The non-uniform image gap of the lower line component changes with thermal repercussions while polycarbonate was melted. It was determined that Cyanine dye has a higher reflection coefficient than Pthalocyanine dye when thickness of lower line is compared. On the substrate layer deposited with Ag, only polycarbonate was melted and separated with less melting of Ag [Figure 5 (D)]. Because Ag has a high melting point, it didn't melt after laser irradiation and little effects are shown as a thin line in the center of the upper line of the OCT image. This correlated very well with the microscopy spot images that are severely distorted. A non-uniform image gap in the lower line is caused by component changes as the temperature sensitive polycarbonate layer changes after laser irradiated and indicates that the reflection coefficient is decreased. The thickness increase in the lower line means that the reflection coefficient of Ag is much higher than polycarbonate and dye. Figures 5 (E) and (F) show the spot marking formation on the recording layer deposited on top of the reflective layer. OCT images show thinner and clearer lower lines from the dye coating, when compared to those from the Ag-reflective coating shown in Figure 5(D). Thin upper lines at the center of the spot marking were also observed in the OCT images in Figures 5(E) and (F) because the laser irradiation did not affect the Ag-reflective layer, while melting dye layers. The inconsistency of the upper line in Figure 5(E) resulted from remaining Pthalocyanine dye dispersion, which survived melting and polycarbonate heat transfer processes from laser irradiation. On the contrary, the OCT image in Figure 5(F) shows a complete upper line because the efficient interaction between Cyanine dye and the laser irradiation lead to the complete decomposition of the dye, leaving the Ag-layer intact. Differences in clarity of upper lines illustrate that Cyanine dye is more sensitive to laser irradiation than Pthalocyanine dye, thus resulting in complete chemical decomposition.

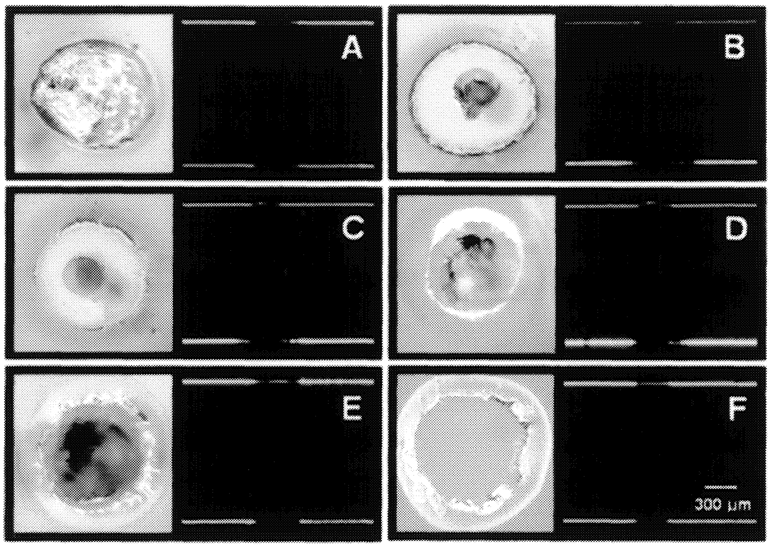

Figure 5. The comparison of optical microscopic and OCT images of post laser irradiated multilayer optical storage media: (A) Substrate layer (Polycarbonate), (B) Substrate layer (Polycarbonate) + Recording layer (Pthalocyanine), (C) Substrate layer (Polycarbonate) + Recording layer (Cyanine), (D) Substrate layer (Polycarbonate) + Reflective layer (Ag), (E) Substrate layer (Polycarbonate) + Recording layer (Pthalocyanine) + Reflecting layer (Ag), (F) Substrate layer (Polycarbonate) + Recording layer (Cyanine) + Reflecting layer (Ag).

5. CONCLUSIONS

We have shown that spot marking including pit formation in multilayered optical storage disks was explained by OCT and microscopy. Microscopy image provide only a top view image, on the other hand, OCT provides a cross-section view. Using OCT and microscopy images, the process of spot marking and different reactions by structure and material were evaluated. In particular, changes in the recording and reflective layers were monitored by OCT, and this provided valuable information to understand the recording mechanism in compact disks after laser irradiation. Result suggests that OCT has the potential to be a powerful method for evaluation of spot marking post laser irradiation. This work focuses on multilayer optical storage disks, but the results should be directly applicable to other material areas to evaluate the optical characteristics and changes of materials.

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REFERENCES

1. D. Huang , E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang W, M. R. Hee, T. Flotte, K. Gregory, C.A. Puliafito, and J. G. Fujimoto, “Optical coherence tomography,” *Science*, **254**, pp. 1178-1181, 1991.
2. Joseph M. Schmitt, “Optical coherence tomography (OCT): A review,” *IEEE J. Sel. Top. Quant.*, **7**, pp. 931-935, 2001.
3. G. J. Tearney, M. E. Brezinski, J. F. Southern, B. E. Bouma, S. A. Boppart, and J. G. Fujimoto, “Optical biopsy in human urologic tissue using optical coherence tomography”, *Journal of Urology*, **157**, pp. 1915-1919, 1997.
4. S. R. Chinn and F. A. Swanson, "Multilayer optical storage by low-coherence reflectometry," *Optics Lett.*, **21**(12), pp. 899-901, 1996.
5. J. T. Oh and S. W. Kim, “Polarization-sensitive optical coherence tomography for photoelasticity testing of glass/epoxy composites,” *Optics Express*, **11**(14), pp. 1669-1676, 2003.
6. Z. Chen, T. E. Miller, D. Dave, and J. S. Nelson, “Optical doppler tomographic imaging of fluid flow velocity in highly scattering media”, *Optics Letter*, **22**(1), pp. 64-66, 1997.
7. Y. Md. Noor, S. C. Tam, L. E. N. Lim, and S. Jana, "A review of the Nd:YAG laser marking of plastic and ceramic IC packages," *J. Mate. Pro. Tech.*, **42**(1), pp. 95-133, 1994.
8. M. C. Gupta, "A study of laser marking of thin films," *J. Mater. Res.*, **3**(6), pp. 1187-1195, 1988.
9. K. F. Wissbrun, "Thermal expansion and flow model for pit formation in laser marking of polymeric film optical disks," *J. Appl. Phys.*, **62**(3), pp. 1123-1124, 1987.
10. J. J. Wrobel, A. B. Marchant, and D. G. Howe, "Laser marking of thin organic films," *Appl. Phys. Lett.,* **40**(11), pp. 928-930, 1982.
11. T. S. Chung, "Pit formation during laser marking of thin organic films," *J. Appl. Phys.*, **60**(1), pp. 55-60, 1986.
12. S. H. Slivinsky and N. E. Ogle, "Laser beam interaction with plastics," *J. Appl. Phys.*, **48**(9), pp. 3660-3664, 1977.
13. K. Y. Law and G. E. Johnson, "Ablative optical recording using organic dye-in-polymer thin films," *J. Appl. Phys.*, **54**(9), pp. 4799-4805, 1983.
14. G. J. Tearney, B. E. Bouma, and F. G. Fujimoto, “High-speed phase- and group-delay scanning with a grating-based phase control delay line,” *Opt. Lett.*, **22**, pp. 1811-1813, 1997.
15. A. M. Rollins, M. D. Kulkarnis, S. Yazdanfar, R. Ung-arunyawee, and J. A. Izatt, “In vivo video rate optical coherence tomography,” *Opt. Express.*, **3**, pp. 219-229, 1998.