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UV TALK LETTER

Vol. 13

UV Talk Letter

Measuring the Absolute Reflectance of Solid Samples

In UV Talk Letter Volume 12, we mainly discussed relative reflectance measurements. However, measuring the reflectance of solid samples often involves measuring absolute reflectance in addition to relative reflectance. Therefore, this issue discusses absolute reflectance measurement.

1. Absolute Reflectance Measurement (Absolute Specular Reflectance Measurement)

Absolute reflectance measurements (absolute specular reflectance measurements) determine the absolute quantity of specular (mirror) reflectance from the sample by measuring the light reflected at the same angle as the angle of incident light, as shown in Fig. 1-1.

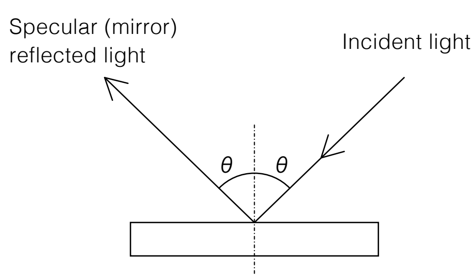


Fig. 1-1 Specular Reflected Light

An absolute specular reflectance attachment is used for these measurements. Absolute specular reflectance attachments are available in two styles, either with a fixed or variable incident angle. Fixed incident angle absolute specular reflectance attachments are available with four angles, 5, 12, 30, or 45 degrees, which can be selected based on objectives. In contrast, variable angle absolute specular reflectance attachments can be adjusted in 1-degree steps anywhere between 5 and 70 degrees.
Fixed absolute specular reflectance attachment is configured as shown below.

Fixed Incident Angle Absolute Specular Reflectance Attachments

Fig. 1-2 shows the operating principle of fixed incident angle absolute specular reflectance attachments.

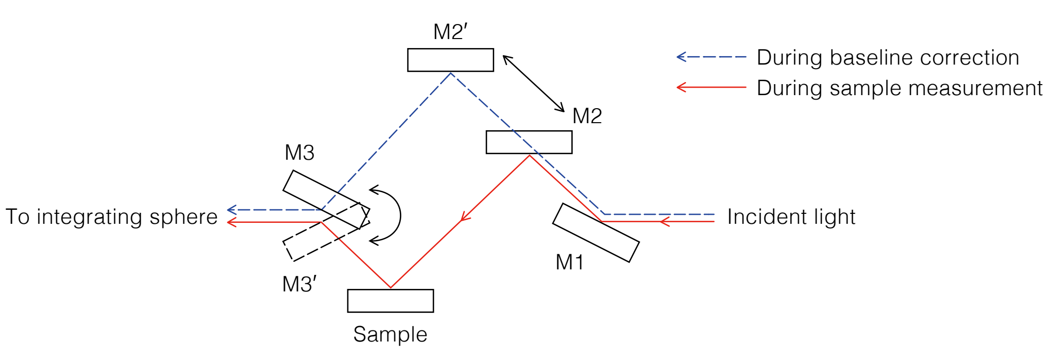


Fig. 1-2 Fixed Incident Angle Absolute Specular Reflectance Attachments

The optical path indicated by the blue dotted line is used during baseline correction. When samples are measured, mirror M2 travels horizontally and mirror M3 rotates to create an optical path indicated by the solid red line. Since the segments between M2', M2, the sample, M3 (or M3') are designed to form a parallelogram, the path length, mirror incident angles, and number of mirrors used are identical for sample measurements and baseline correction. However, sample measurements involve one additional reflection from the sample, compared to baseline correction. Given an incident light intensity of I_0, absolute reflectances R_{m1}, R_{m2}, and R_{m3} at mirrors M1, M2, and M3, respectively, and the absolute reflectance of the sample R_S, then the absolute reflectance of the sample, R_S, is determined by measuring the light quantity during baseline correction, I_{base}, and the light quantity during sample measurement, I_S.

$$Rs = \frac{\text{Quantity of Light During Sample Measurement}}{\text{Quantity of Light During Baseline Correction}} = \frac{I_s}{I_{base}} = \frac{I_0 \times R_{m1} \times R_{m2} \times R_s \times R_{m3}}{I_0 \times R_{m1} \times R_{m2} \times R_{m3}}$$

Variable Incident Angle Absolute Specular Reflectance Attachments

Fig. 1-3 and 1-4 show a variable incident angle absolute specular reflectance attachment.

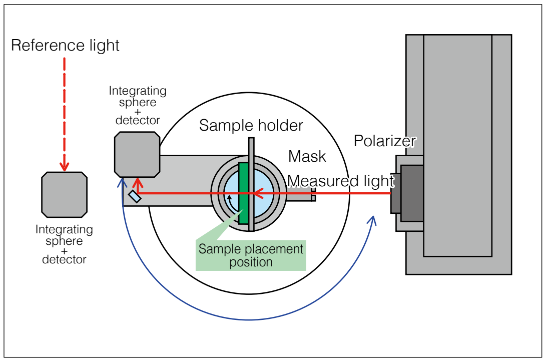


Fig. 1-3 Variable Incident Angle Absolute Specular Reflectance Attachment During Baseline Correction

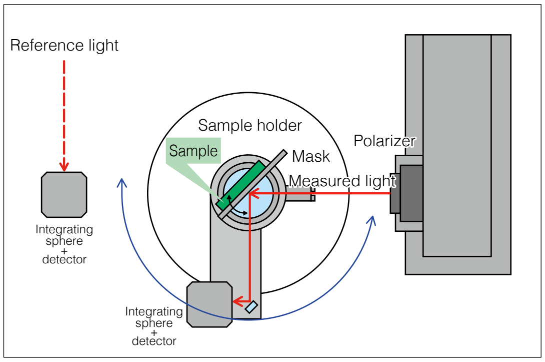


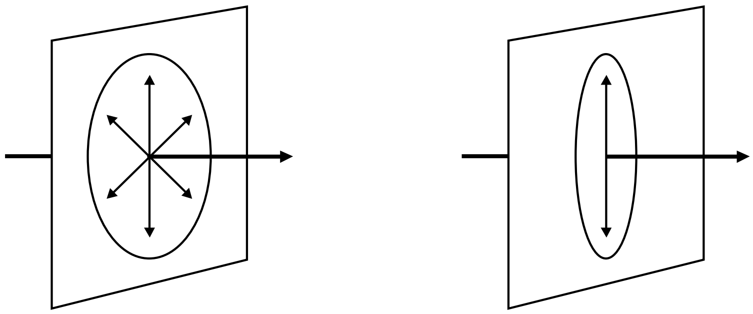
Fig. 1-4 Variable Incident Angle Absolute Specular Reflectance Attachment During Sample Measurement

The variable incident angle absolute specular reflectance attachment uses a goniometer method that is able to move the sample holder angle and integrating sphere (sample light detector) angle independently around the same axis. Once the baseline is corrected one time, this method allows the absolute reflectance of a sample to be measured by varying the incident angle in 1-degree steps within the range from 5 to 70 degrees.

Key Points for Measuring Absolute Reflectance

A. Polarized Light

Light consists of electromagnetic waves that vibrate within planes per pendicular to the advancing direction. Light that vibrates in all directions within a plane, such as sunlight, is referred to as non-polarized light (natural light). Light that only vibrates in one direction is referred to as polarized light. Fig. 1-5 illustrates polarized light.



(a) Non-polarized Light (natural light) (b) Polarized Light

Fig. 1-5 Non-Polarized and Polarized Light

Absolute reflectance measurements generally consider the reflectance of both S-polarized and P-polarized light. When light shines on a substance, the incident plane includes both the incident and reflected light. Light components that vibrate in a direction perpendicular to the incident plane are referred to as S-polarized light (perpendicular-polarized light), whereas light components that vibrate in a direction parallel to the incident plane are referred to as P-polarized light (parallel-polarized light). Fig. 1-6 shows a diagram of S-polarized and P-polarized light.

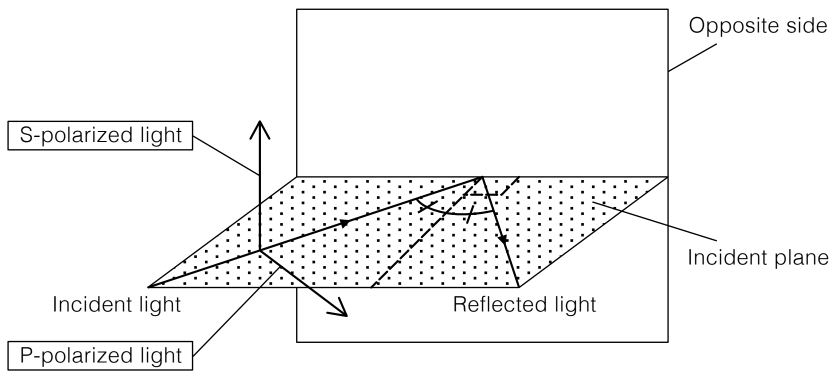


Fig. 1-6 S-Polarized Light and P-Polarized Light

B. Angle of Incidence and Polarizers

Fig. 1-7 shows the results of calculating the absolute reflectance of S-polarized light and P-polarized light from aluminum, copper, germanium, and BK-7 optical glass. The angle of incidence is indicated on the horizontal axis and absolute reflectance on the vertical axis. For each sample, the upper curve indicates the absolute reflectance of the S-polarized light and the lower curve indicates the absolute reflectance of the P-polarized light.

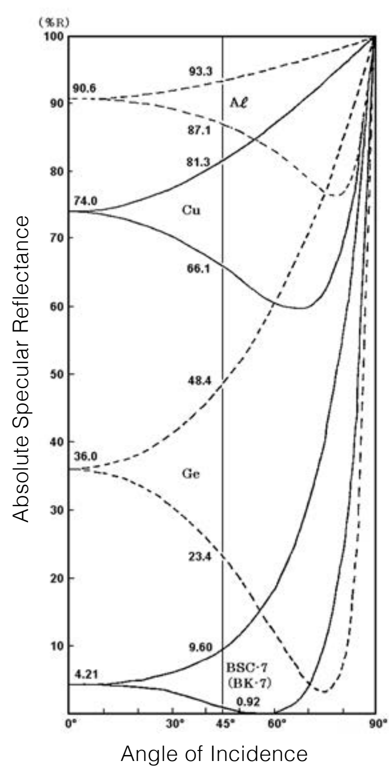


Fig. 1-7 Absolute Reflectance of Aluminum, Copper, Germanium, and BK-7 Optical Glass
(Upper: Absolute Reflectance of S-Polarized Light; Lower: Absolute Reflectance of P-Polarized Light)

Table 1 Complex Refractive Index of Various Substances

	ñ
Al	0.65+5i
Cu	0.617+2.62i
Ge	3.42+1.35i
BK-7	1.5168

Source:
Cu and Ce data from "Physical Optics", Kunio Yoshihara
Al data from "Fundamental Properties of Solids,"Kyoritsu Shuppan Co., Ltd.
BK-7 optical glass data from OHARA Inc. product catalog
All data is for wavelengths near λ = 580 to 590 nm

Fixed incident angle absolute specular reflectance attachments are available with four angles, 5, 12, 30, or 45 degrees, where the reflectance of S- and P-polarized light is approximately the same at an angle of 5 degrees, as shown in Fig. 1-7. However, as the incident angle increases, the reflectance varies for S- and P-polarized light. At 12 degrees, a slight difference appears, and at 30 and 45 degrees, the difference is quite large. Therefore, absolute specular reflectance attachments include a place for installing a polarizer. For 12, 30, and 45-degree fixed incident angle absolute specular reflectance attachments, a polarizer is installed to measure S- and P-polarized light separately. Even for variable incident angle absolute specular reflectance attachments, samples are often measured at large angles of incidence, so that measurements are performed with a polarizer installed.

C. Measurement Surface

The sample measurement surface must be a flat mirror surface due to the long distance from the sample to the detector (integrating sphere) for absolute reflection. If the measurement surface is not a mirror surface, then the detector cannot capture all the scattered light, which prevents determining the absolute reflectance correctly.

D. Pre-Treating the Opposite Side

Anti-reflective (AR) coatings are sometimes only applied to one side of a resin or glass substrate. If such samples are measured without pre-treating the opposite side, incident light might pass through the sample and reflect off the opposite side, resulting in data from light components reflected off the opposite side being included in reflectance data. To prevent inclusion of components reflected off the opposite side, the opposite side must be pre-treated as follows.

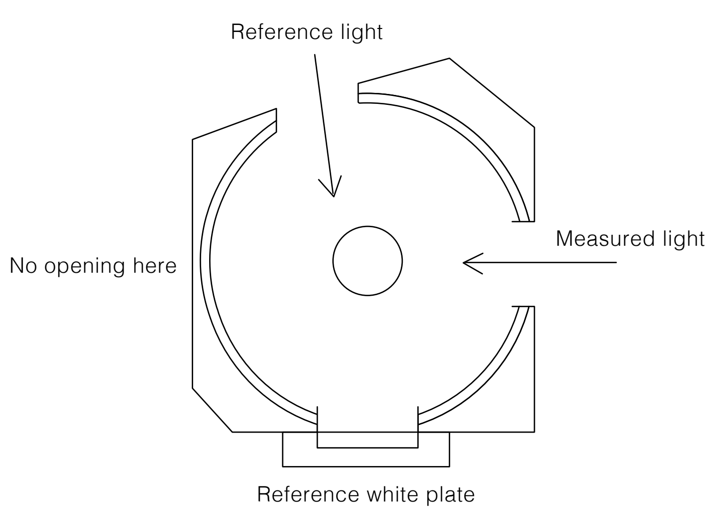
(1) Taper the opposite side (ground surface or scattering surface).

(2) Blacken the opposite surface so that light is absorbed.

These measures will reduce the reflection from the opposite surface.

E. Integrating Sphere

The integrating sphere used to detect light for absolute reflection measurements is a transmission integrating sphere, as shown in Fig. 1-8. Transmission integrating spheres do not include an opening at a portion where the measurement light first hits after entering the integrating sphere. Using this type of integrating sphere allows more accurate determination of the absolute reflectance. For more detailed information on transmission integrating spheres, refer to UV Talk Letter Volume 12. However, transmission integrating spheres cannot be used to measure diffuse reflectance that contains no specular reflectance or diffuse transmittance that contains no linear transmittance.



During baseline correction

Fig. 1-8 Transmission Integrating Sphere

2. Measurement Procedure

The following describes the measurement procedures for fixed and variable incident angle absolute specular reflectance attachments.

Fixed Incident Angle Absolute Specular Reflectance Attachments

[12, 30, or 45-degree angles of incidence]

1. Set the polarizer angle to zero degrees for S-polarized light, as shown in Fig. 2-1. Set the two levers on the absolute specular reflectance attachment to [100%T] (baseline correction position). Perform baseline correction.
2. Move the two levers on the absolute specular reflectance attachment to [MEASURE] (sample measurement position), as shown in Fig. 2-2.
3. Place the sample in the absolute specular reflectance attachment sample holder and then measure the sample.
4. Repeat step 3 for all the samples.
5. Set the polarizer angle to 90 degrees for P-polarized light. Set the two levers on the absolute specular reflectance attachment to [100%T]. Perform baseline correction.
6. Move the two levers on the absolute specular reflectance attachment to [MEASURE], as shown in Fig. 2-2.
7. Place the sample in the absolute specular reflectance attachment sample holder and then measure the sample.
8. Repeat step 7 for all the samples.

[5-degree angle of incidence]

1. Set the two levers on the absolute specular reflectance attachment to [100%T]. Perform baseline correction.
2. Move the two levers on the absolute specular reflectance attachment to [MEASURE].
3. Place the sample in the absolute specular reflectance attachment sample holder and measure the sample.
4. Repeat step 3 for all the samples.

Note: Other than not requiring a polarizer, the 5-degree absolute specular reflectance attachment is the same as attachments with other angles. Therefore, its figure has been omitted.

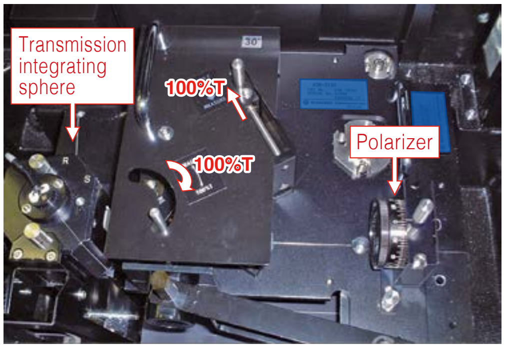


Fig. 2-1 Baseline Correction with 30-Degree Incident Angle Absolute Specular Reflectance Attachment (same settings for 12 and 45-degree incident angle absolute specular reflectance attachments)

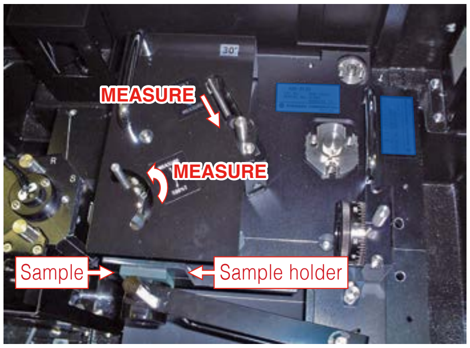


Fig. 2-2 Sample Measurement with 30-Degree Incident Angle Absolute Specular Reflectance Attachment

Variable Incident Angle Absolute Specular Reflectance Attachments

1. Set the polarizer angle to zero degrees for S-polarized light, as shown in Fig. 2-3. Set the integrating sphere (detector) to the baseline correction position. Perform baseline correction.
2. Place the sample in the sample holder, as shown in Fig. 2-4.
3. Position the sample holder at the incident angle to be measured. Move the integrating sphere to the position where it captures the specular reflected light from the sample, fasten it in place, and measure the sample.
4. Repeat step 3 for all incident angles to be measured.
5. Repeat steps 2 to 4 for all the samples.
6. Set the polarizer angle to 90 degrees for P-polarized light and set the integrating sphere in the baseline correction position. Perform baseline correction.
7. Place the sample in the sample holder.
8. Position the sample holder at the incident angle to be measured. Move the integrating sphere to the position where it captures the specular reflected light from the sample, fasten it in place, and measure the sample.
9. Repeat step 8 for all incident angles to be measured.
10. Repeat steps 7 to 9 for all the samples.

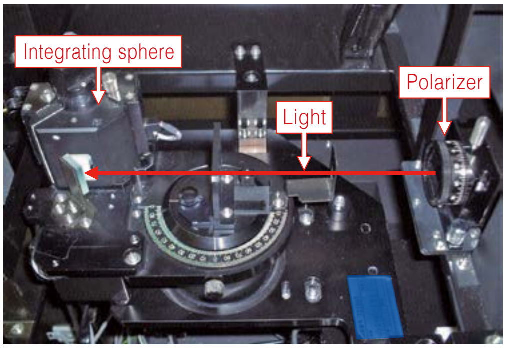


Fig. 2-3 Baseline Correction with Variable Incident Angle Absolute Specular Reflectance Attachment

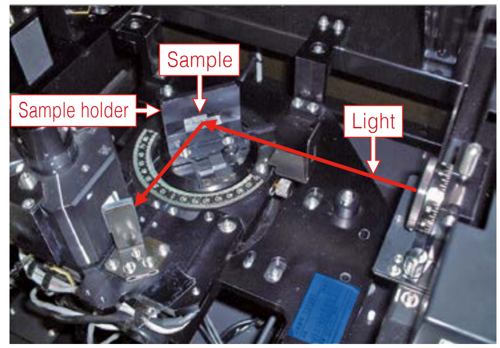


Fig. 2-4 Sample Measurement with Variable Incident Angle Absolute Specular Reflectance Attachment

3. Measurement Example

In this example, a variable incident angle absolute specular reflectance attachment was used to measure the absolute reflectance from a silicon wafer with a mirror finish at 5, 12, 20, 45, and 60-degree angles of incidence. Fig. 3-1 shows the absolute reflectance spectra measured at 5, 20, 45, and 60-degree angles of incidence. Fig. 3-2 shows the absolute reflectance spectra measured at 5 and 12-degree angles of incidence. These figures show that as the angle of incidence increases, reflectance from S-polarized light increases and reflectance from P-polarized light decreases. Fig. 3-1 shows that the reflectance from S- and P-polarized light is about the same at a 5-degree angle of incidence. In contrast, results in Fig. 3-2 from measuring at a 12-degree angle of incidence show that the reflectance from S- and P-polarized light differs by about 1.5%.

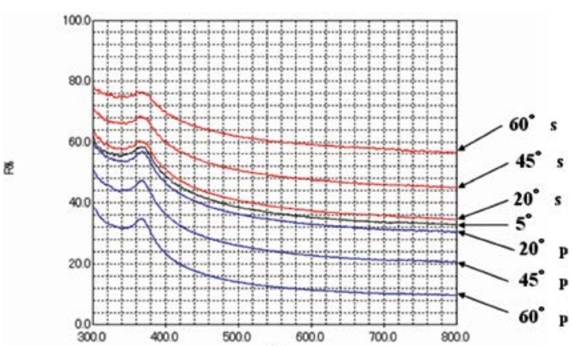


Fig. 3-1 Absolute Reflectance Spectra of Silicon Wafer Measured at 5, 20, 45, and 60-Degree Angles of Incidence

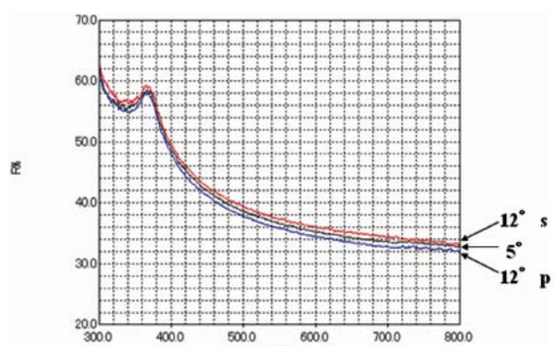


Fig. 3-2 Absolute Reflectance Spectra of Silicon Wafer Measured at 5 and 12-Degree Angles of Incidence

4. Summary

This article describes the measurement principle, measuring method, and key points for measuring absolute reflectance. Absolute reflectance measurements are often used to determine the reflectance of optical materials and electronic circuit boards. Measuring the absolute reflection provides a useful means of determining the absolute reflectance of samples, but at the same time, there are many precautionary points to consider, as discussed above. In particular, absolute reflectance cannot be determined correctly from measuring the absolute reflection from samples that do not have a specular surface. Hopefully, this article will be helpful for performing absolute reflectance measurements.

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Ultraviolet Protection Factor (UPF) of Sun Protection Clothing

The UPF is an index used to indicate the UV protection level of clothing. These UPF values are calculated based on transmittance measured using a UV-VIS spectrophotometer and integrating sphere. UPF measurement and calculation methods vary depending on the country, and some methods may involve quite complicated calculations. This article describes the measurement and calculation methods, and introduces the UPF Excel macro program that we developed for easy calculation of UPF values.

1. Conditions for Analyzing the Ultraviolet Protection Factor (UPF)

The UPF value is a UV protection index that indicates how well the clothing prevents sunburn, where the larger the value, the higher the protection from UV rays.

Applicable wavelengths are from 280 to 400 mm (or 290 to 400 nm), with those from 315 to 400 nm referred to as UV-A waves and those from 280 to 315 nm (or 290 to 315 nm) referred to as UV-B waves. Some calculation methods calculate the UPF value separately for UV-A and UV-B waves. Analytical conditions differ depending on the country, as shown in Table 1.

Table 1 Analytical Conditions for Germany, Britain, the United States, Australia, and New Zealand

(Test Methods of Germany/British, America, and Australia/New Zealand)

	Germany and Britain DIN EN13758-1 BS EN135758-1	United States AATCC 183	Australia and New Zealand AS/NZS 4399
Wavelength Measurement Range	290 to 400 nm	280 to 400 nm	290 to 400 nm
Sampling Interval	1 nm	2 nm	5 nm
Calculation Ranges	UPF (290 to 400 nm)	UPF (280 to 400 nm)	UPF (290 to 400 nm)
	UVA (315 to 400 nm)	UVA (315 to 400 nm)	UVA (315 to 400 nm)
	UVB (290 to 315 nm)	UVB (280 to 315 nm)	UVB (290 to 315 nm)

2. Formulas for Calculating the Ultraviolet Protection Factor (UPF)

Table 2 shows the formulas used in Germany/Britain, United States, Australia/New Zealand for calculating UVA, UVB, and UPF values. The UVA value is calculated for the wavelength range from 315 to 400 nm and the UVB value for the range from 280 to 315 nm (or 290 to 315 nm).

The symbols used in the table are explained below the table.

For E_λ, S_λ, and $\varepsilon(\lambda)$ values, refer to the respective official methods.

Table 2 Calculation Methods Used in Various Countries

Calculation Formula for UPF, UVA and UVB

	Germany and Britain DIN EN13758-1 BS EN13758-1	United States AATCC 183	Australia and New Zealand AS/NZS 4399
UVA	$\frac{1}{86}\sum_{\lambda=315}^{\lambda=400} T_i(\lambda)$	$\frac{\sum_{315\,nm}^{400\,nm} T_\lambda \times \Delta\lambda}{\sum_{315\,nm}^{400\,nm} \Delta\lambda}$	$\frac{T_{315}+T_{320}+T_{325}+\dots+T_{395}+T_{400}}{18}$
UVB	$\frac{1}{26}\sum_{\lambda=290}^{\lambda=315} T_i(\lambda)$	$\frac{\sum_{280\,nm}^{315\,nm} T_\lambda \times \Delta\lambda}{\sum_{280\,nm}^{315\,nm} \Delta\lambda}$	$\frac{T_{290}+T_{295}+T_{300}+T_{305}+T_{310}+T_{315}}{6}$
UPF	$\frac{\sum_{\lambda=290}^{\lambda=400} E(\lambda)\varepsilon(\lambda)\Delta\lambda}{\sum_{\lambda=290}^{\lambda=400} E(\lambda)T(\lambda)\varepsilon(\lambda)\Delta\lambda}$	$\frac{\sum_{280\,nm}^{400\,nm} E_\lambda \times S_\lambda \times \Delta\lambda}{\sum_{280\,nm}^{400\,nm} E_\lambda \times S_\lambda \times T_\lambda \times \Delta\lambda}$	$\frac{E_{eff}}{E'} = \frac{\sum_{290}^{400} E_\lambda \times S_\lambda \times \Delta\lambda}{\sum_{290}^{400} E_\lambda \times S_\lambda \times T_\lambda \times \Delta\lambda}$

E_λ: Sunburn spectral coefficient for each wavelength

T : Transmittance at each wavelength

S_λ, and $\varepsilon(\lambda)$: Solar spectral irradiance

$\Delta\lambda$: Interval between measured wavelengths

3. Spectra of Clothing, Hat, Shawl, and Umbrella Fabric Treated for UV Protection

Using a Shimadzu UV-2600 UV-VIS spectrophotometer and an ISR-2600Plus integrating sphere, spectra were measured from commercial clothing (both white and black portions), a hat, shawl, and an umbrella that were treated for UV protection by placing samples as shown in Fig. 1. Table 3 lists the analytical conditions and Fig. 2 shows the transmittance spectra obtained.

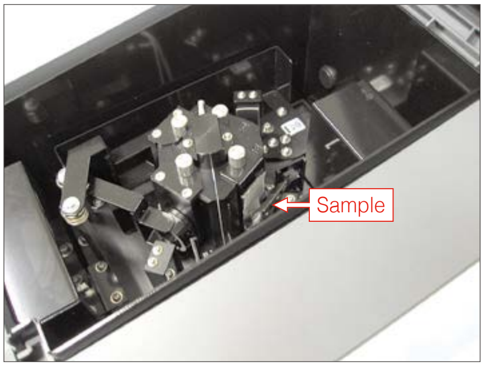

Fig. 1 Sample Placed on ISR-2600Plus Integrating Sphere

Table 3 Analysis Conditions

Instrument Used	Shimadzu UV-2600 UV-VIS Spectrophotometer ISR-2600Plus Integrating Sphere
Wavelength Measurement Range	280 to 400 nm
Scan Speed	Medium speed
Sampling Interval	1.0 nm
Photometric Value	Transmittance
Slit Width	5 nm

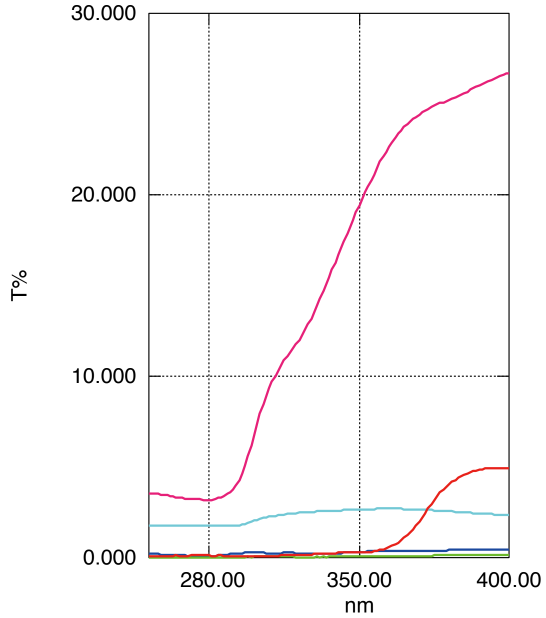

Fig. 2 Transmittance Spectra of Clothing (white and back portions), Hat, Shawl, and Umbrella Fabric Treated for UV Protection
(Pink: White portion of clothing; Light blue: Black portion of clothing; Red: Umbrella fabric; Blue: Shawl; Green: Hat)

4. UPF Excel Macro Program and Calculation Results

After converting data obtained using a Shimadzu UV-VIS spectrophotometer to CSV format, the UPF Excel macro program can be used to instantly calculate UPF values in accordance with the selected official method.

Three official methods are available for selection, EN 13578-1 for Germany and Britain, AATCC 183 for the United States, or AS/NZ 4399 for Australia and New Zealand. By selecting an official method and measured spectrum and starting the calculation, this macro program generates results as shown in Fig. 3. In addition to UPF values, it also displays UVA and UVB values and the transmittance spectrum between 280 and 400 nm at the same time. Title and comment fields can be edited by users.

Table 4 shows the measurement results from the samples described above. These results indicate that the black clothing, hat, shawl, and umbrella fabric all have UPF values over 50, which means they allow almost no UV rays through the fabric.

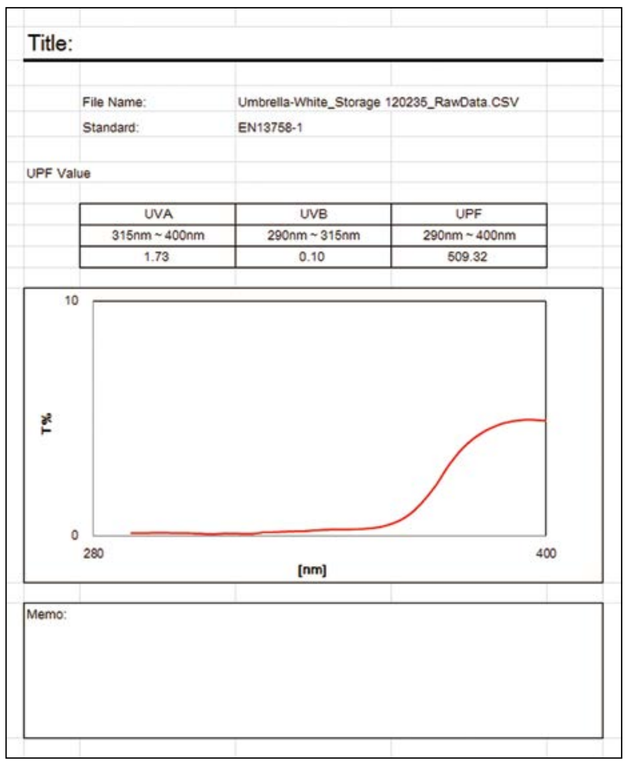

Fig. 3 UPF Calculation Results Display

Table 4 UPF Values of Clothing Treated for UV Protection

	Germany and Britain DIN EN13758-1 BS EN13758-1	United States AATCC 183	Australia and New Zealand AS/NZS 4399
White Portion of UV Protection Clothing	16.2	15.3	19.0
Black Portion of UV Protection Clothing	UPF>50 (51.7)	50+ (51.0)	50+ (3202)
UV Protection Hat	UPF>50 (2896)	50+ (2932)	50+ (3202)
UV Protection Shawl	UPF>50 (490)	50+ (489)	50+ (437)
UV Protection Umbrella	UPF>50 (509)	50+ (516)	50+ (899)

5. Summary

This investigation showed that even among items marked as providing UV protection, they each have different spectra and different UPF values. In addition, due to differences in calculation methods, the same spectrum could result in different UPF values depending on the regulation applied. Without using special software, calculating the UPF values in accordance with the regulation of each country is a complicated process that requires considerable time and effort. However, results can be obtained instantly using the UPF Excel macro program introduced above.

Nevertheless, to ensure measurements are performed in accordance with official methods, confirming the original regulation document is recommended.

References

・DIN EN13758-1
Textile Solar UV protective properties -
Part 1：Method of test for apparel fabric（includes Amendment A1：2006）
English version of DIN EN 13758-1：2007-03

・BS EN 13758-1
BRITISH STANDARD
Textiles - Solar UV protective properties -
Part 1：Method of test for apparel fabrics

・AATCC Test Method 183-2010
Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation through Fabrics

・Australian/New Zealand Standard
Sun Protective clothing - Evaluation and classification

・Shimadzu Application News A450 and A472

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Q

Measuring the transmittance spectrum of a thin film using two different spectrophotometers resulted in different results. Why is that?

A

Measuring the transmittance spectra of films or other samples with two different spectrophotometers can result in different transmittance spectra, even for identical samples. This can be caused by the following.

(1) Transparent Samples

Results from transparent samples rarely differ if measurement is done using the standard sample compartment or integrating sphere attachment. However, for thin films of only a few micrometers thick, different measurement parameters, such as slit width, can result in significant differences in the interference fringe amplitude.

A Check the slit width setting.

(2) Non-Transparent Samples

For cloudy samples, rather than transparent, results can vary depending on the instrument model or configuration used. The following are two common examples.

a. Standard sample compartment is used, but spectrophotometer model is different.

If the spectrophotometer models are different, the sample placement position in the standard sample compartment and the distance to the detector can be significantly different.

If the sample is not transparent but cloudy, then the sample can generate diffuse transmitted light, the level of which varies with the degree of cloudiness when light passes through the sample, as shown in Fig. 1 The amount of diffuse transmitted light detected varies depending on where the sample is positioned and its distance from the detector. Higher diffuse transmitted light levels are detected if the sample is closer to the detector, whereas only a portion of the diffuse transmitted light is detected if the sample is farther from the detector. This can result in differences in the data. In such cases, use an integrating sphere attachment, which detects all the diffuse transmitted light. this eliminates any variations in the data, even for different spectrophotometer models.

A If possible, use the same model. If the same model is not available, use an integrating sphere attachment.

b. Spectrophotometer model used is the same, but accessories are different

Even if the same model is used, using different accessories can result in different data. For example, if one sample is measured placed in a film holder in a standard sample compartment and another is measured with an integrating sphere installed, then the integrating sphere will result in higher transmittance values.

A Use the same accessories.

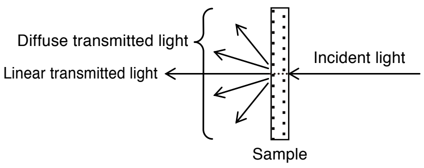

Fig. 1 Diagram of Light Transmitted Through the Sample

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