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Optical Monitoring System Enables Greater Accuracy in Thin-Film Coatings

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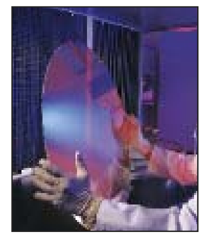

One of the biggest challenges in applying optical thin-film coatings is maintaining accurate layer thickness. Variations in thickness affect all coatings, but any coating with a slope is more affected because the change in thickness will cause the slope to move, changing the transmission and reflection values. The way to combat that problem is to use an effective process monitoring system. To learn more, see the feature article on page 2.

(*Image courtesy of PG&O*)

Optical Monitoring System — *Enables* — Greater Accuracy In Thin-Film Coatings

The challenges in achieving greater accuracy in optical thin-film coatings, both historically and in today's coating processes, are many and deserve our scrutiny. The "old" way of designing and manufacturing coatings was to use a thin-film design software like TFCalc, which included analysis, optimization, results, optical data, and coating files. In this instance, one would create a design using high-, medium-, and low-index materials to come up with a theoretical design (Figure 1). The design of the coatings would be the easy part; the hard part comes in replicating the design thickness and the material indexes inside the coating chamber each and every time.

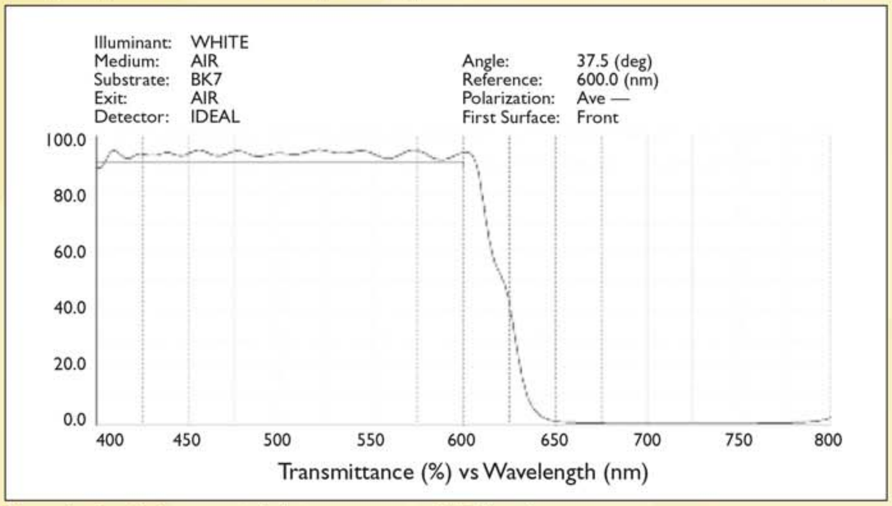

Figure 1. Graph shows optical design curve using TFCalc software.

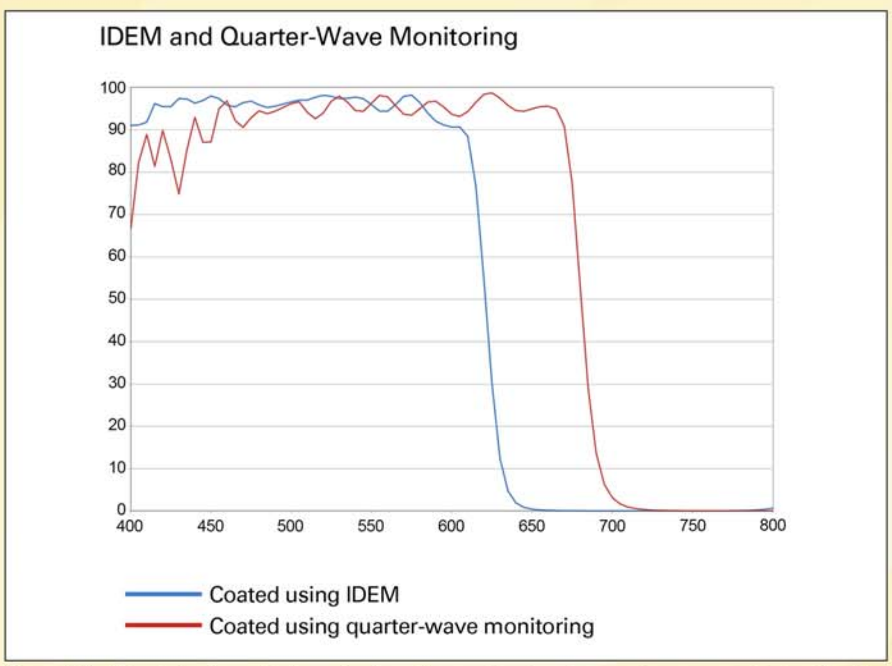

Figure 2. Red line indicates optical monitoring with overshoots using quarter-wave monitoring; the blue line is the coating curve using the new IDEM monitoring system.

All coatings are impacted when the layer thickness is not accurate. Variations in thickness affect all coatings, but any coating with a slope, such as a longwave pass (LWP) and/or shortwave pass (SWP), is often more affected by changes in thickness. Because the change in thickness will cause the slope to move, which in turn, causes the transmission and reflection values to change, it is essential to have an effective process monitoring system in place.

Historically, there have been two ways to monitor the layers when you coat them. One method is to use a crystal to monitor the physical thickness of your layer. The problem with using crystal monitoring is that crystals are very sensitive to temperature and pressure, and therefore, are only accurate to around ±5%. When you consider that most coatings can have as many as 50 layers, and you have an error window of ±5%, you can end up with a coating that is way out of specification.

The second method, and better choice, is to use a quarter-wave monitoring system with overshoots. Based on the layer thickness and work-to-monitor ratios, you can calculate how many quarter waves it would take to achieve the correct layer thickness. This technique is accurate to ±2%, yielding better results than crystal monitoring. However a factor of ±2% can still be problematic, especially over long runs.

Both of these traditional monitoring techniques have a fundamental shortcoming: There is no sure way of knowing if the index dispersion of your material remains the same as your design during the actual process of evaporating your material. If your material index is different, then your coating will not meet the specification.

The new, real-time optical monitoring system that Precision Glass & Optics (PG&O) has implemented has the capability of calculating the thickness of each layer to within 1 nm of the design thickness. It also accurately shows you what the index dispersion is during the coating process, so you know if and when there is an issue. The new Eddy Company SpectraLock system is an in-situ, full-spectrum optical monitoring and rate control system that allows the production of single and multi-layered thin films with ultra-precision and accuracy that had been previously unattainable.

Index dispersion is the variation of refractive index of a material as a function of wavelength. The new monitoring system is based on this unique technology and is called "index dispersion enhanced monitoring," or IDEM. It produces optical coatings that precisely match the optical design every time, without iteration or error. It gives the user the ability to match the true index dispersion of each deposition material and the individual coating chamber characteristics, making it possible for the thin film design to match the actual coating produced (Figure 2).

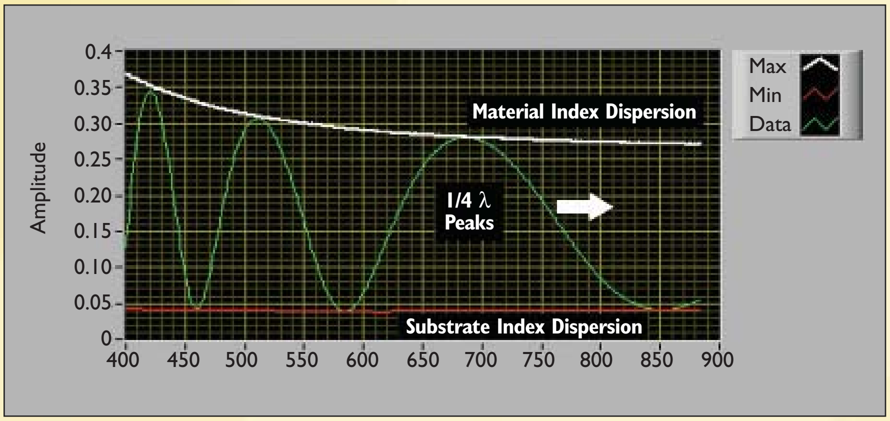

Figure 3. SpectraLock display during calibration process. (Graph courtesy of Eddy Company).

Figure 4. SpectraLock Controller and IDEM software screen capture during monitoring process.

Prior to this innovation, thin film design programs and optical coating systems have used standard materials reference table values for refractive index dispersion in the design and monitoring of the coatings. Unfortunately, the refractive index dispersion for each material in any given optical coating process deviates from the standards by a small amount.

As mentioned earlier, these small errors will multiply with each additional layer applied. In the past, in order to achieve successful results, it has required expert compensation by highly trained specialists. With the IDEM system in place, the coating thickness can be determined from zero up and the index dispersion can be seen from 1nm. In other words, as each optical coating is layered, the IDEM provides rate control and process monitoring throughout each layer.

How It Works

The new IDEM is an automated, full-spectrum optical monitoring system that provides calibration of the exact refractive index dispersion for each material substrate and process you use (Figure 3). Before fabrication of the designed coatings begins, a 2000 nm - 3000 nm calibration layer is deposited on witness chips and sample substrates for each coating process that is to be used. The refractive index dispersion of the coating on each witness chip is measured and the curves are stored for future use. Then the substrate samples are measured to determine the monitor-to-work ratio for each material. These process index dispersions and monitor-to-work ratios are translated and loaded into both the thin film design software program and the SpectraLock controller for precise coating thickness control at each layer (Figure 4).

This is the first commercially available instrument that is capable of measuring in-situ the broadband optical index dispersion produced by the coating machine.

Accuracy With Multiple Coating Layers

Wayne Rodgers, president of Eddy Company, notes, “When developing the IDEM system we were concerned about how many layers we could put on a chip with relative accuracy. So we put a 5-layer coating using 1-layer per chip, 2-layers per chip, 3-layers per chip, up to all 5 layers on one chip. We also ran two interrupted layer coatings. We interrupted it by removing the USB connection between the computer and the monitor…everything shut down. We reconnected and restarted the process. When we measured these, we got a little bit of a surprise. Prior to the full-spectrum monitoring, we've used single-wavelength monitoring and we've usually gotten within 1 percent from run to run. We assumed that this 1 percent was caused basically by the monitor-to-work ratio change. After these runs and we saw 0.19 percent or 0.2 percent deviation, we then realized the main cause of deviation was the monitoring technique and probably a 0.2 percent is somewhere in the monitor-to-work ratio problems."

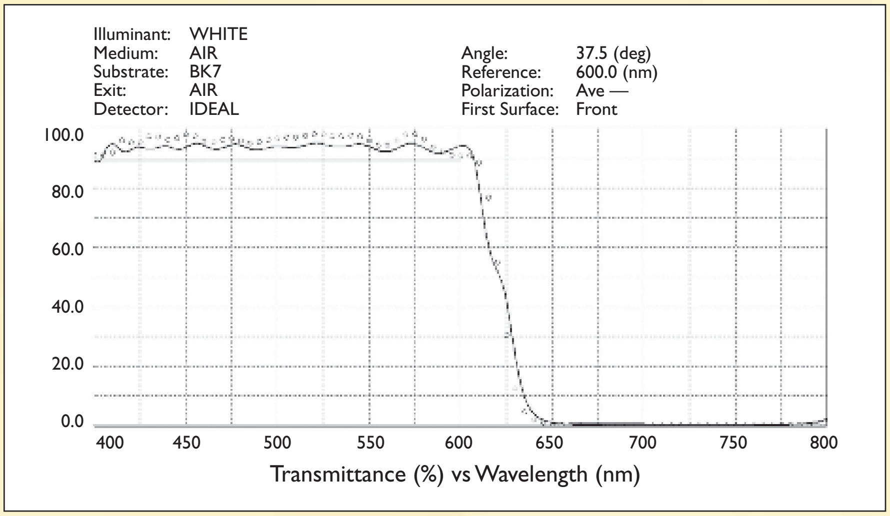

Figure 5. Graph illustrates improved accuracy after the IDEM system was installed at PG&O. The original design curve is shown, with the actual coating data imported, represented by circles and superimposed over the design.

Mr. Rodgers continues, "With this system of index dispersion and the correct monitor-to-work ratio, we can make a 37-layer design and just plain coat it; we measure, and it matches the design. There are no test runs necessary, there's no advantage to even doing a test run, because during the monitoring process we can see if the index dispersion of the material has changed from drift, or other factors."

Conclusion

With the new capabilities available using the index dispersion enhanced monitoring system, the company can now produce optical thin films that perfectly match the design programs and accurately predict the films that the coating chambers produce with optical thickness monitoring and control from 1 nm to over 5,000 nm (Figure 5). This makes the new optical thin films about 10x more precise than ever before.

This article was written by Dan Bukaty, Jr., President, Precision Glass & Optics (PG&O®). For more information, contact Mr. Bukaty at danjr@pgo.com or visit ***http://info.hotims.com/65857-200.***