Korea Polymer Journal, Vol. 9, No. 6, pp 313 − 318 (2001)

Experimental Study on Spin Coated Thin Cover Layer for High Numerical Aperture Optical Disc

Dohoon Chang, Myongdo Ro, Duseop Yoon, Insik Park, and Dongho Shin

High Density Recording Group, Digital Media R&D Center, Samsung Electronics, Suwon, Kyunggi 442-742, Korea

Jinhwan Kim*

Polymer Sci. and Eng. Dept. and Polymer Technology Institute, Sungkyunkwan University, Suwon, Kyunggi 440-746, Korea

Received July 30, 2001

Abstract : The present study relates to a method of manufacturing 100μm thick cover layer for the high density digital versatile disc system (HD-DVD), which uses a high numerical aperture of 0.85 at 405 nm wavelength. Spin coating technique was investigated as means for manufacturing the cover layer within sufficient margins of thickness variation and with good mechanical properties including small radial and tangential tilts. The influence of processing variables such as spinning speed, spinning time, and dispensing position was investigated. The effect of viscosity of UV-curable resin was also investigated.

Introduction

Optical recording technology is developing very rapidly, driven by the demands for higher storage capacities and increasing data rates. As the demand for higher capacity and more reliable data storage is growing, a great deal of research and development is undertaken on the optical disc systems of various formats including CD-DA (compact disc-digital audio), CD-ROM (compact disc-read only memory), CD-WORM (compact disc-write once read many), CD-R (compact disc-recordable), and DVD (digital versatile disc). In order to meet the demand for increasing optical disc capacity, it is desirable to use shorter wavelength laser and/or the objective lens of higher numerical aperture (NA) since the laser spot size is approximately proportional to λ/NA, where λ is the laser wavelength. If one applies the high numerical aperture value of 0.85 and blue-violet diode lasers of 405 nm of wavelength, the next-generation optical recording system, HD-DVD (high density-digital versatile disc), having over 22 GB capacity on a single layer of an 120 mm diameter disc can be possibly materialized.[1-4] In this case, the tilt margin is approximately equal to that of DVD (NA = 0.60, λ = 650 nm, 0.6 mm substrate) and the thickness of cover layer should be 100 μm to allow sufficient tilt margin.[5] Yamamoto *et al.*[5] have proposed that it is possible to address the information layer through an 100 μm thin cover layer on an 1.1 mm thick polycarbonate substrate. Martynov *et al.*[6] also reported that the thickness of cover layer for HD-DVD should be less than 160 μm to obtain a disc tilt tolerance which is normally larger than the tolerance for DVD. Several technologies can be considered as the possible method to manufacturing the thin cover layer on a rigid substrate. Decre and Vromans[7] presented the results of two possible technologies for the cover layer, namely spin coating and bonding of a polycarbonate(PC) sheet. Among possible technologies, spin coating technology is considered as the best method due to some advantages such as small residual focusing error and low processing cost. Fundamental descriptions of spin coating of Newtonian fluids on flat substrates were reported by Emslie *et al.*[8] and by Meyerhofer.[9]

In this study, we investigate the effects of the

*e-mail : jhkim@skku.ac.kr

fundamental material and processing variables such as viscosity of resin, spinning speed, spinning time, and dispensing amount on the uniformity of 100 μm thick cover layer which would be used for the next-generation high capacity optical disc system.

Experimental

Materials. A commercial polycarbonate (AD5503), obtained from Teijin Co., was used as a rigid 1.1 mm thick substrate. It was supplied in the form of spherical pellets and has the refractive index of 1.51 and the glass temperature of 146°C. The mastered information was replicated by injection molding.

In order to manufacture the 100 μm cover layer on the top of injected molded PC by spin coating technique, four different UV-curable resins commercially available were used. These resins were supplied in transparent fluids and differs in viscosity. Their characteristics are presented in Table I. The UV-curable resins were found to be Newtonian.

Apparatus and Coating Procedure. The spin coating process described below was employed to make a thin cover layer and the resin was immobilized by exposing it to ultraviolet light right after the spin coating. All processes were performed in a clean room to prevent defects caused by contamination. To investigate the effects of processing variables, a resin of 5 g quantity was dispensed at different positions of disc and spin coater was operated at different spinning speeds and spinning times. After coating, the resin was immediately cured in a nitrogen atmosphere for 5 sec with 3 KW UV-lamps. The thickness distribution of cover layer at radii from 25 to 55 mm was measured by a laser focus displacement meter.

Table I. Characteristics of UV-Curable Resins Employed in This Study

Viscosity (cps at 25 °C)	1300	2100	5000	10000
Refractive Index (at 25 °C)	1.503	1.505	1.508	1.511
Transmittance at 405 nm for 100 μm Thickness(%)	89	89	89	89
Shrinkage on Cure (%)	5.6	5.2	5.2	5.3

Results and Discussion

First, the effects of different dispensing positions on the thickness of a cover layer have been investigated. UV-curable resin which has the viscosity of 5000 cps was dispensed at five different positions starting from the center of disc, that is the radii of 0, 20, 30, 40, and 45 mm. For center-dispensing case, an inner hole of 15 mm-diameter located in the center of injection-molded optical discs have been covered by specially designed cap. Radial distribution of film thickness as a function of different dispensing positions is shown in Figure 1. As shown in the figure, the better thickness uniformity is obtained as the dispensing position approaches the center of disc. Great thickness variation is thought to be an intrinsic phenomenon for non-center-dispensing system.

Figure 2 shows the effect of resin viscosity on the thickness and uniformity of a cover layer. If highly viscous resins whose viscosities are greater than 1000 cps are dispensed at the center, the thickness increases with increasing the resin viscosity while the uniformity does not change a lot. We estimated the proper processing conditions for four different resins which will give the thickness of 100 μm using center-dispensing process. The results are summarized in Table II. The speci-

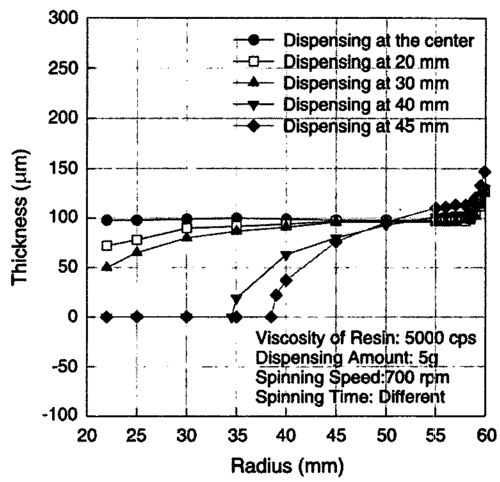

Figure 1. Radial distribution of cover layer thickness as a function of dispensing position.

Table II. Comparison among Resins Viscosities and Spinning Conditions Giving the Optimum Cover Layer Thickness

Viscosity (cps at 25 °C)	1300	2100	5000	10000
Amount of Resin Dispensed (g)	5	5	5	5
Dispensing Position	Center	Center	Center	Center
Spinning Condition (rpm & sec.)	700 & 20	700 & 30	700 & 70	1000 & 100
Average Thickness (μm)	99.0	101.0	98.0	99.5
Thickness Variation (μm from 22 to 55 mm)	±3	3	±1	±0.5

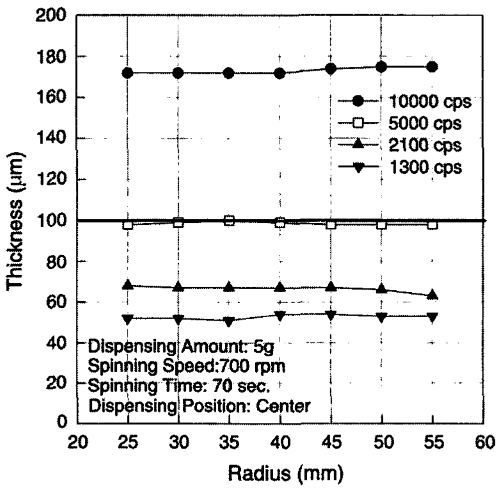

Figure 2. Radial distribution of cover layer thickness as a function of resin viscosity.

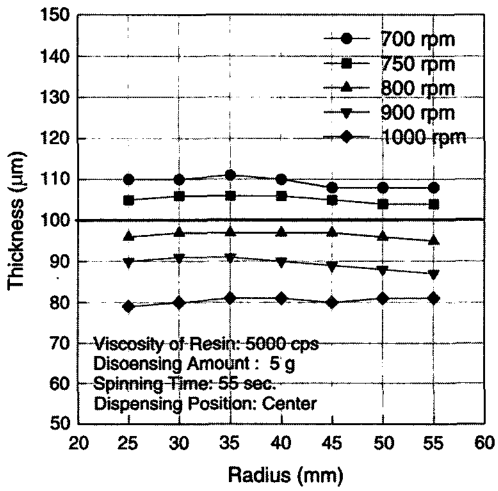

Figure 3. Radial distribution of cover layer thickness as a function of spinning speed.

fication for overall cover layer thickness for DVD is set at 100± 3μm in order to a player to be able to focus on the top of disc. It has been found that a thickness greater than this specification can cause errors in reading information on the disc.[1] Even though all resins employed in this study can have the proper uniformity within the specification, the resin having a viscosity of 5000 cps shows better processability compared to less viscous ones and less sensitivity in defect and bubble formation compared to more viscous one. Thus, the resin having the viscosity of 5000 cps was used for the following experiments.

The effect of spinning speed on the thickness with fixed spinning time (3 sec), dispensing amount (5 g), and dispensing position (center of a disc) was investigated and the results are shown in Figure 3. Generally, as spinning speed increases, the thickness of the layer becomes thinner but little change in the thickness uniformity is observed.

Figure 4 shows the thickness of the cover layer with different spinning times with other variables fixed. The thickness of the layer becomes thinner but the thickness uniformity changes very little with increasing spinning time.

The change in the surface morphology with different curing times was also investigated by atomic force microscopy as shown in Figure 5 and 6. Polymerization of the resin is not complete at the very short curing time such as 0.3 sec and the surface is rougher while smoother surface is obtained for the specimen cured for 3 sec. The average roughness for the former is 3.44 Å and the latter has the average roughness of 1.65 Å.

In order to apply spin coating technology for manufacturing the cover layer, the maximum deviation of the cover layer thickness from the nominal thickness should not exceed± 3 μm

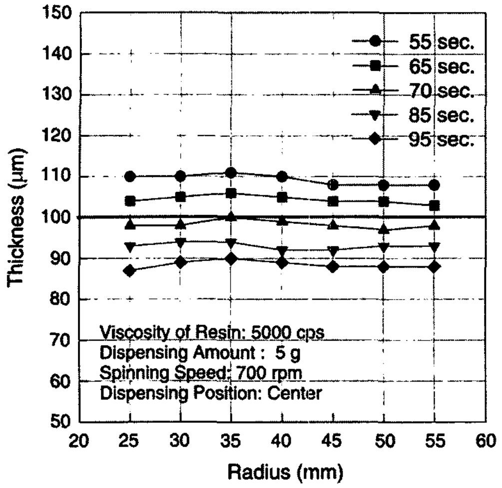

Figure 4. Radial distribution of cover layer thickness as a function of spinning time.

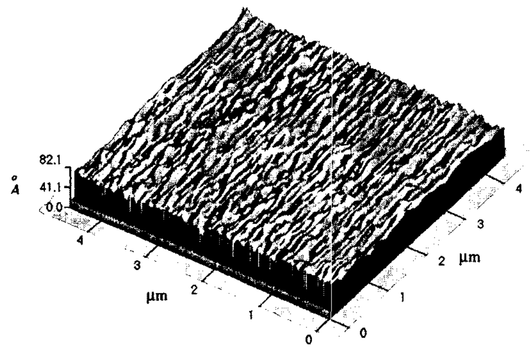

Figure 5. AFM image of cover layer with very short curing time (0.3 sec).

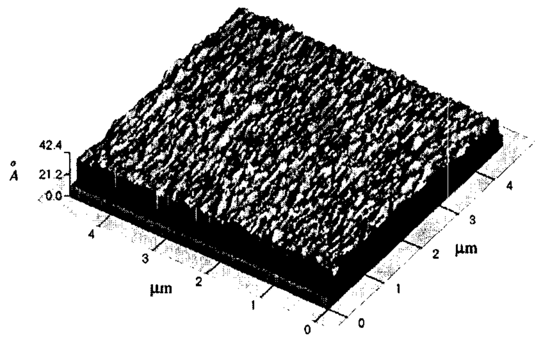

Figure 6. AFM image of cover layer with a proper curing time (3.0 sec).

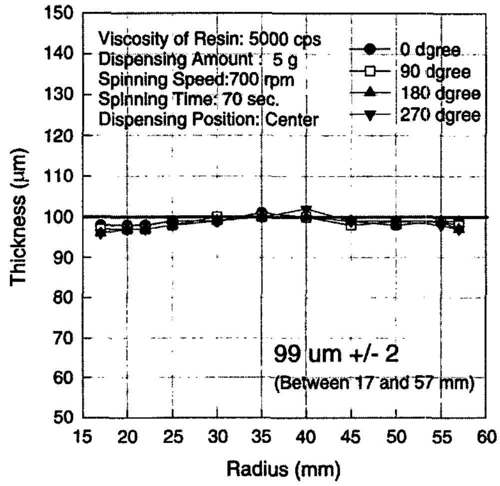

Figure 7. Radial and tangential distributions of cover layer thickness at the optimum conditions.

when measured from R = 22.0 to 58.5 mm. Here, R denotes the radius from the center of the disc. It can be seen in Figure 7 that the radial and tangential thickness varies from a minimum of 97 μm to a maximum of 101 μm, with an average thickness of 99 μm. The variation is therefore $\pm$ 2 μm in between 17 and 57 mm of a disc. This indicates that the spin coating process fully satisfies the specification requirement for a cover layer, 100 $\pm$ 3 μm, up to R = 57 mm. However, the bump is made at the outside end of disc after spinning because of viscoelastic nature of polymer (see Figure 8). This occurrence of bump is inevitable for spin coating process and the bump area should be removed after spin coating since the data access is impossible. We measured the bump width of

Figure 8. Lateral view of cover layer coated on polycarbonate substrate.

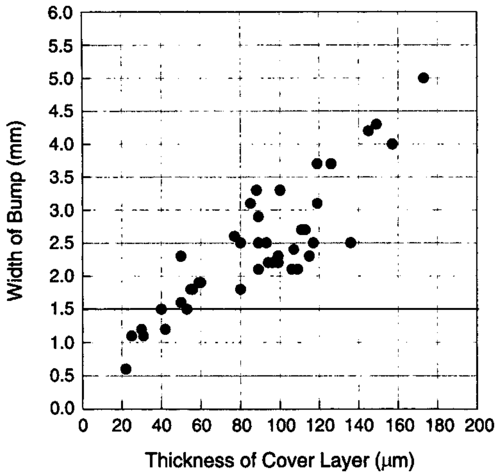

Figure 9. Width of bump as a function of cover layer thickness for spin coating method.

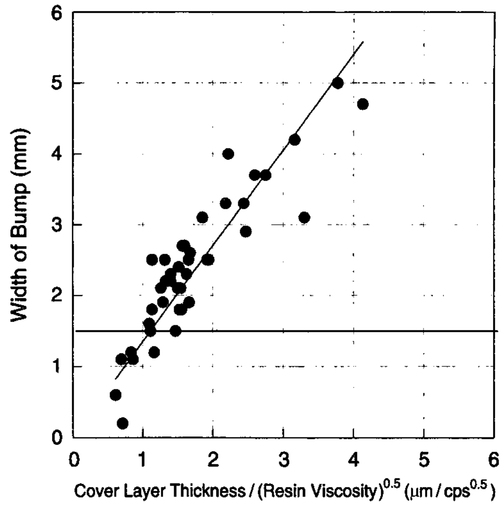

Figure 10. Width of bump as a function of cover layer thickness and resin viscosity for spin coating method.

specimens having different cover layer thickness. As shown in Figure 9, the width of bump is greater than 1.5 mm for the cover layer of 100 μm thick. We found that the width of bump depends on the viscosity of resin and the thickness of cover layer when spinning speed, spinning time, and the viscosity of resin are the same. Therefore, the width of bump can be described by the following empirical equation

$$W = A\frac{t}{\sqrt{\eta}} \quad (1)$$

where W represents the width in the unit of mm, t is the thickness of cover layer in the unit of mm, η is the viscosity of resin in cps, and A is the converting factor which shows the linear relationship among W, t, and η. The data shown in Figure 9 were plotted again using Equation (1) and the results are presented in Figure 10. Very good linear relationship is obtained and the converting factor, A, is approximately $1.35\times 103\sqrt{g/\mathrm{sec}\cdot\mathrm{mm}}$. It should be mentioned at this juncture that the bump is influenced not only by the factors mentioned above but also by surface tension of the fluid. However, the effect of surface tension of the fluid on bump has not been considered in this study and it was assumed that all the resins have the same surface tension. Further study is necessary in systematic manners for this matter.

We also consider the effects of cover layer on the mechanical and optical properties of a substrate. Since the resin used for cover layer is cured by UV-light, the shrinkage resulting from the polymerization of the resin is inevitable and the disc experiences deformation which is normally determined by radial and tangential tilts. The tilt of the disc must be within 0.40° in the radial direction and within 0.15° in the tangential direction although those are tentative criteria. Figure 11 shows the change in radial and tangential tilts after resin curing. According to this figure, both

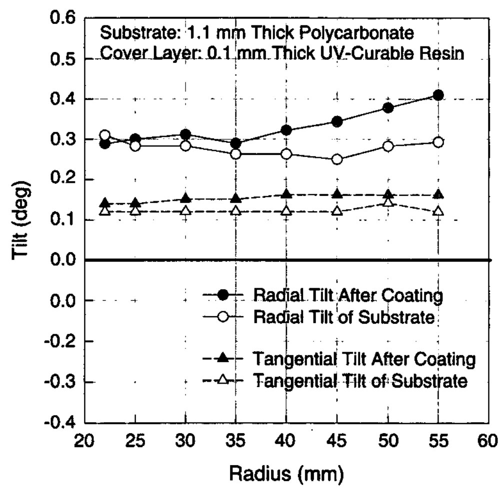

Figure 11. Radial and tangential distributions of tilts.

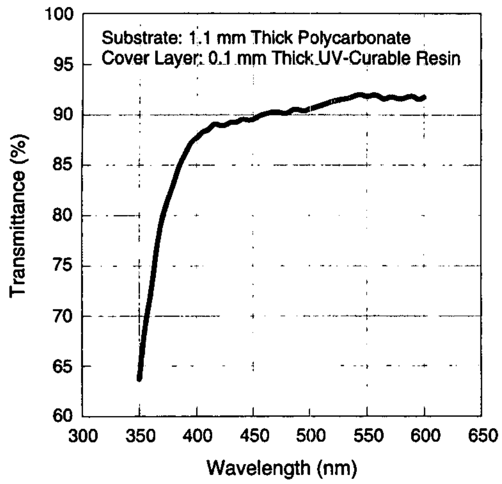

Figure 12. Transmittance of 100 μm thick cover layer on 1.1 mm thick polycarbonate substrate.

the radial and tangential tilts are within the tentative specification.

Although the transmittance of cover layer is relevant to the main theme of this article, we measured that property because of its technical importance. Figure 12 shows the transmittance of 100 μm thick cover layer coated on 1.1 mm thick polycarbonate substrate. The substrate with a cover layer seems to have the sufficient transmittance of more than 88% in the wavelength range greater than 400 nm while that of the substrate without cover layer is approximately 89%.

Conclusions

We have presented the spin coating techniques to make 100 μm thickness cover layer for high-density digital versatile disc having 25 GB capacity at NA = 0.85 and 405 nm wavelength. The material and processing variables were investigated including dispensing position, spinning speed, and spinning time as well as viscosity. As expected, the thickness of the layer becomes thinner as spinning speed and spinning time increase and viscosity decreases. It was found that the dispensing position closer to the center of disc tends to give more uniform thickness. It was possible to make the cover layer with an average thickness of 100 μm and a thickness variation well within $\pm$ 3 μm using spin-coated UV-curable resins. Both the radial and tangential tilts were within the physical specification required for the HD-DVD system and the sufficient transmittance of more than 88% was also obtained.

References

(1) T. Narahara, S. Kobayashi, M. Hattori, Y. Shimpuku, G. van den Enden, J. Kahlman, M. van Dijk, and R. van Woudenberg, *Jpn. J. Appl. Phys.,* **39**, 919 (2000).

(2) S. Nakamura and S. Fasol, *The Blue Diode Laser,* Spring Verlag, Berlin, 1997.

(3) B. Tieke, M. Dekker, N. Pfeffer, R. van Woudenberg, G. F. Zhou, and I. P. D. Ubbens, *Jpn. J. Appl. Phys.,* **39**, 762 (2000).

(4) I. Ichimura, F. Maeda, K. Osato, K. Yamamoto, and Y. Kasami, *Jpn. J. Appl. Phys.,* **39**, 937 (2000).

(5) K. Yamamoto, K. Osto, I. Ichimura, F. Maeda, and T. Watanabe, *Jpn. J. Appl. Phys.,* **36**, 456 (1997).

(6) Y. U. Martynov, B. Hendriks, F. Zijp, J. Aarts, J. Baartman, G. van Rosmalen, J. Schleipen, and H. van Houten, *Jpn. J. Appl. Phys.,* **38**, 1786 (1986).

(7) M. M. J. Decre and P. H. G. M. Vromans, *Jpn. J. Appl. Phys.,* **39**, 775 (2000).

(8) A. G. Emslie, F. T. Bonner, and L. G. Peck, *J. Appl. Phys.,* **29**, 858 (1958).

(9) D. Meyerhofer, *J. Appl. Phys.,* **49**, 3993 (1978).