TODAY SINGULUS OFFERS COMPLETE systems for the replication of all formats of optical disc, from CD to DVD to 3rd generation HD DVD and Blu-ray Disc. The BLU-LINE BD 50, with the BD DL wet-embossing integration, represents a powerful solution for 50GB Blu-ray Disc replication. The BLU-LINE BD 50 is a result from the close cooperation with Sony and the in house availability of all major process steps, BD mastering, BD molding and BD replication.

Based on this technology, Singulus will ship and install BD DL – Modules to major replicators within 2007 to speed up the replication availability of BD 50 disc.

With these installations, Singulus is underlining the importance that Blu-ray Disc is acquiring in the American and European markets and will also react to the growing interest that many movie majors are showing in the 50GB Blu-ray Disc.

Application of the Coverlayer for 100µm–SL and 75µm–DL Blu-ray Discs

The production of Blu-ray discs is now continuously ramping up. Dedicated manufacturing equipment is available and the process is well understood, resulting in high manufacturing yields of at least 80% to more than 90%. Key factor is the 100µm–SL and 75µm–DL coverlayer that represents the laser light transmitting and focussing surface. This coverlayer is currently mainly achieved by lacquering techniques, and it has to be free of optical defects with a total thickness of 95 to 105µm and a uniformity of ±3µm. Sophisticated optical inspection scanners control the defect level down to around 200µm diameter, and in addition check the coverlayer regarding absolute thickness and deviation from the inner 23mm diameter reference value. The Blu-ray Disc specification imposes the most stringent requirements for the lacquering process in the optical disc replication equipment.

Spreading and distribution of lacquer on a spinning disc is primarily a technique used for the coating of wafers, glass and optical discs. Substantial levels of knowledge and experience have been accumulated over the years and the lacquer distribution has also been investigated theoretically in 1958 [1]. Wilson et al. calculated the spreading of a thin drop of Newtonian fluid on a uniform substrate rotating with constant angular velocity (fig.1).

During spinning, the drop dispensed in the centre of the disc spreads along the radius. In the calculation it is assumed that the contact angle between the fluid and the disc stays constant. At the outer rim of the moving fluid the so-called ‘ski-jump’ develops. The exact form of the fluid is determined by a combination of the contact angle, the surface tension and the viscosity.

In the case of a centre dispense, a very uniform lacquer thickness can be achieved over the disc radius with the exception of the edge where the fluid can not spread and the ski-jump will be formed.

This centre dispense technique is applied in some replication machines also for Blu-ray disc. The centre hole of the disc must be covered by a hat on which the lacquer is dispensed. During the disc spinning the lacquer flows from the hat and is evenly distributed along the radius. But handling, positioning and cleaning of the centre hat are additional delicate process steps and therefore dispensing the lacquer as an annular ring around the centre hole is regarded as a much simpler process. But due to the missing lacquer in the centre the thickness exhibits a strong radial profile.

The lacquer shows a steep increase at inner radius after spinning which flattens out at larger radius (fig.2). Therefore the simple method of annular lacquer dispensing cannot be applied for a uniform lacquer on the BD-disc.

Uniform lacquer layers using infrared heating technique

THE TEMPERATURE EFFECT

The radial profile of fig.2 is quite insufficient for the Blu-ray disc application. An efficient tool to change the lacquer distribution is the temperature, which has also been analysed theoretically [3]. The different radial spreading profiles of Newtonian fluid depend on the viscosity and the different radial spreading profiles of the lacquer on a disc are shown in fig.3.

In the case of a centre dispense, the liquid is at a constant temperature and during spinning the fluid is distributed over the radius. But due to the missing lacquer in the centre the thickness exhibits a strong radial profile.

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lacquer temperature changes the viscosity and therefore the flow along the disc radius during spinning. The left part of figure 3 shows the dependence of lacquer viscosity $\mu$ for typical CD, DVD and Blu-ray lacquers. The temperature dependence is given by an Arrhenius type law:

$$\mu(T) = \mu_0 \exp\left(\frac{E_a}{k_B T}\right)$$

$E_a$ denotes an activation energy, $k_B$ the Boltzmann factor and $T$ the absolute temperature. The exponential behaviour results in $\log -1/T$ linear plot (left side). The right side of fig. 3 shows the viscosity as a linear plot. Increasing the lacquer temperature by 10°C reduces the viscosity by a factor of about two. The lacquering process is therefore very easy to manipulate by the temperature but imposes on the other hand a very stringent control on the disc and lacquer temperature.

According to fig. 3 the thickness gradient is depending on the radius. This implies that the temperature of the lacquer has to be increased very locally along the radius.

Uniform layers over the disc surface
To achieve a radial uniform thickness profile along the disc radius, the BLU-LINE uses a series of heating steps. In each step, both the heating power and time can be controlled. By the superposition of the heating steps the profile can be tuned for optimum radial uniformity.

From the above findings it is clear that for the radial lacquer thickness a certain radial temperature profile is required. In circumferential direction the temperature should be very constant to avoid any thickness modulation. This requires homogeneous cooling of the disc after they left the moulding machine with a temperature of about 90 to 100°C. The BLU-LINE uses a combination of an air cooling conveyor and well temperature controlled disc receivers.

The circumferential uniformity is some 0.1°C which is the resolution limit of the IR-camera, which was used for the temperature investigations. After the discs have reached the thermal equilibrium they undergo the IR-heating procedure and the spin-off. Figure 6 shows the lacquer distribution over the disc area.

The minimum value amounts to 100.7μm, the maximum to 101.5μm, which gives an overall variation of 1.8μm. The residual fluctuation in uniformity is most likely caused by the lacquer dispensing.

Production stability
Blu-ray disc production operates currently at a cycle time below 4 seconds. Molding machine, disc cooling conveyor, lacquer dispensing, infrared heating, spinning, UV curing, hard-coating of the front side and backside coating with low water transmission layer are all integrated into an automatic production line.

Quality control of the produced discs is done within the machine by the installed final scanner. A lot of effort has been put into the specification of the disc surface properties/disc faults and the correlation to the scanner measurements. The defect characterisation and permitted defect sizes continue to be under discussion. Scanners with multiple tracks are now available and the coverlayer thickness can easily be monitored over the whole surface with sufficient spatial resolution and accuracy.

A prerequisite for a stable process is a constant disc and lacquer temperature. As mentioned before, disc cooling down and temperature stabilisation are implemented into the line. An infrared sensor measures the disc temperature before the lacquering. Fig 8 shows a temperature plot for the incoming discs.

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On the eight measuring tracks the average thickness is shown (fig. 9). After the cold start the total thickness is high.

![Fig 4: Radial lacquer profile for optimised heating](image1)

![Fig 5: IR-picture of cooled Blu-ray substrate before lacquer coating](image2)

![Fig 6: Lacquer distribution over the disc area and thickness versus reference radius](image3)
most likely caused by the time to warm up the IR-heaters. It takes about 15-20 discs to bring the coverlayer down to the desired value. From here onward the thickness is constant. In addition an integrated closed-loop regulator serves for keeping the coverlayer at the specified value.

**BD DL Wet-Embossing Module**

The SINGULUS TECHNOLOGIES BD DL production system BLU-LINE DL-Module based on wet-embossing technology is designed for the economical production of Blu-ray Dual-Layer Discs according to the specifications issued by the BDA. With the following BD DL-Module, the SL – machine can be upgraded for the production of BD 50 employing the wet-embossing technology.

**Summary**

The manufacturing technology for single layer Blu-ray of 25GB capacity has already turned into a more or less standard manufacturing technology. The productivity of the replication line is at a level of 20000 discs per day. The ongoing work has turned the replication into a mature process. Whereas in the beginning it was discussed to apply the 100μm coverlayer either by foil or a lacquering process nowadays the production runs with lacquer. Special issues with the dealing of the lacquer to reduce defects and to achieve a uniform layer are well understood and resolved. Based on this experience for single layer BD-ROM discs the industry is now moving fast to the double layer 50GB Blu-ray SINGULUS is fully committed to deliver already within this year, the adequate equipment having all the experience from the single layer BD in the back.

**Biography**

Stephan Hotz Head of Product Management for Blu-ray Disc

Stephan Hotz Dipl.-Ing. was appointed as the head of product management Blu-ray Disc in 2004. He is responsible for all SINGULUS TECHNOLOGIES AG activities related to the next generation of Optical Media, with primary focus on the technological development of the Blu-ray Disc.

After studying Communications Engineering at the Telekom University of Dieburg, Germany, he experienced various engagements in the vacuum technology industry. Previously he was employed in the commissioning department for mastering technology at Leybold Corporation and joined SINGULUS TECHNOLOGIES AG in 1999 as software engineer responsible for the integration of the servo motor technology in the production equipment for optical discs. In 2002 he became key account manager for rewritable optical discs for the Asian and European countries.

**LITERATURE**


**Fig 9: Result from the final scanner for the coverlayer thickness**

**Fig 10: Result from the final scanner for 24 h production run**

**Fig 12: BD50 replication steps**

**Fig 13: Design of the embossing unit**

**Fig 14: L1 pit replication of >96%**

**Fig 15: Results of BD 50 with wet-embossing process made with Singulus’ BLU-LINE**

**Fig 16: Results of L9/L1 Jitter**

**Fig 11: BD DL – Module**

**Fig 16: Results of L9/L1 Jitter**