LAAN-A-UV-E019

SHIMADZU

Application News

Spectrophotometric Analysis No.A419

Evaluation of Transmittance Dependence on Incident Angle in Glass Plate Coated with TCO Film used for Thin Film Solar Cell

In Application News A418, we introduced the distribution measurement of vertically-incident light transmitted through a glass plate coated with TCO (transparent conductive oxide) film.
Here, we looked at the irradiation of sunlight at various angles of incidence on a solar cell, and measured the transmittance of this light irradiated at 6 different angles of incidence (0˚, 10˚, 20˚, 30˚, 40˚, 50˚) using the SolidSpec-3700 UV-VIS-NIR spectrophotometer.

■ Attachment and Sample Used for the Measurement

A variable angle absolute reflectance attachment was used for the measurement. Fig. 1 shows a schematic diagram of the experiment, and Fig. 2 shows a photograph of the glass plate (5 × 5 cm, 1.1 mm thick) coated with TCO film mounted in the instrument. The variable angle absolute reflectance attachment is a device that allows measurement of the absolute reflectance at any desired angle of incidence, and also allows measurement of transmittance. Especially, when the sample is thin, deflection of the optical axis due to refraction can almost always be ignored, so transmittance measurement can be conducted at various angles of incidence (corresponding to θ in Fig. 1). To do this, the detector is fixed in the default position, and the angle of the sample holder is changed for each measurement. Since the sample and detector are separated in this system, the transmittance that is obtained from measurement is linear transmittance.
Transmittance is dependent on the absorption and reflection of light with respect to the sample, but since reflectance is dependent on the state of the polarized light and the angle of incidence, here we conducted the experiment separately for s polarized light and p polarized using a polarizer. As shown in Fig. 3, the s polarized light shows the vertically oscillating light component with respect to the plane of incidence, and the p polarized light shows the parallel oscillating light component with respect to the plane of incidence. For details regarding polarized light and the variable angle absolute reflectance attachment, refer to Application News A394 and A390, respectively.

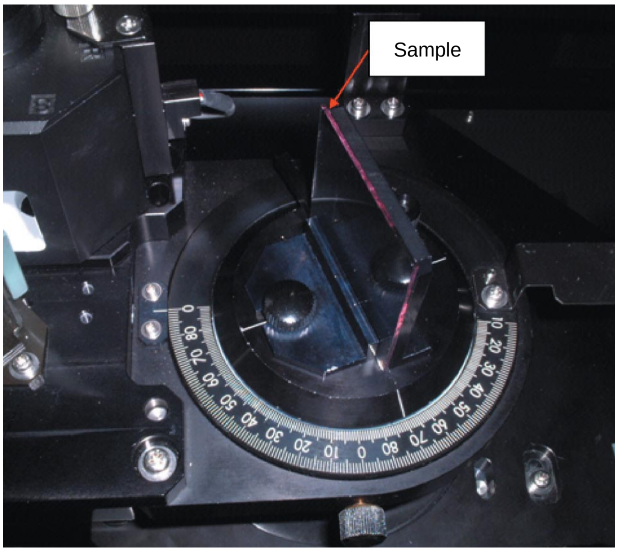

Fig. 2 Sample Mounted on Variable Angle Absolute Reflectance Attachment

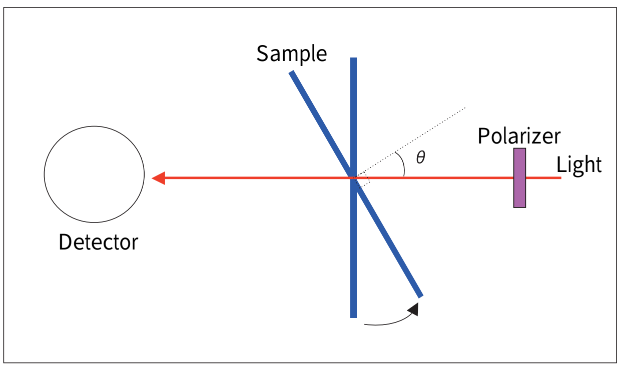

Fig. 1 Schematic Diagram of Experiment

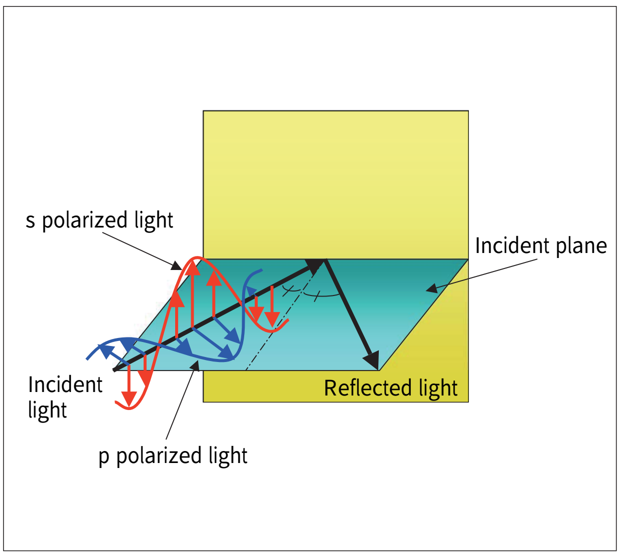

Fig. 3 s Polarized Light and p Polarized Light

■ Evaluation of Transmittance Dependence on Incident Angle in Glass Plate Coated with TCO Film used for Thin Film Solar Cell

We measured the vertical transmittance in glass plate coated with TCO film using 6 different angles of incidence (0˚, 10˚, 20˚, 30˚, 40˚, 50˚). Light was irradiated from the side opposite that from the film-coated side. The results of measurement using the s polarized light are shown in Fig. 4, and the results of measurement using the p polarized light are shown in Fig. 5. Since the reflectance at each incident angle is different for the s polarized light and p polarized light, different oscillations are shown for the respective types of polarized light. The waveform seen in the visible region is an interference waveform caused by interference due to the film. The measurement conditions are shown in Table 1.

Considering that sunlight is nonpolarized light (natural light), we calculated the transmittance corresponding to nonpolarized light by averaging the data obtained from measurement of the s polarized light and p polarized light. The results are shown in Fig. 6, and the results for an extended region of the spectra from 350 nm - 900 nm are shown in Fig. 7.

When the angle of incidence changes, the optical path length through the film changes, thereby causing a shift in peak position in accordance with the interference waveform. Looking at Fig. 7, it is evident that there are alternating large and small differences in transmittance between the data sets depending on that shift in peak position. For example, the difference in transmittance between the data sets in the region of 650 nm is large, but in the region of 760 nm, the difference is small.

The transmittances at 650 nm and 760 nm are shown in Table 2. When evaluating the plate materials of solar cells, it is important to check the transmittance at various angles, but in this experiment, the actual differences between the spectra have been captured.

Using this system in this way makes it possible to grasp the transmittance characteristics of translucent conductive films, photoabsorption layers, and substrate materials, etc. at various angles of incidence.

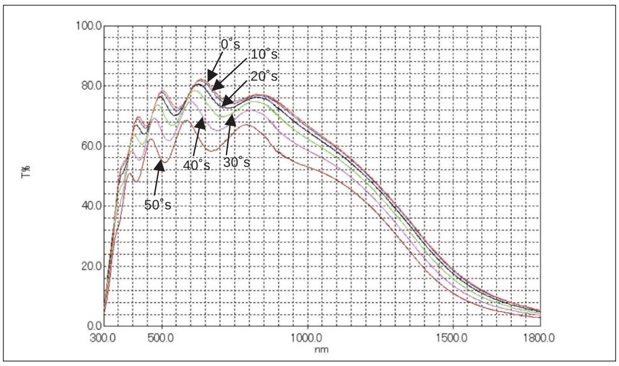

Fig. 4 Transmittance Spectra Measured with s Polarized Light at 0, 10, 20, 30, 40, and 50 Degrees

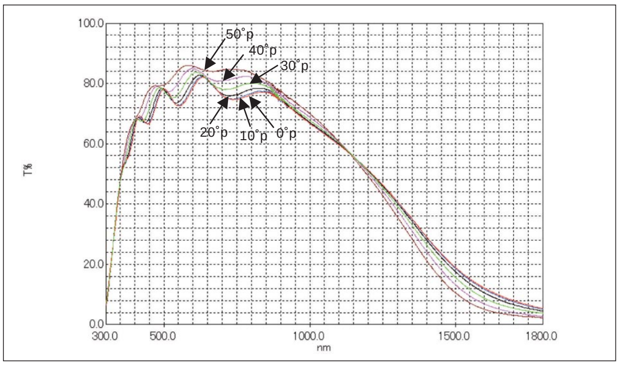

Fig. 5 Transmittance Spectra Measured with p Polarized Light at 0, 10, 20, 30, 40, and 50 Degrees

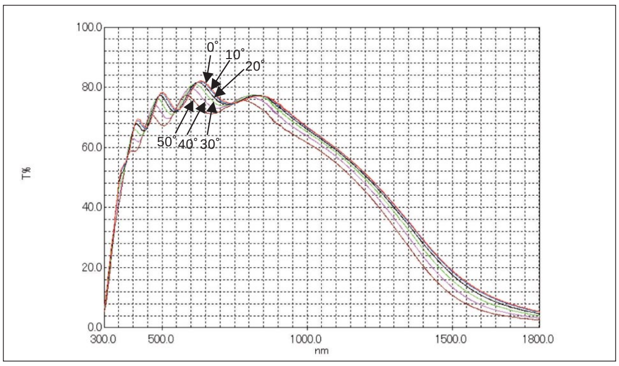

Fig. 6 Transmittance Spectra of Nonpolarized Light Calculated using s Polarized Spectra and p Polarized Spectra at 0, 10, 20, 30, 40, and 50 Degrees

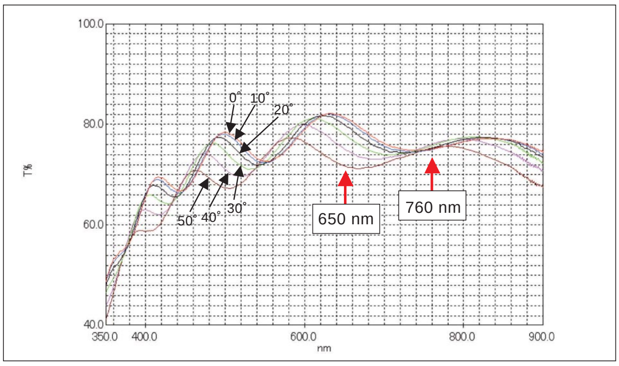

Fig. 7 Expanded Region of Spectra of Fig. 6

Table 1 Measurement Parameters

Measurement Wavelength Range	: 300 nm to 1800 nm
Scan Speed	: Medium
Sampling Pitch	: 1.0 nm
Photometric Value	: Transmittance
Slit Width	: (20) nm
Lamp Switching Wavelength	: 290 nm
Grating Switching Wavelength	: 720 nm
Detector Switching Wavelength	: 870 nm, 1650 nm

Table 2 Transmittance at 650 nm and 760 nm

	Transmittance at 650 nm	Transmittance at 76 nm
Angle of Incidence: 0˚	81.4	75.1
Angle of Incidence: 10˚	81.0	75.0
Angle of Incidence: 20˚	79.9	75.2
Angle of Incidence: 30˚	78.0	75.7
Angle of Incidence: 40˚	75.0	76.0
Angle of Incidence: 50˚	71.7	75.2

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