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Improvement of dimensional accuracy of blu-ray disc cover layer

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Abstract

In order to obtain uniform thickness of a blu-ray disc cover layer, a CFD analysis and an experimental comparison of the cover layer thickness distribution during the spin-coating process were conducted. The blu-ray disc, a next-generation optical disc format having 25GB capacity over, consists of a thermoplastic polymer substrate layer which has a thickness of 1.1mm, a sputtered reflective metal layer and UV polymer cover layer which has a thickness of 100μm. Especially, the cover layer, which primarily governs the optical quality of the disc, is made by a precise spin coating process. However, it is still hard to get a satisfactory coating uniformity, typically, the thickness variation of the cover layer should be maintained under ±3μm, because of the unavoidable bump formed around the rim of the disc. In order to improve the dimensional accuracy of the cover layer, first, through the CFD analyses of spin coating process, the optimal spin coating conditions were obtained; and second, the edge of the disc substrate was modified into various shapes, such as chamfer, round, step, the height of the bump can be kept under the desired accuracy.

Keywords: Blu-ray disc; Spin coating process; Cover layer; Bumps; Edge shapes; CFD analysis

1. Introduction

The blu-ray disc is being developed to be the optical storage solution of the next generation, ready to be the common standard specification of HD-DVD [1]. It can hold more than 25 GB, and can be used to record more than 13 hours of SDTV (standard-definition television) or over 2 hours of HDTV [2]. Recently, not only the domestic market with LG and Samsung, but also the international market with Sony, Philips, Matsushita, Hitachi, Pioneer, Mitsubishi, JVC, Sharp and Thomson is actively participating in developing the blu-ray disc [1].

The blu-ray disc demands 0.1 mm thickness for transmitting medium so called cover layer, to achieve more margins than, DVD when using an NA 0.85 objective lens and a 405 nm wavelength laser. The thickness variation of this cover layer should be maintained under +3 m. However, it is difficult to maintain a uniformity of the cover layer such a fin value by using the spin-coating process [3, 4].

The spin-coating process used in the cover layer coating gives a lower cost and simple procedure, but there is trouble in maintaining uniformity of thickness. Because the thickness of the rim edge of substrate is greater than that of the inside area after the coating process [5, 6]. The factors influencing thickness variation of the cover layer during the spin-coating process are rotation speed and time, surface tension, viscosity, and rotational acceleration [7, 8].

In this study, in order to improve the thickness uniformity and minimize the bump shape at the edge of the cover layer, we introduce an efficient method of spin coating with respect to the variation of the substrate's edge shape such as trench, step and chamfer.

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The flow behavior and cover layer thickness distribution were analyzed according to various edge shapes during the spin coating process through numerical and experimental approaches. The optimal spinning conditions were obtained through the simulation. Based on the simulation results, spin coating experiments were carried out. Consequently, the bumps on the disc rim can be minimized and the dimensional accuracy can be improved to under ±3 μm.

2. Description of blu-ray disc

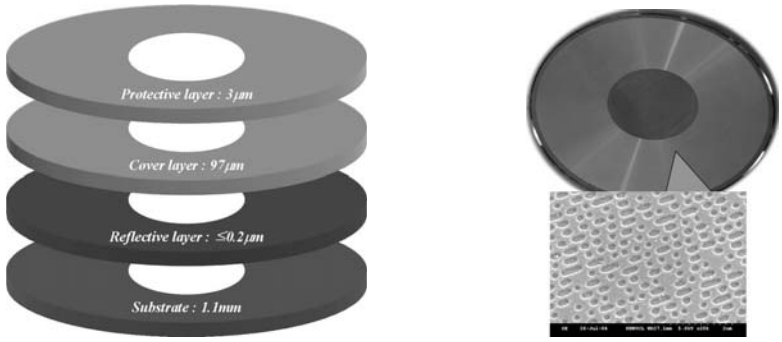
2.1 Structure of blu-ray disc

The blu-ray disc is one of the promising optical storage solutions for the next generation. It can hold more than 25 GB, about 5 times of the capacity of common DVDs, and can be used to record more than 2 hours of high definition TV.

Fig. 1 shows the structures and SEM image of a blu-ray disc. The disc consists of a substrate, a reflective layer, a cover layer and a protective layer, which have thicknesses of 1.1 mm, 0.2 μm, 97 μm and 3 μm, respectively. The blu-ray disc's diameter is commonly 120 mm and contains uncountable patterns of 150 nm width and 76nm depth as shown in Fig. 1(b).

2.2 Fabrication of cover layer of blu-ray disc

Fig. 2 shows a schematic of the spin coating process for the cover layer of a blu-ray disc. Unlike the flat substrate of conventional spin coating, substrates with various edge shapes such as trench, step and chamfer were used. As shown in Fig. 2, the spin coating was composed of edge modification with 1.1 mm substrate, nickel coating, dispensing UV resin, spinning and UV irradiation. Duralumin as a substrate material was used. During the spin coating process, the temperature and humidity had to be maintained at 22℃ and 50-60% respectively. PUA as a UV resin was dispensed on substrate with pressure of 490 kPa for 3.5 seconds. The total weight of the resin dispensed on the substrate was 3.5 g. After UV resin dispensing, the spinning process was performed with



(a) Structure of blu-ray disc (b) SEM image of blu-ray disc

Fig. 1 Structures and SEM image of blu-ray disc

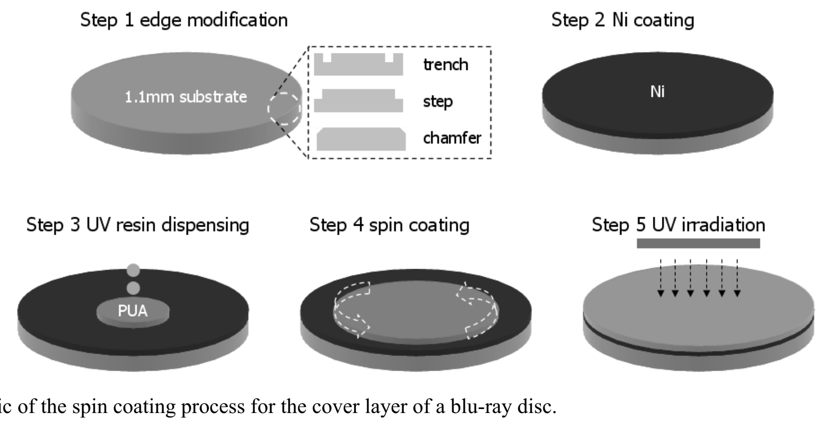


Fig. 2. Schematic of the spin coating process for the cover layer of a blu-ray disc.

4,000 rpm for 4 seconds. The tolerance of the thickness of the cover layer had to be maintained under ± 3 μm at 58 mm radial diameter [9, 10]. The factors influencing on thickness variation of the cover layer are rotation speed, time, viscosity and surface tension.

3. Analyses of resin flow behavior

3.1 3D model for analysis

In order to obtain the optimal coating conditions of the cover layer spinning and meet the required tolerance, the numerical simulation using FDM commercial code, Flow-3D, was conducted. Newtonian 3-dimensional mathematical model for the spin coating process of a viscous fluid was firstly reported by G. Emslie [11]. A non-Newtonian model was introduced by M. Dietrich considering the effect of the temporal thinning velocity [12]. In recent years, theoretical and numerical simulation on various viscous liquids was introduced by Schwartz and Roy [13].

Table 1 shows the boundary conditions for the nu merical simulation. The diameter and the thickness of model are given by 120 mm and 1.1 mm, respectively. Actually, since the blu-ray disc has a through hole at its center, a cap is usually used to close the hole during spin coating process.

Table 1. Simulation conditions.

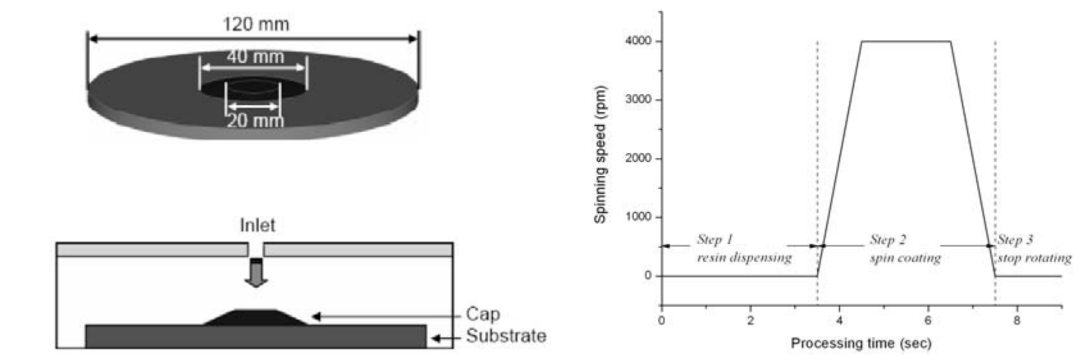
Item	Detail
Governing equation	Navier-Stokes
Viscous	Variable
Flow mode	Viscous flow, Laminar flow, incompressible
Slip condition	No-slip
Solution scheme	Explicit

For convenience and simplification, the substrate and cap are regarded as a single rigid body. The resin is modeled to flow through the inlet at the center of the created virtual structure above the substrate. Viscous, laminar-flow, and incompressible conditions are used in the simulation as shown in Fig. 3(a). Fig. 3(b) also shows the variation of the rotation speed of the substrate according to the time. During step 1, the resin is dispensed on the substrate for 2 seconds. In this step, the amount of resin is controlled by the inflow time and the flow velocity through the inlet. The resin coats the substrate during step 2, and spin coating machine stops rotating at step 3.

3.2 Analysis of flow behavior

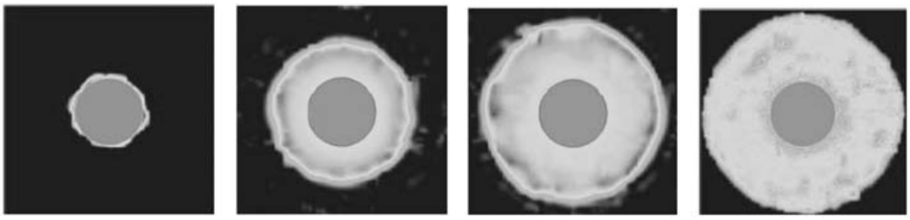
Fig. 4 shows the flow behaviors of resin during the spin-coating process with respect to viscosity change. Spin speed, resin quantity and total analysis time were 4,000 rpm, 3.5 g and 7 sec, respectively. When viscosity is 5,000 cps as shown in Fig. 4(c), the flow behavior of the resin film is much more stable than the others. When the viscosity is too low as shown in Fig. 4(a), (b), the resin is scattered irregularly and can not maintain the smooth front line. Because a fluid with a low viscosity is very fluid and easy to flow such as water. Moreover, vice versa, at high viscosity, the resin is hard to be spread outside as shown in Fig. 4(d).

Fig. 5 shows the flow behaviors of the resin according to the spinning time variation. Spin speed and viscosity were 4,000 rpm and 5,000 cps. The front of the flow has dark color that indicates thicker distribution of resin compared to the inner part. Consequently,



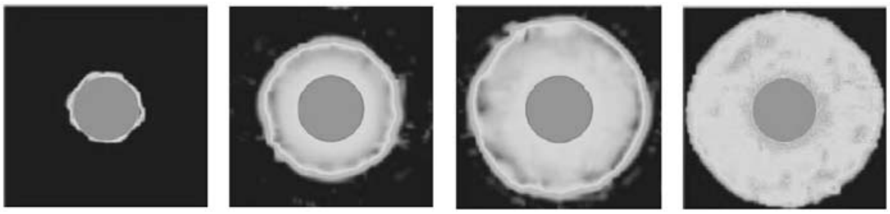
(a) 3D simulation model (b) Spinning procedure

Fig. 3. 3-dimensional model and speed variation according to time.



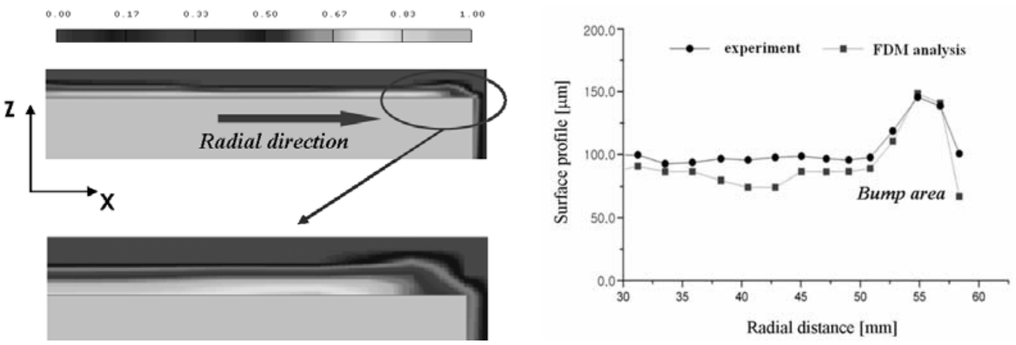
(a) 50 cps (b) 2,500 cps (c) 5,000 cps (d) 10,000 cps

Fig. 4. Flow behaviors of resin during spin-coating process with respect to viscosity change.



(a) 2.0 sec (b) 3.0 sec (c) 3.5 sec (d) 4.0 sec

Fig. 5. Flow behaviors of resin during spin-coating process with respect to time variation.



(a) Simulation of bump formation (b) Comparison of surface profiles with experiment

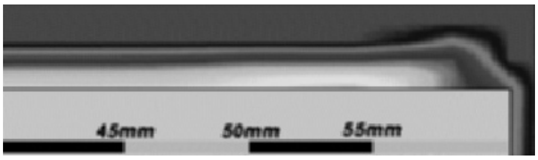
Fig. 6. Simulation and experimental result of bumps formation on the rim.

the unwanted bumps are usually built up and remain on the rim of the cover layer. This phenomenon is quite similar to the results of real processes.

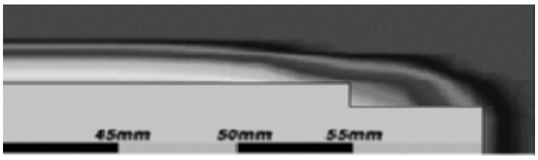
3.3 Analysis of bump formation according to edge shape

The preliminary simulation of spinning was performed to investigate the effect of the edge shape on the formation of bumps on the rim and the simulation result was compared with the measured one to verify the validity of the simulation results. Fig. 6 shows two-dimensional analysis result of bump forming simulation and the surface profile of the cover layer with respect to the radial position. In Fig. 6(b), the solid line with circular marks is the measured profile and the square marked one is the calculated. As indicated in Fig. 6(b), thickness variation exceeds the allowed tolerance of 3 μm at radial direction of 58μm. This bump results in some kind of optical reading problems such as reading error, jitter and so on. There is little difference in the inside area, but at the bump, FEM analysis shows good agreement with the experimental result.

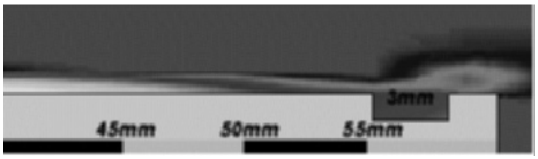
Fig. 7 also shows simulation results with respect to the variation of the edge shapes. In case of the chamfered and the stepped edge, the bump disappears dramatically as shown in Fig. 7(b), (d). However, the



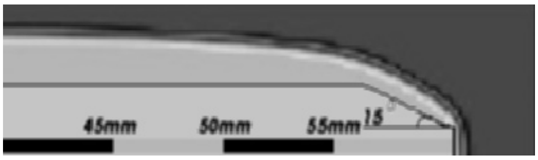
(a) Flat squared edge



(b) Stepped edge



(c) Trenched edge



(d) Chamfered edge

Fig. 7. Simulation results with respect to various edge shapes.

Table 2. Experiment conditions for spin coating.

Material	substrate		duralumin
	polymer resin		PUA (Polyurethane acrylate)
Spinning conditions	viscosity		5,000 cps
	spinning speed		4,000 rpm
	spinning time		4 sec
Edge patterns	stepped pattern	width	2mm
		depth (D_s)	50, 100, 200, 500μm
	trenched pattern	width	1mm
		depth (D_t)	100, 500μm
	chamfer pattern	angle (θ_c)	0, 5, 10, 15, 20, 30, 45°

stepped edge can not maintain the uniform and smooth outer edge profile of the cover layer. According to the simulation result only, the chamfered way can be selected as the simplest and most effective way to minimize the bump.

4. Experiments and Discussion

Table 2 shows the experiment conditions. For spin coating experiments, the spin coating machine (SMART CUBE-M), the resin dispenser (ACCURA) and UV hardening machine (DYMAX) were used. The cover layer thicknesses were measured by the laser measuring system (LT-8010) and surface profiler (ALPHA STEP-IQ, KLA TENSOR). The substrate was made of duralumin because of the ease of machining and the material of the cover layer was PUA (Polyurethane acrylate). Nickel was coated on the duralumin substrate to obtain close conditions to a real process. The substrate's edge was modified by step, trench, and chamfer like the simulation.

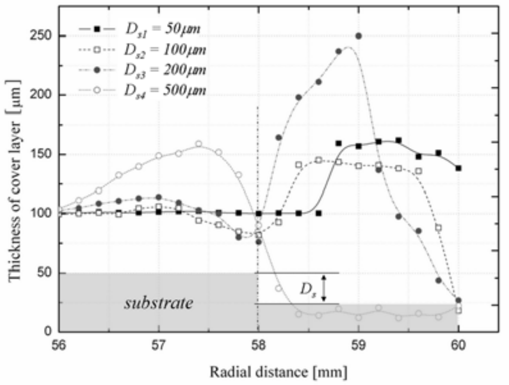


Fig. 8. Thickness variation of cover layer with respect to step depth.

Fig. 8 shows the thickness variation of the cover layer with respect to the depth of the stepped edge, D_s. When the step depth is about 50 μm, the bump is shifted to the outside and the variation of the cover layer thickness can be maintained under ±3 μm at the inside of the 58mm radial position. However, for other cases, the variations exceed the allowable tolerance. Stepped patterns deeper than 50 μm can not meet the required dimensional accuracy of the cover layer because of their dual bump formation characteristics. Especially, when the depth becomes too big, as D_s is 500 μm in the Fig. 7, the effect of the step is fully diminished and the bump forming mode turns to the mode of the plain square edge.

Fig. 9 shows the thickness variation of the cover layer with respect to the depth of the trench, D_t. When the trenched pattern is machined adjacent to the 58 mm radial position, the thickness variation can be maintained in the allowable tolerance. However, the outer edge of the cover layer was formed irregularly

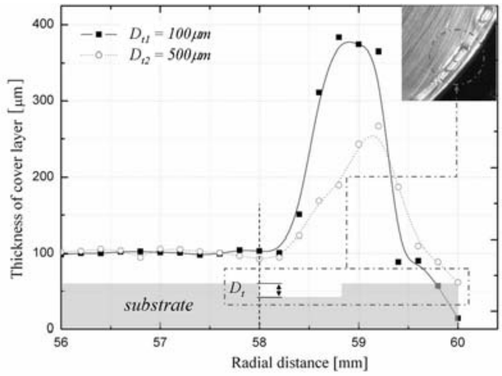


Fig. 9. Thickness variation of cover layer with respect to trench depth.

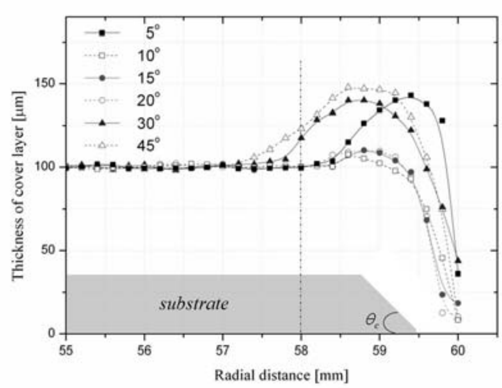


Fig. 10. Thickness variation of cover layer with respect to chamfer angle.

as shown in the top-right photograph of Fig. 9 because the trench pattern prevents the continuous and stable flow behavior of the resin during high speed spinning (the simulated result in Fig. 7(c) also shows such a phenomenon clearly!).

Fig. 10 shows the thickness variation of the cover layer with respect to the chamfer angle variation, θ_c. Similar to the simulation results, when the chamfer angle is 10^o or 20^o, the variation of over layer thickness in 58 mm decreases under 3 μm. When the chamfer angle passes over 20^o, the variation of the thickness in 58 mm increases gradually. Hoever, when the chamfer angle goes to 5^o (near zero), the bump forming mode at the disc rim changes to the squared edge's way. But the position of the bump slightly moves outward (*58→58.5 mm*), the variation of thickness in 58 mm can be maintained under the allowable tolerance as well. When the edge is chamfered, the outer edge's profile of the cover layer is much smoother than the stepped and trenched ones. The cost of manufacturing for chamfer shape is similar to the others due to the simple fabrication method.

5. Conclusion

The blu-ray disc spin-coating process was analyzed and investigated through empirical and analytical approaches. Under several numerical simulations using FDM commercial code, Flow-3D, and actual spin coating experiments, the optimal spinning condition, such as 4,000 rpm spinning speed and 5000 cps viscosity could be obtained. In order to obtain a uniform thickness distribution and to minimize the bump on the rim, the edge of the disc substrate was modified into various shapes. A chamfered edge, around 5 to 20 degrees, is the simplest and most effective way to minimize the bump on the cover layer. In order to obtain generality, more investigation is needed to obtain optimal dimension of the chamfered shape with respect to the variation of the spin coating conditions.

Acknowledgements

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Nomenclature

NA : Lens numerical aperture,
D_s : Step depth,
D_t : Trench depth,
θ_c : Chamfer angle

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