TECHNICAL NOTE

UV/Vis/NIR

Reflectance Measurements of Materials Used in the Solar Industry

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Selecting the Appropriate Accessories for UV/Vis/NIR Measurements

Introduction

One of the most common measurements made by the solar energy industry today is quantification of a material's surface reflectance. These materials are as diverse as metal coatings, semiconductor coatings, anti-reflective coatings on window material, as well as the window material itself. While both transmission and reflectance are of interest to the industry, we will consider only reflectance measurements in this technical note. These measurements are most commonly made between 300 nm and 1500 nm which is where the solar cell is responsive to energy from the sun. Reflection comes in two varieties, specular and diffuse. This technical note will concentrate on the instrumental accessories used to measure both types of reflection and compare/contrast spectra collected on the accessories.

Unfortunately many materials manifest a combination of both specular and diffuse reflectance. This can present a problem in selection of the best reflectance accessory that will yield correct intensity data (%R) with minimal spectral artifacts. The primary goal of this technical note is to guide the user through the accessory selection process for different specular/diffuse samples. This will be achieved by measuring identical samples with varying contributions of diffuse and specular reflection, on three different reflection accessories, and then comparing the spectra generated.

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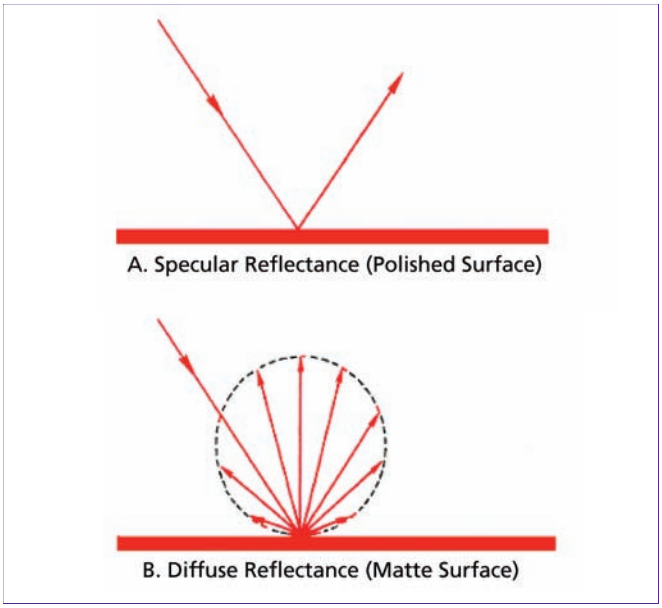

Figure 1. Types of reflection.

Specular reflection (Figure 1-A) is generated by a smooth surface. The light ray's angle of incidence is equal to the angle of reflection; therefore, specular materials frequently produce images on their surface (mirror). Specular reflectance is measured by a number of different types of accessories (VW, VN, and Universal Reflectance Accessory).

Diffuse reflection (Figure 1-B) is generated by a rough surface. In this case, the light ray's incidence angle gives rise to a multiplicity of reflection angles; therefore, images are not produced. Diffuse reflectance is how people see the world since the vast majority of objects in the world are diffuse reflectors. Diffuse reflection is measured by integrating spheres, two sizes are available, small (60 mm diameter) and large (150 mm diameter).

Definitions

Relative Specular Reflectance Accessory – This refers to the simplest and least expensive specular accessory. A relative specular accessory must use a calibrated reference mirror to measure the background values. When samples are measured, a mathematical calculation must be performed using the known values from the reference mirror to correct the samples to absolute reflectance.

Absolute Specular Reflectance Accessory – This type of specular accessory does not require a reference mirror to make an absolute reflectance measurement. The accessory is designed with moving transfer optics (mirrors) that have different configurations for background collection and sample measurement. As long as the transfer optics move in such a way that the same mirrors are used for the background and sample collection, and the total distance along the beam path is the same between background and sample collection, then the reflectance measurement is absolute by accessory design. The most common types of absolute specular accessories are the VN, VW and Universal Reflectance Accessory (URA). The VN (single sample bounce) and VW (double sample bounce) accessories are named from the beam path geometry of the background (V) and the sample (N and W) collection modes. Mirror movement between background and sample modes is by hand. The URA is a variable angle, single sample bounce, VN style accessory where the mirror movement and incidence angle selection are totally automated by electronic stepper motors.

General Integrating Sphere – Figure 2 shows the general optical design for an integrating sphere. The transfer optics for the reference beam (M3, M4) and the sample beam (M1, M2) direct the light through open holes in the Spectralon® sphere body into the sphere where they strike the sample reflectance port and reference port areas. In the interior of the sphere you can see through the center-mount port the baffles that shield the detectors from first bounce sample reflectance or transmittance. Under normal measurement conditions the sample reflectance port and the reference port are covered by either a Spectralon® plate or sample material. The transmittance port and reference beam entry port are usually open during reflectance measurements and are areas where light diffusely reflected from the sample can escape from the sphere.

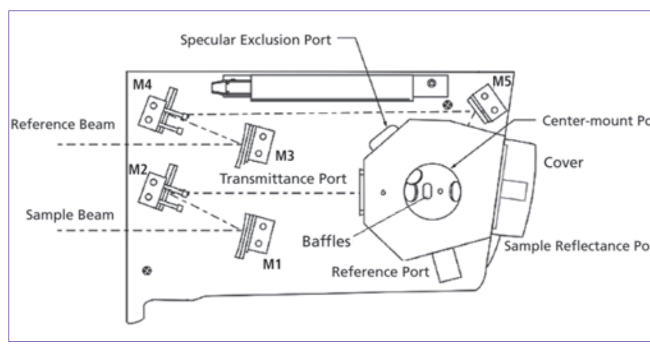

Figure 2. Basic optical layout for a double beam integrating sphere.

60 mm Integrating Sphere – This is a low cost reflectance accessory that measures both diffuse and total reflectance. It consists of a hollow 60 mm sphere of highly reflective Spectralon® polymer with two ports for the sample and reference beam to enter and two ports for placement of sample and reference material. Background collection is performed by placing two Spectralon® plates at the sample and reference ports. Since Spectralon® has a diffuse reflectance of > 99.0 %R, the reflectance of spheres can be assumed to be close to absolute %R. Because of the size of the sphere and the lack of baffling of the detectors in the sphere from first bounce sample reflectance, this sphere type is subject to several types of spectral artifact such as incorrect %R values and steps at instrumental filter and detector change points.

150 mm Integrating Sphere – This larger 150 mm sphere operates in a similar fashion to its smaller 60 mm counterpart. The two notable differences are its larger sphere diameter and the baffling of the internal detectors via Spectralon® coated paddles. The larger sphere size makes the port area for the sample and reference beams a smaller proportion of the total sphere area than in the smaller 60 mm sphere. The baffles prevent a first bounce reflectance ray from the sample from striking the detectors. The ideal number of bounces in a sphere is around ten. The 150 mm sphere is typically known as a standard color sphere. Its design is controlled by the color industry regulatory agencies to ensure uniformity of data between spheres manufactured by different companies. Its design also eliminates or reduces artifacts present in smaller non-regulation spheres.

Experimental

Reflectance accessory evaluation employed four samples that span the range of typical solar industry materials. Sample 1 is a diffuse material with a small specular component, Sample 2 is a clear specular coating of low intensity, Sample 3 is a colored specular coating of medium intensity, and Sample 4 is a specular semi-conductor material of high intensity.

Each of the four samples was measured on a 60 mm integrating sphere, a 150 mm integrating sphere, and a URA accessory. All sphere measurements were 8 degree hemispherical in total reflectance collection mode. The URA measurements were at 8 degree angle of incidence. All other instrumental parameters were the same for all four samples.

Results and Discussion

Two basic characteristics of integrating spheres relate to their photometric accuracy and freedom from such artifacts as steps at filter and detector changes. These are sphere size (diameter) and the presence of internal baffles that protect the detectors from first bounce reflectance from the sample. The nature of the artifacts and inaccuracies depends on the sample's reflection intensity and properties (specular or diffuse).

Figure 3 plots the spectra from Sample 1 (diffuse material with a small specular component) measured by the two types of integrating spheres. The spectra are qualitatively similar yet different quantitatively. The textured sample in Figure 3 is a diffuse sample. So why are the spectra different when measured on different size spheres? All spheres must have ports for the instrumental beam to enter. Light that is reflected from the sample can escape through these ports and is therefore not measured. The larger the sphere is, the smaller the area of the ports to the total surface area of the sphere. The spectra from the 150 mm sphere is higher because the relative hole to surface area is smaller than the 60 mm sphere. Therefore, more diffusely reflected light from the sample is collected. So which spectra are correct? Neither technically. The 150 mm sphere data are, however, much closer to the absolute diffuse reflectance of the sample (within 1 or 2 %R) than the 60 mm sphere.

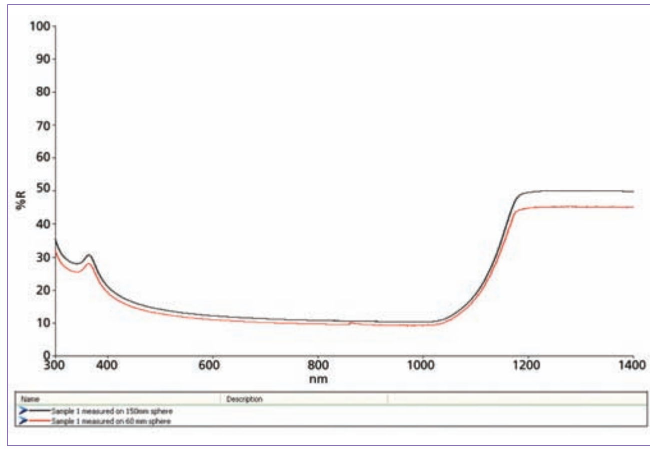

Figure 3. Spectra of Sample 1 (textured sample).
Black line – measured on 150 mm sphere.
Red line – measured on 60 mm sphere.

What happens when you measure a totally specular sample with little or no diffuse component in a sphere? In order to answer this question we need understand what happens to the light inside the sphere. Figure 4A depicts how both diffuse and specular light reflects off the sample into the sphere. The diffuse reflected light will illuminate the entire area inside the sphere through 380 degrees. The specular reflected light will strike only an area along the midline of the sphere in the vicinity of the transmittance port. Photographs of this area, taken via a webcam inserted inside the sphere, are shown in Figures 4B, C, and D.

The photograph in Figure 4B shows the even illumination of the sphere from a 100% diffuse reflectance sample. However, if a specular sample is placed at the sample port, a 'hot spot' is formed on the wall of the sphere. This hot spot is photographed in Figures 4C and 4D for a 10% R and a 90% R specular sample respectively. Note that there is little illumination of the sphere

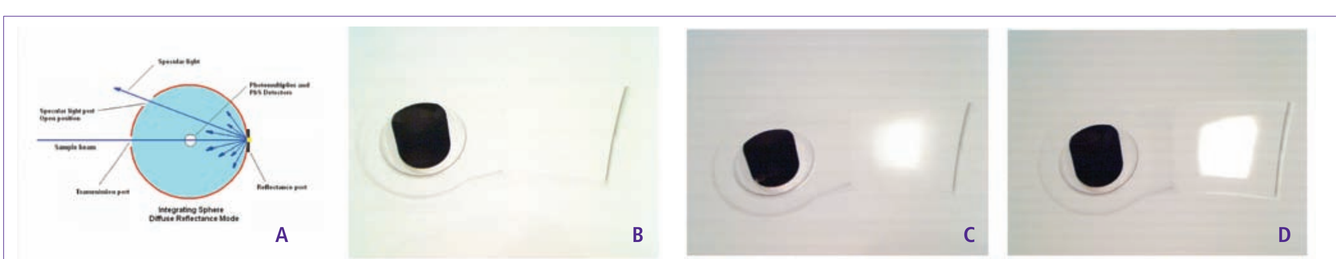

Figure 4.

interior and only the concentrated hot spot shows up. The brightness of the hot spot is directly related to the reflectivity of the specular sample. Errors result from the fact that the background correction performed with the diffuse Spectralon® plate illuminates the sphere differently from the specular sample hot spot illumination. The resulting different sphere interior images that the detector measures between background and sample causes error artifacts.

Figure 5 plots the spectra from Sample 2 (clear specular coating of low intensity) measured by the two types of integrating spheres plus the URA specular accessory. Note that the 150 mm sphere (black) and URA (green) agree very closely. However, the spectra for the 60 mm sphere has a higher %R and suffers from a small step artifact at the detector change point at 860 nm. It is interesting that with specular samples the highest %R value is from the 60 mm sphere (compare with Figure 4). This is because the hot spot dominates and concentrates the light the detector measures. In addition, since there is little diffuse light in the sphere, there is no light to escape from the open ports.

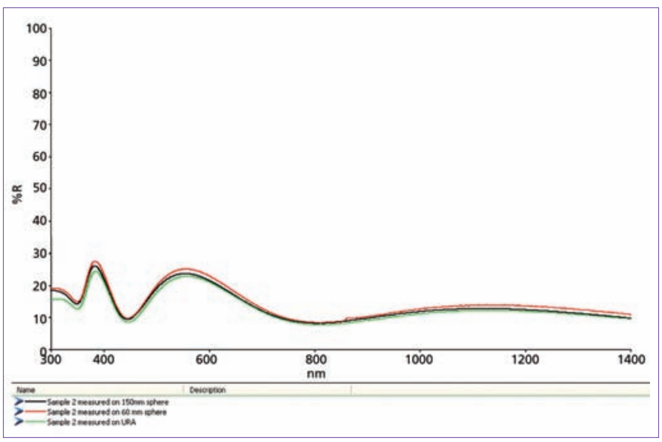

Figure 5. Spectra of Sample 2 (low intensity specular sample).
Black line – measured on 150 mm sphere.
Red line – measured on 60 mm sphere.
Green line – measured on Universal Reflectance Accessory.

Figure 6 plots the spectra from Sample 3 (colored specular coating of medium intensity) measured by the two types of integrating spheres plus the URA. This sample is somewhat unusual because of the increased spectra structural detail and is a more intense specular sample. However, it follows the general pattern of Sample 3. The 60 mm sphere spectrum suffers from pronounced wavelength shift and intensity offset. There are now irregularities between the 150 mm sphere and URA spectra. The step at the detector change in the 60 mm sphere data is most likely masked by the steep slope of the spectrum at this wavelength.

Figure 7 plots the spectra from Sample 4 (specular semi-conductor material of high intensity) measured by the two types of integrating spheres plus the URA. When the reflectance intensity becomes high enough there is disagreement for the same sample throughout all three reflectance accessories. There is, with this sample, a pronounced difference (5%R) between spectra from the 60 mm sphere and the URA. In addition, the 150 mm sphere and the URA spectra no longer share any overlap. The detector step at 860 nm in the 60 mm sphere spectrum is also now very pronounced.

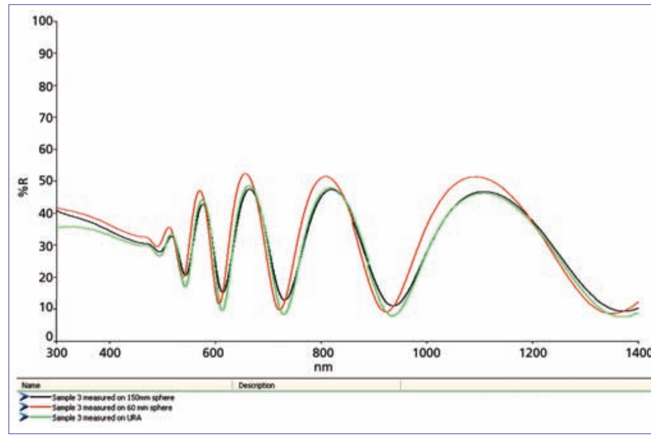

Figure 6. Spectra of Sample 3 (medium intensity specular sample).
Black line– measured on 150 mm sphere.
Red line – measured on 60 mm sphere.
Green line – measured on Universal Reflectance Accessory.

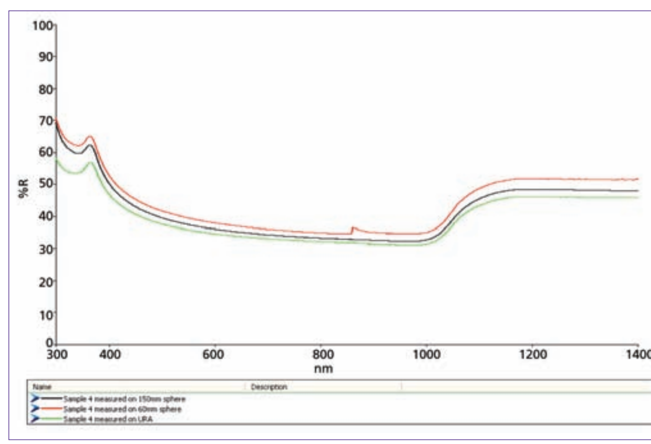

Figure 7. Spectra of Sample 4 (high intensity specular sample).
Black line – measured on 150 mm sphere.
Red line – measured on 60 mm sphere.
Green line – measured on Universal Reflectance Accessory.

Conclusion

1) For accurate and artifact free data, highly or totally specular samples should be measured on a suitable absolute specular reflection accessory such as a URA, VN, or VW accessory. Integrating spheres can only provide approximate specular reflection data with the degree of error depending on the nature of the sample and the intensity of its reflection.

2) In the solar industry however, ***total*** reflection measurements must be obtained for highly specular samples. Under these circumstances integrating spheres can provide acceptable spectra for diffuse and combination diffuse/specular samples. In addition, most spheres have the ability to measure either diffuse only and total reflectance (diffuse plus specular). In diffuse-only mode the sphere is configured to allow the specular component to exit the sphere via an open port. CAUTION: It is not possible to obtain an absolute specular spectrum by measuring the total and diffuse reflection spectra and then subtract. The port that allows the escape of the specular component also permits a small amount of diffuse component to escape, thus the subtraction calculation will yield an inaccurate, higher than expected %R. The primary purpose of the diffuse-only mode is to eliminate specular glare from diffuse sample measurements.

3) The standard color 150 mm sphere is the only sphere that will give accurate and comparable spectra between different instrument/sphere models. The smaller 60 mm sphere with its larger port to surface area ratio and lack of detector baffling will cause lower %R measurements and step artifacts in the spectra respectively.

4) Some solar industry materials are highly specular but also contain small amounts of a diffuse component that make measurement on an absolute specular accessory problematic. For these types of samples, a 150 mm integrating sphere can be employed with the following procedure. A calibrated front surface aluminum mirror, rather than the Spectralon® plate, is used for the background correction at the sample port. A mathematical correction using the values of the calibrated mirror is employed to correct the raw spectral data to absolute %R (the %RC mode automatically calculates this correction in UV/WinLab™ software). The aluminum mirror replicates the hot spot of the specular sample, thereby eliminating the hot spot artifact and yielding acceptable absolute %R data. Best results are achieved when the intensity of the sample and calibrated mirror are of similar %R values.

5) The 60 mm sphere is a lower cost alternative when the primary use is as a transmittance collection sphere or where qualitative or relative quantitative spectra are of interest.

Ordering Information

Part Number	Description
L6020208	Universal Reflectance Accessory (UV/Vis only) for L650 and L850
L6020202	Universal Reflectance Accessory (UV/Vis/NIR) for L950
L6020358	Universal Reflectance Accessory (UV/Vis/NIR) for L1050
L6020203	Integrating Sphere Accessory – 60 mm PbS Detector
L6020204	Integrating Sphere Accessory – 150 mm PbS Detector

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