Exploring the cover layer

Dr Leonhard Schwab (CTO, dr.schwab Inspection Technology GmbH) explains how the Blu-ray Disc (BD) cover layer has taken inspection technology into previously uncharted waters.

To help understand why the cover layer makes BD so different from its predecessors, we start with a brief look at the evolution of the optical disc.

	CD	DVD	BD
Track Pitch (mu)	1.6	0.74	0.32
Numerical Aperture	0.45	0.6	0.85
Wavelength (nm)	780	650	405
Cover Thickness (mm)	1.2	0.6	0.1
Aspect Ratio*	100	200	1200

*Diameter divided by cover thickness

Table 1: Format evolution - key parameters

Each successive generation is characterised by key parameters such as track pitch, wavelength and numerical aperture of the pick-up head (Table 1). Another defining parameter is "cover thickness": the depth of material through which the information layer is read. For CD, this corresponds to the substrate thickness of 1.2mm; for DVD, it is the 0.6mm half-disc.

Figure 1 charts the changes in some of these parameters, normalised against CD and plotted against a logarithmic scale. The progression from CD to DVD saw a 50% reduction in cover thickness, but much smaller changes in wavelength and numerical aperture.

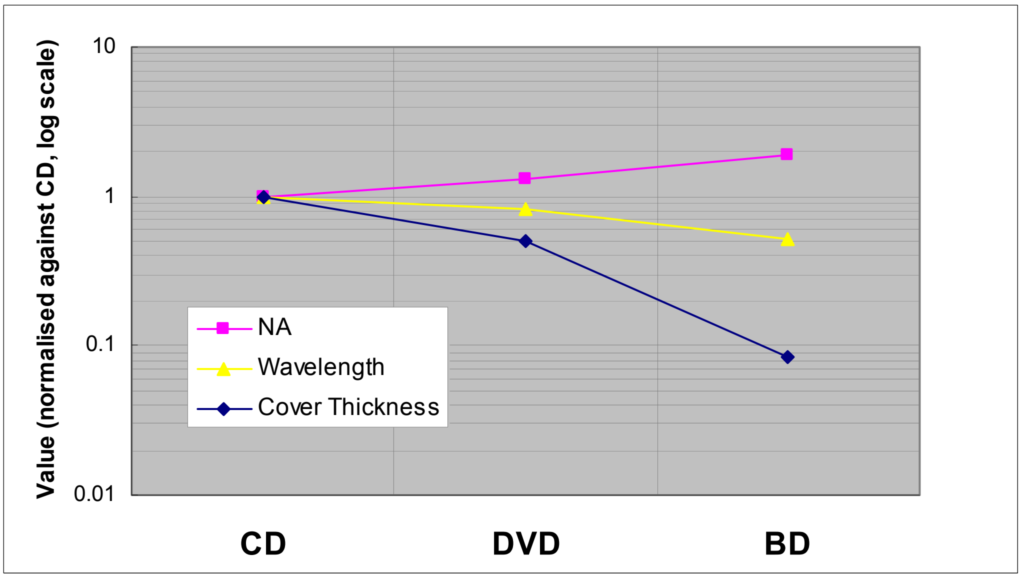


Figure 1: Format evolution – comparison of key parameters

From CD to BD, numerical aperture and wavelength change by a factor of 2 whereas the cover thickness decreases from 1.2mm to 0.1mm – a factor of twelve. If we look at other characteristic parameters in addition to those listed in Table 1, we see the same thing: only the cover thickness has changed by more than an order of magnitude.

This ultra-thin cover layer marks a significant departure from earlier generation discs and, because it is comparable in thickness with the space layer, defines a limit for this branch of optical disc evolution. It also has major implications for the manufacturing process, production tolerances and testing.

How is such a thin cover layer made?

The introduction of DVD made significant new demands on production technology. With an aspect ratio (Table 1) twice that of CD, the DVD half-disc is much more difficult to mould and the process had to be modified accordingly. And, of course, bonding the two half-discs necessitated an additional, carefully-controlled process step.

Turning to BD, the cover layer aspect ratio of 1200 puts it beyond the capabilities of established moulding technology. New production methods – currently at varying stages of development – revolve around two techniques:

a) Cover foil (solid material process)

The more advanced process in terms of production-readiness and installed base. A polycarbonate 'foil', manufactured by a draw or cast process, is cut to shape and bonded to the substrate.

b) Spin coat (liquid material process)

Lacquer is applied to the inner diameter of the substrate, and spun out to cover the entire surface. Simple in principle, spin coating such a thick layer with the requisite uniformity is, in fact, a highly demanding task.

In both cases, the disc is finished with a thin layer of hard-coating material which protects it from surface scratches and has anti-fingerprint properties.

Irrespective of which process is used, the thin cover layer introduces a raft of new challenges for inspection and measurement. Our objective was to explore the implications for our technology, and to develop an in-line inspection system which meets all the requirements for BD production. Although the journey revealed a few surprises, we have reached our goal with the universal acceptance of our IQPC scanner. Here, we offer an insight into some of the discoveries we've made along the way.

Cover layer inspection

The cover layer must be precisely centred on the substrate, completely covering the sputter layer but, in the case of the foil process, not exceeding the outer edge of the disc. Failure to cover the sputter material leaves it exposed to the risk of corrosion, which could spread to the information area. If the cover foil extends beyond the edge of the disc (Figure 2), substrate and cover layer may start to separate.

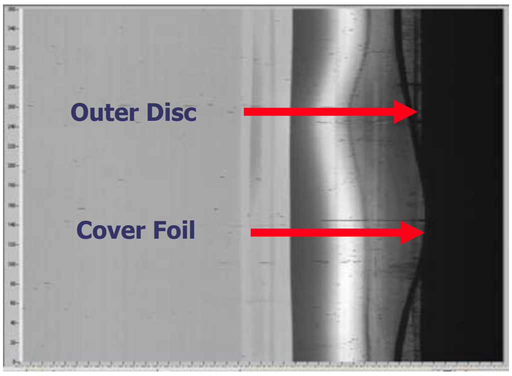


Figure 2: Cover foil exceeds outer edge of disc

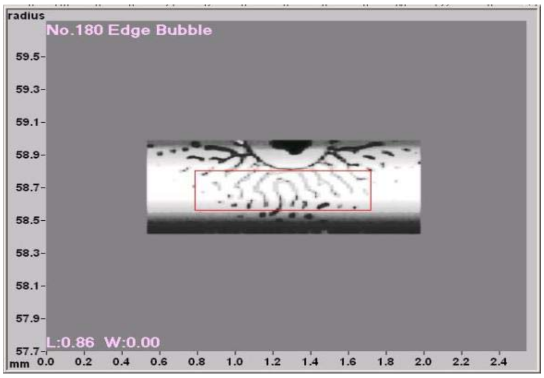


Figure 3: Outer edge inclusion

Cover foil bonding must be free of inclusions, even at the outer edge. Although many outer-edge defects are unimportant, inclusions can separate the cover foil from the substrate. Figure 3 shows a typical separation defect, caused by an included particle. This type of separation can easily spread into the data area, leading to read-out problems and damage from corrosion.

So, outer edge inspection is a critical new task for the scanner. In the information area, reflectivity is highly uniform and any non-uniformities can be detected relatively easily. At the extremes of the disc, things become more difficult: the various layers which terminate in the outer area, for example, do not have clearly-defined edges and, as we can see in Figure 2, there is a huge variation in reflectivity.

The scanner must evaluate vast amounts of data to identify defects against such a non-uniform background. IQPC is equipped with individual processors for different tasks so that it can perform multiple measurement and data-processing operations in parallel; this exceptionally high processing capability, coupled with sophisticated image analysis, enables it to detect and classify defects even in the difficult outer or inner areas.

At the final step in the process, it is important to monitor the uniformity of the hard coating layer. The high numerical aperture of the pick-up head makes it highly susceptible to focus errors arising from localised surface deformation. So, although there is no formal specification (except absolute thickness tolerances) for the uniformity of the hard-coating layer, its importance is implied in the focus error limit: less than 45nm for BD, compared to 200nm for DVD.

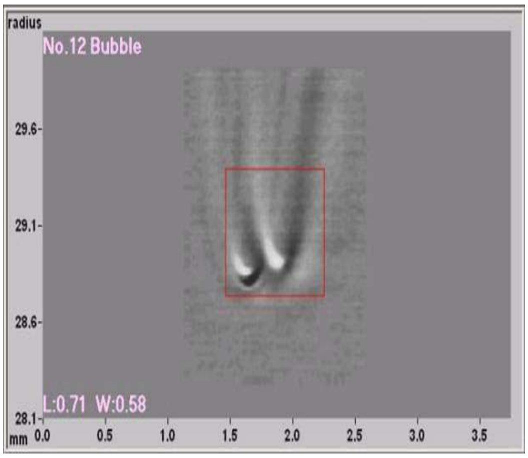


Figure 4: Hard-coating defect

The majority of hard coating defects have no contrast: they neither absorb nor reflect light. They can only be detected using a near darkfield arrangement, which IQPC incorporates within its camera. The scanner's data processing capability enables it to evaluate the entire area around a defect, analyse all its properties, and give a definitive classification. For example, the head of the comet shown in Figure 4 would give a small contrast, but it is also necessary to identify the long tail which could cause a focus error.

Surface defects

Larger defects can be accepted on the surface of the disc than in the information layer, so – whatever the format - it is important to discriminate between them.

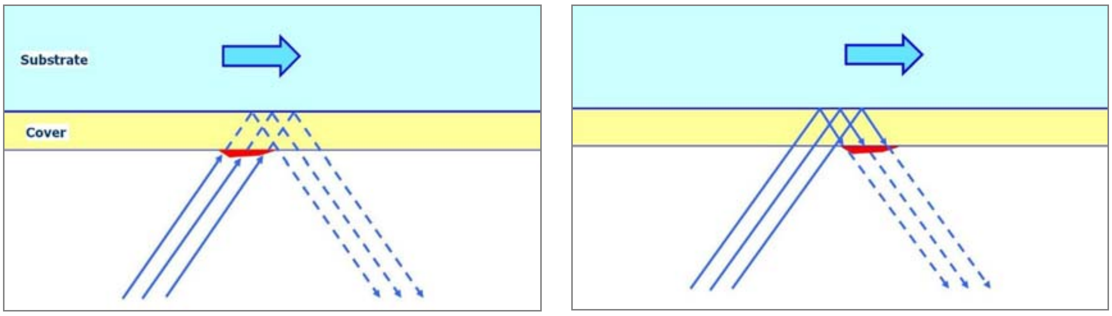


Figure 5: Surface defect blocks the incoming beam then the reflected beam, creating a dual image

As a surface defect is scanned, first the incoming is blocked, then the reflected beam (Figure 5), creating a characteristic dual image at the camera. The two images are identical, but the echo image has a slightly lower contrast than that of the defect itself. The distance between the images depends on angle of incidence and cover thickness: approximately 1mm for CD, 0.5mm for DVD, but just 60mu for BD.

The allowable limit for a defect in the information layer for DVD is 100mu, so provided that the defect is less than 0.5mm the two images are always clearly separated, making it reasonably straightforward to identify and classify surface defects.

The thinness of the BD cover layer makes it much more difficult for the inspection system to identify and classify surface defects. An 80mu surface defect and an image separation of 60mu would generate a single image of around 140mu; the defect could not be identified as an acceptable surface defect and the disc would be rejected. Cost-effective production is paramount, so it is essential to measure and classify defects accurately.

A traditional approach to this problem involves a two-camera scanning system. One camera at zero angle of incidence - where the defect and its echo coincide - determines the defect size; correlation with results from another camera at a different angle of incidence reveals whether it is a surface defect. This method works only when the echo image has sufficient contrast to exceed the threshold in both cameras; in addition, there is an inaccuracy of approximately twice the pixel resolution – almost the same value as the echo distance - in correlating defects from the two cameras.

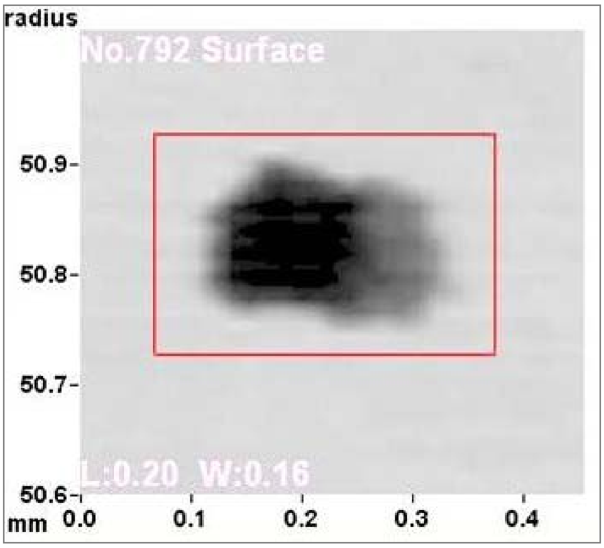


Figure 6: Surface defect and echo image

IQPC takes a novel approach, drawing upon our experience and co-operation with leading development partners. First, we recognised that by enhancing the contrast we could clearly identify the defect and its echo from one single camera channel (Figure 6); then, by analysing the data, we found that there is always a detectable difference between the defect and echo images, irrespective of how irregular the defect may be.

When we detect an event, we automatically evaluate an area around it and analyse the complete greyscale, with no minimum threshold; in this way we are able to capture events which may otherwise be overlooked (eg: by the two-camera method). By using all the characteristics which we can detect we are able not only to safely identify surface defects, but also to accurately determine their size.

Measuring up

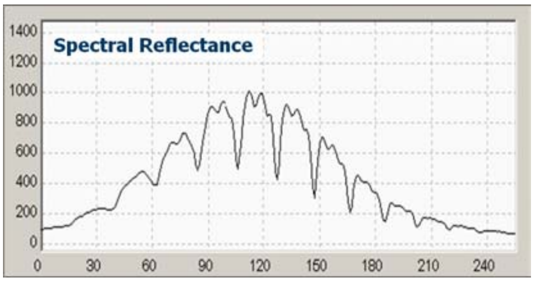
While the thin cover layer makes BD relatively more tolerant of birefringence than earlier formats, the high numerical aperture means that the contribution from perpendicular birefringence becomes significant and must be monitored for the first time.

Cover and space layer thicknesses must, of course, be precisely controlled, but once again the slim profile of the BD cover layer makes new demands on measurement technology.

Space layer, cover layer and substrate thicknesses are measured by an interferometer principle. The modulation of the reflected spectrum is analysed using a Fourier transformation; as a rule, high frequency modulation is caused by thick layers and low frequency modulation by thin layers.

Looking at dual-layer DVD, we have a space layer of 50 – 60mu, and a cover layer of 600mu, a ratio of 10 to 1. The Fourier transformation yields well-spaced and clearly defined peaks which can easily be evaluated.

For dual-layer BD, the space layer is 25mu and the cover layer 75mu, a ratio of just 3 to 1. The high frequency and low frequency components of spectral reflectance are very close together; in addition, the reflectance from layers L0 and L1 is very close, which causes the appearance of significant amplitude higher harmonics from the space layer. As a result, the reflected intensity no longer has a sinusoidal modulation as in the case of DVD, and the Fourier spectrum shows not only the space layer peak but also its higher harmonics (Figure 7). In fact, the position of the cover layer peak coincides almost exactly with the third harmonic of space layer, and because of its smaller contribution, is engulfed.



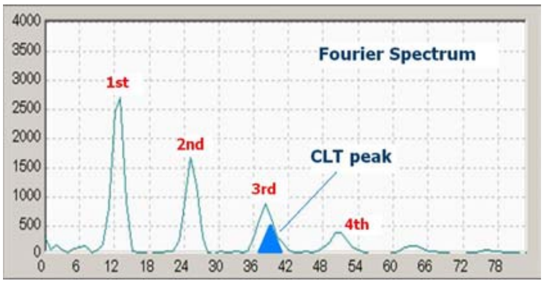


Figure 7: BD spectral reflectance and its Fourier transformation; CLT and SLT peaks coincide

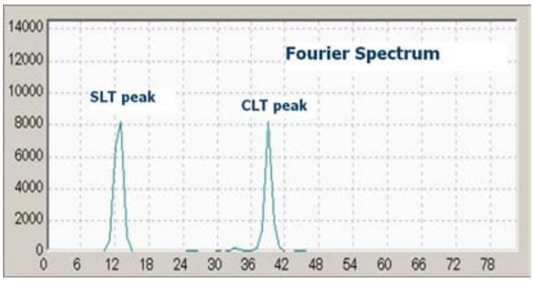


Figure 8: Stochastic filter isolates the peaks

So, the standard method for calculating layer thickness cannot be used to measure the cover layer. It is, however, a critical process parameter, so a new technique is necessary. We have devised a special 'stochastic filter' (Figure 8) which isolates the modulation originating from the cover layer. Once again, this was only possible because of the advanced data processing capability of IQPC.

Conclusion

In terms of its impact upon the manufacturing process, the BD cover layer is surely the most significant development in the evolution of the optical disc. From the inspection system supplier's perspective, it challenges established methodologies and demands creative solutions to new problems. And, of course, the ability to process huge volumes of data without compromising cycles times. It's been an exciting voyage of discovery!

Claire Backshall
Sales & Marketing
dr.schwab Inspection Technology GmbH
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