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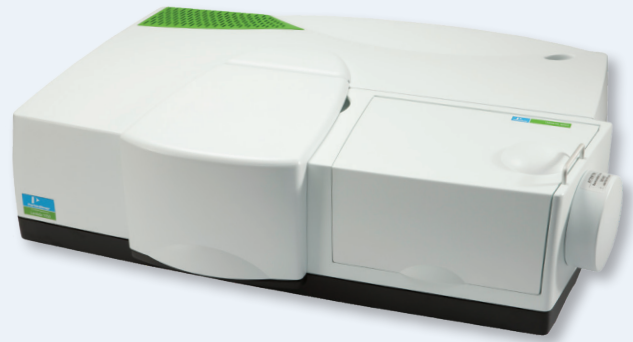
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## Measurement of Enhanced Specular Reflector (ESR) Films Using a LAMBDA 1050+ UV/Vis/NIR Spectrometer and URA Accessory

### Introduction

Enhanced Specular Reflector (ESR) multilayer polymeric interference mirrors were pioneered in the late 1960's.<sup>1</sup>

Enhanced Specular

Reflectors (ESR) such as 3M Vikuiti™ ([www.vikuiti.com](http://www.vikuiti.com)) is ultra-high reflective, mirror-like optical enhancement films used for high efficiency brightness enhancement in light recycling LCD applications. Utilizing multi-layer polymer technology, these films are non-metallic, flexible, and are very thin (i.e., 65 microns). The thin film construction lends itself for incorporation into a wide variety of configurations and devices, including phones, televisions, and monitors. Light recycling conserves energy by increasing the brightness of displays without any increase in power requirements.

Currently, ESR films are integrated into the backlight of nearly all LCD displays – from TVs and desktop displays to laptops, tablets, phones, and mobile devices. ESR films can also be used to manage and optimize light for applications in other industries, such as architectural lighting, automotive, and solar lighting, such as Tubular Daylighting Devices (TDDs, an example of which is shown in Figure 3).



Figure 1. A rolled sheet of Enhanced Specular Reflector (ESR) polymer film.

ESR films typically reflect >98% of light, allowing more light to be recycled and reflected for a brighter display. This reduces the amount of energy needed to power an LCD display and helps broaden the viewing angle by increasing the brightness of light coming through the display.

A simplified diagram of a typical LCD display is shown in Figure 2, illustrating where the ESR film is used.

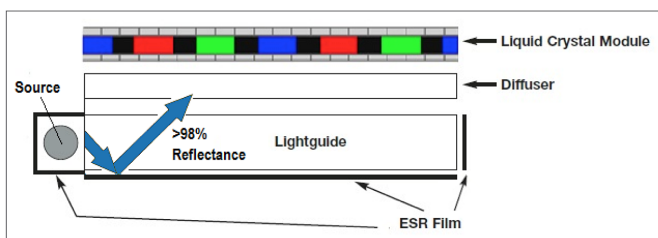


Figure 2. Diagram of a simplified LCD panel illustrating where ESR film is typically used.

Tubular Daylighting Devices (TDDs) capture sunlight using a rooftop dome, and then transfer it indoors through a reflective tube that runs from the roof to the ceiling, Figure 3. From there, the light is evenly dispersed into the interior space using a diffuser. For most commercial TDDs, ESR film is used in the interior of the light transfer tube to achieve high specular reflectivity (up to 99.7% reflective in the visible spectrum), thereby delivering maximum visible light with minimal solar heat gain. The light output of a TDD is high, providing the same amount of light you would expect from a skylight many times its size. TDDs conserve energy and reduce environmental pollution by allowing electric lights to be switched off during the day.

### The Measurement Challenge

To verify the performance of ESR films represents a measurement challenge for many commercial spectrophotometer systems. Not only are ESR films designed to achieve very high reflectance (>98% R) in the visible spectral range, but are required to



Figure 3. Example of Tubular Daylighting Devices (TDDs) which capture sunlight using a rooftop dome, and then transfer it indoors through a reflective tube that runs from the roof to the ceiling. For most commercial TDDs, ESR film is used in the interior of the light transfer tube to achieve high specular reflectivity (up to 99.7% reflective in the visible spectrum) thereby delivering maximum visible light.

achieve this high reflectance at any angle of incidence and under any state of light polarization. Therefore, the ESR films need to be measured with an absolute variable angle reflectance accessory combined with an automated polarization accessory (relative specular reflectance accessories inherently do not have the accuracy to measure the very high reflectance from ESR films). Lastly, because the ESR films are ultra thin, there is an additional challenge for a user to mount the ESR films properly in the reflectance sample fixture so that the surface of the film remains perfectly flat to the incident beam.

The PerkinElmer LAMBDA™ 1050+ fitted with the Universal Reflectance Accessory (URA) is an ideal tool for studying the properties of these ultra-thin films. A picture of a LAMBDA 1050+ fitted with the URA accessory is shown in Figure 4. The PerkinElmer LAMBDA 1050+ is a state-of-the-art research UV/Vis/NIR spectrometer utilizing 3D (three detector) technology. Because the LAMBDA 1050+ incorporates holographic gratings in a true Littrow double monochromator design, the stray radiation level is specified at < 0.00007%T in the UV/Vis range. The Universal Reflectance Accessory (URA) is a recent PerkinElmer development for high accuracy absolute specular reflectance. This unique accessory offers angles from 0° to 70°, is motorized in 0.5° increments, and does not have a sample holder. Samples are simply laid flat on a measuring

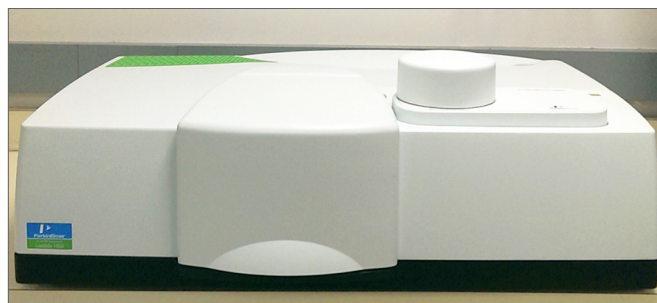


Figure 4. LAMBDA 1050+ with Universal Reflectance Accessory (URA).



Figure 5. Sample measurement surface of the URA accessory. Using internal kinematic optics the light beam is directed to the measurement port at the center. Samples lay flat covering the port.

plate on the top of the accessory, where the beam is directed to a measurement port by the internal optics (Figure 5). The accessory has its own kinematic detector module and pathlength compensator, maintaining identical pathlengths and angle of incidences between the background and the sample measurement.

Measurements with the URA consist of a baseline measurement and then a sample measurement that involves one additional reflection at the sample. Switching between baseline and sample configurations involves rotating one mirror and translating the detector assembly automatically. This is illustrated for measurement at 70 ° incidence (Figure 6). The input mirror rotates to direct the beam onto the measurement sample. At the same time, the detector assembly is translated to maintain the same relationship with the input beam. The total optical path remains the same so that the ratio of the two measurements gives the reflectance of the sample.

Having the ability to simply lay the samples flat on the measurement port of the URA is extremely helpful in obtaining accurate specular reflectance measurements, as the thin nature of these films, typically 65 microns, makes these films very difficult to measure in a vertical sample holder in a conventional absolute specular reflectance accessory. Fitting the ultra-thin ESR films properly in a sample holder designed for glass and filters makes it highly unlikely the film will be held perfectly flat to the incident beam. If the thin ESR film is not perfectly flat to the incident beam, the measurement results for any angle of incidence and polarization state will be in error.

Control of the URA is integrated into UVWinlab™ V6 software for the LAMBDA series, allowing the sequence of angles and the measurement spot size to be determined by the user. Once a method is created, the measurements proceed automatically. The URA accessory settings in UVWinlab are shown in Figure 7.

A single measurement angle can be entered on this page, of UVWinlab or alternatively a sequence of measurement angles can be entered into the sample table. Of significance, the measurement port beam spot size can be controlled here. The URA accessory is unique in its capability to adjust the beam spot

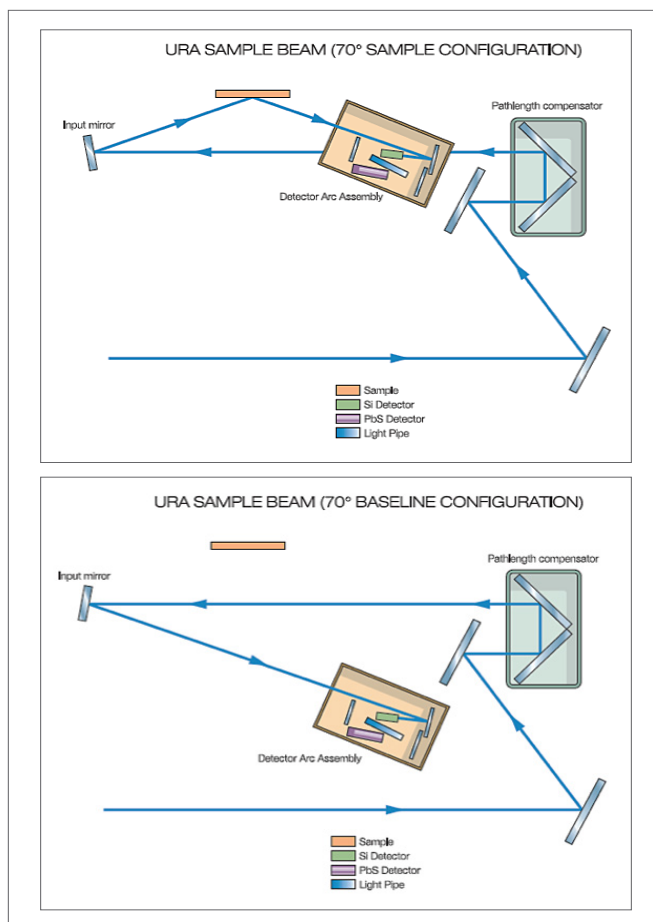


Figure 6. Illustrated are the URA sample and baseline measurement configurations at 70°.

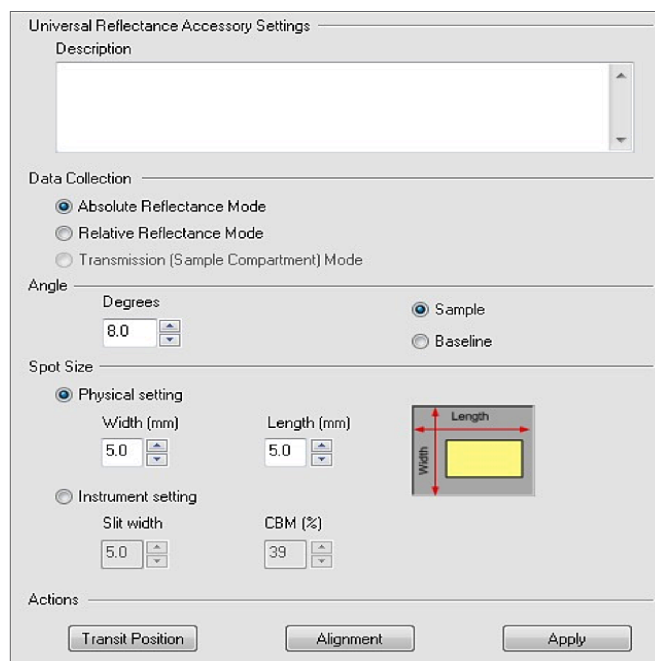


Figure 7. Shown is the Universal Reflectance Accessory settings page of UVWinlab. In addition to the measurement angle, the beam spot size can be finely adjusted.

size on the sample in the range of 0.1 x 0.1 mm to 5.0 x 5.0 mm in 0.1 mm increments (note – minimum useable setting is approximately 0.5 x 0.5 mm). This range allows typically difficult small samples to be accommodated easily.

In addition to the installation of the URA accessory, an automated polarization drive accessory is fitted in the sample compartment area of the LAMBDA 1050+ Figure 8. This polarizer drive, when fitted with a Glan-Taylor or Glan-Thompson calcite polarization crystal, allows the polarization state of the sample beam to be modified in the range of 0-360 degrees. In the UVWinlab method, if the polarizer is set to "Sample Table", labeled 1 in Figure 8. The polarization angles can be conveniently entered in the sample table sequence, allowing automated operation.

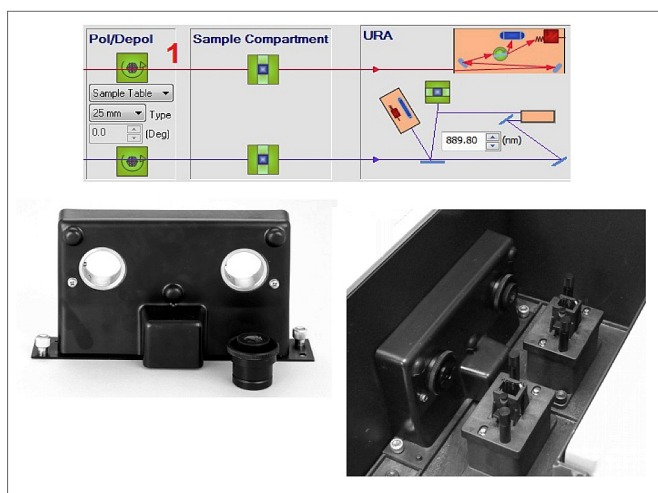


Figure 8. Polarizer drive accessory (left) and drive accessory mounted in the LAMBDA 1050+ sample compartment (right). With this motorized accessory the polarization angles can be programmed automatically.

### Measurement of ESR Films Using the LAMBDA 1050+

The LAMBDA 1050+ is operated using UVWinlab V6 software. This easy to use software uses a modern, state-of-the-art, workflow design, and is Windows® 8 compatible. The software allows a method to be designed integrating the operation of the URA and polarizer accessories into the sample sequence.

In the first series of measurements, the ESR film sample was scanned from 1200 to 350 nm at five angles with the URA, 8, 15, 30, 45, and 60 degrees, with the common beam depolarizer (CBD) installed to obtain depolarized light. The sample table that was created is shown below. Shown are the entry columns for width and length of the URA measurement beam (4.0 x 4.0 mm was used), and the URA angle.

Sample ID	Description	Type	CBDep	Width	Length	Angle
1	film1 polymer high reflector	8 Measurement 1	On	4.0	4.0	8.0
2	film1 polymer high reflector	15 Measurement 2	On	4.0	4.0	15.0
3	film1 polymer high reflector	30 Measurement 3	On	4.0	4.0	30.0
4	film1 polymer high reflector	45 Measurement 4	On	4.0	4.0	45.0
5	film1 polymer high reflector	60 Measurement 5	On	4.0	4.0	60.0

Figure 9. Sample Table example.

Once the sample table is defined, the measurements with the URA at the angles entered will proceed automatically. The background corrections are automatically acquired and stored for each angle. Shown in Figure 10 is the overlaid data from these measurements. The slight interference pattern that can be observed is normal for a thin film having many layers.

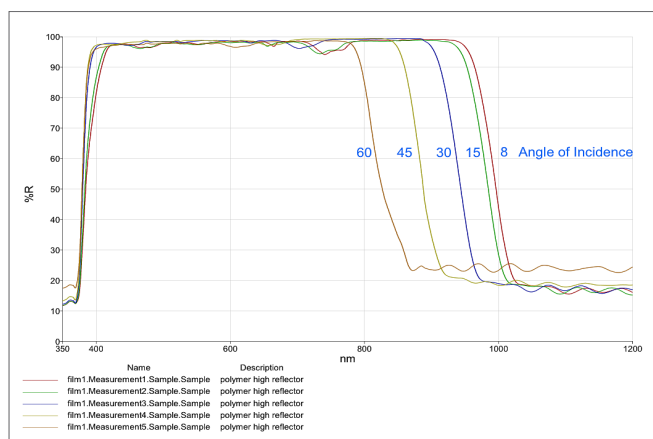


Figure 10. Absolute reflectance spectra of an ESR film sample collected with the LAMBDA 1050+ and URA accessory from 1200 to 350 nm. URA angles of 8, 15, 30, 45, and 60 degrees were used, with a 4.0 x 4.0 mm beam spot size, and with depolarized light. An expansion of the spectra is shown in Figure 11.

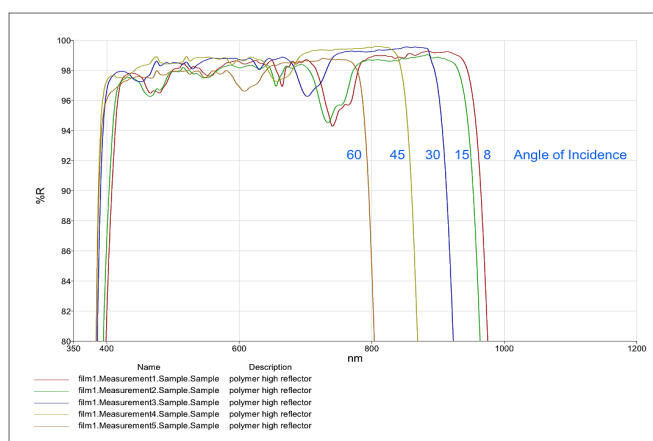


Figure 11. Expanded view of the spectra shown in Figure 10.

For this example the mean reflectance in the visible range was calculated in UVWinlab with a data processing equation and was determined to be 98% R or greater, Figure 12. Note that minor amounts of surface abrasion of the ESR film and minute particulates on the film surface can affect the reflectivity values. The URA collects only specular reflection, and not scatter. Therefore, if it is observed that the curves tail down as the blue region is approached, likely this is due to scatter loss.

Sample ID	Description	Mean %R (720-420 nm)
✓ 1 film1.Measurement1.Sample.Sample	polymer high reflector	98.24
✓ 2 film1.Measurement2.Sample.Sample	polymer high reflector	98.01
✓ 3 film1.Measurement3.Sample.Sample	polymer high reflector	98.50
✓ 4 film1.Measurement4.Sample.Sample	polymer high reflector	98.70
✓ 5 film1.Measurement5.Sample.Sample	polymer high reflector	98.04

Figure 12. Calculated mean value displayed in table.

In the second series of measurements of an ESR film sample, the effect of polarized light as well as incident angle was investigated with the URA and a LAMBDA 1050+ fitted with a polarizer drive and Glan-Taylor calcite crystal. The ESR film sample was scanned from 1200 to 350 nm at four angles with the URA, 15, 30, 45, and 60 degrees, with polarization angles of 0, 30, 45, and 90 degrees. In theory, if the ESR film is performing properly, the visible reflectivity should remain high regardless of the angle of incidence or polarization state.

For these measurements, the UVWinlab sample table that was created is shown in Figure 13. Shown are the entry columns for width and length of the URA measurement beam (4.5 x 4.5 mm was used), the URA angle, and the polarization angle.

Sample ID	Description	Type	CBDep	Width	Length	Angle	Pol. Angle
1	Sample1	polymer high reflector	Measurement 1	On	4.5	4.5	15.0 0.00
2	Sample1	polymer high reflector	Measurement 2	On	4.5	4.5	15.0 30.00
3	Sample1	polymer high reflector	Measurement 3	On	4.5	4.5	15.0 45.00
4	Sample1	polymer high reflector	Measurement 4	On	4.5	4.5	15.0 90.00
5	Sample2	polymer high reflector	Measurement 1	On	4.5	4.5	30.0 0.00
6	Sample2	polymer high reflector	Measurement 2	On	4.5	4.5	30.0 30.00
7	Sample2	polymer high reflector	Measurement 3	On	4.5	4.5	30.0 45.00
8	Sample2	polymer high reflector	Measurement 4	On	4.5	4.5	30.0 90.00
9	Sample3	polymer high reflector	Measurement 1	On	4.5	4.5	45.0 0.00
10	Sample3	polymer high reflector	Measurement 2	On	4.5	4.5	45.0 30.00
11	Sample3	polymer high reflector	Measurement 3	On	4.5	4.5	45.0 45.00
12	Sample3	polymer high reflector	Measurement 4	On	4.5	4.5	45.0 90.00
13	Sample4	polymer high reflector	Measurement 1	On	4.5	4.5	60.0 0.00
14	Sample4	polymer high reflector	Measurement 2	On	4.5	4.5	60.0 30.00
15	Sample4	polymer high reflector	Measurement 3	On	4.5	4.5	60.0 45.00
16	Sample4	polymer high reflector	Measurement 4	On	4.5	4.5	60.0 90.00

Figure 13. A sample table created for the measurement of ESR film. These measurements will verify the ESR reflectivity as a function of both incident angle and polarization angle.

The data obtained from the second series of measurements is shown in Figure 14. It can be observed that regardless of the angle of incidence, or the state of polarization, the visible reflectance remains high.

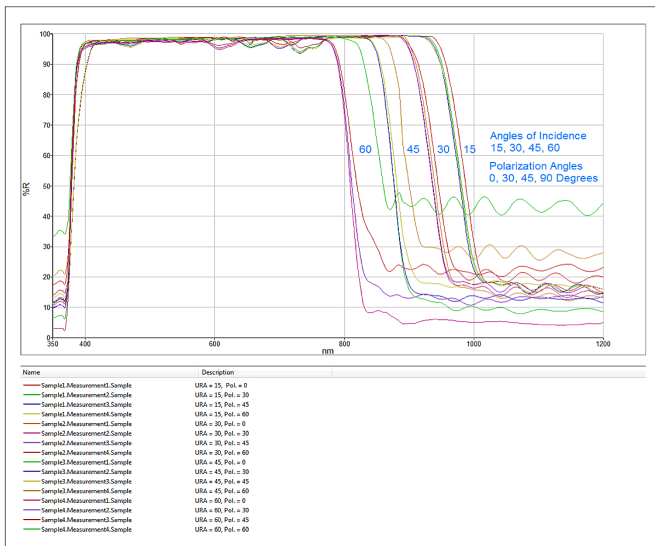


Figure 14. Shown here are the URA measurements of the ESR film sample at angles of incidence of 15, 30, 45, and 60 degrees. Each URA angle is measured with polarization angles of 0, 30, 45, and 90 degrees. This illustrates that the ESR film sample performs as designed, with reflectivity in the visible remaining high regardless of angle of incidence and polarization state.

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## Conclusion

The LAMBDA 1050+, fitted with the Universal Reflectance Accessory and automated polarizer drive, is proven to be an ideal tool to research the performance characteristics of Enhanced Specular Reflector (ESR) films. The design of these films offers high reflectivity in the visible range regardless of the angle of incidence, and the state of polarization. Because the ESR reflectivity is very high (> 98%), and the films are very thin, the measurement of these films will challenge conventional spectrophotometer systems and accessories. Accurate specular reflectance measurement of ESR films requires an absolute variable angle specular reflectance accessory, and to verify the polarization response, a polarizer accessory. As is shown in this application paper, adding the absolute variable angle motorized URA accessory and the motorized polarizer drive accessory to a LAMBDA 1050+ allows easy automated verification of the ESR film performance. Because the ESR films are very thin and flexible, proper mounting of these films in a conventional specular reflectance accessory having a vertical sample holder that was designed for holding rigid filters and glass, is very difficult. The unique design of the URA accessory (i.e., there is no sample holder and samples are merely laid flat on the top plate measurement sample port) ensures accurate reflectivity measurements of these films.

## References

1. Weber, M., Stover, C., Gilbert, L., Nevitt, T., Ouderkirk, J., "Giant Birefringent Optics in Multilayer Polymer Mirrors", Science, Vol. 287, March 31, 2000