

SEMI PV31-0212 (Reapproved 0317) TEST METHOD FOR SPECTRALLY RESOLVED REFLECTIVE AND TRANSMISSIVE HAZE OF TRANSPARENT CONDUCTING OXIDE (TCO) FILMS FOR PHOTOVOLTAIC APPLICATION

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1 Purpose

1.1 Transparent conducting oxide (TCO) films used in the photovoltaic industry are textured in order to optimize light absorption and maximize cell efficiency. Frequently, haze measurements are used to characterize such films. The required texture usually is not well defined by a single haze result because the relative amounts of low and high frequency roughness on the surface can both be important. Therefore the haze is frequently determined for a spectrum of source wavelengths. Then the haze values can often be correlated with useful properties of the material.

1.2 In the photovoltaic (PV) field, haze is taken as the total integrated reflective or transmissive scatter from the surface of the sample. The basics of this measurement are covered in SEMI MF1048.

2 Scope

2.1 This Test Method extends SEMI MF1048 and SEMI PV15 to measurements of reflective and transmissive haze as a function of source wavelength on TCO films used in the PV industry.

2.2 Reflective haze can be obtained on TCO films deposited on amorphous or other types of silicon.

2.3 Transmissive haze can be obtained in a similar fashion on TCO films deposited on transparent materials, such as glass.

2.4 Haze is determined as a function of the incident wavelength of the source beam.

2.5 Haze is also determined as a function of the incident angle between the source beam and the film surface normal.

2.6 If desired, it can also be determined at different positions on the sample film.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 Measured haze (or TIS) values change with measurement parameters such as the source wavelength, incident angle, polarization, and scatter collection regions. As a result comparing haze values found for samples where these parameters were different is meaningless. Thus, these parameters need to be reported directly, or implied by identifying the measurement system used for the tests.

3.2 Variations in detector response as a function of the angle of incidence can affect the precision of the measurement.

3.3 Lack of proper calibration and adjustment of the two detectors makes the ratio of their readings meaningless.

3.4 Defects, such as scratches or pits, that are not characteristic of the surface finish, or contaminants on the surface can produce scattering that is not characteristic of the texture of the surface.

3.5 Stray background radiation affects the precision of measurement.

3.6 Detector offset voltages affect the precision of measurement.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI M59 — Terminology for Silicon Technology

SEMI MF1048 — Test Method for Measuring Reflective Total Integrated Scatter

SEMI PV15 — Guide for Defining Conditions for Angle Resolved Light Scatter Measurements to Monitor the Surface Roughness and Texture of PV Materials

4.2 *ANSI Standard*¹

ANSI Z136.1 — Safe Use of Lasers

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 Acronyms, terms, and symbols related to silicon technology, including most of those in this Test Method, are listed and defined in SEMI M59.

5.2 *Other Acronyms Used in this Test Method*

5.2.1 *TCO* — transparent conducting oxide

6 Summary of Method

6.1 For either reflective or transmissive haze measurement, the scattered beam detector array is mounted a known distance from the sample surface at a known location on the sample.

6.2 The wavelength of the source beam of light is selected.

6.3 The scattered light and the specularly reflected (or transmitted) light are measured.

6.4 The ratio of the scattered light to the sum of the scattered and specularly reflected (or transmitted) light is calculated to determine the haze value at that wavelength.

6.5 The haze measurement is repeated for as many values of source wavelength as desired.

6.6 If desired, the sample is moved so that the source light strikes another known location on the sample surface, and the haze measurement is repeated at each location to map the haze as a function of source wavelength over the sample surface.

6.7 The results are plotted as a function of source wavelength or position or both.

7 Apparatus

7.1 Haze measurements of TCO films can be made using the total integrating sphere specified in SEMI MF1048. However, in the PV industry a somewhat simpler apparatus such as that shown schematically in Figure 1 is often used for reflective and transmissive haze measurements. The incident angle is ϕ_i° from the sample surface normal, where ϕ_i can be set to any desired angle. In this figure, the ϕ_i are set to 20° for convenience in illustrating the system.

7.2 *Light Source* — A broadband source is projected through spectrometer transfer optics to have a beam that can be varied over the desired range of wavelengths. The source beam diameter is 1 mm or less, the beam divergence is 5 mrad or less and the output power is approximately 2 mW. The narrow band source beam passes through an adjustable mirror to enable its being directed to the top or bottom of the TCO film.

7.2.1 In the case of reflective haze measurement, the source mirror is set at α_i° from the surface normal, where, in Figure 1, $\alpha_i = \frac{1}{2}(90 + \beta_i)^\circ$ and $\beta_i = \phi_i$ sending the beam to strike the TCO film after passing through the fixed mirror and the small aperture A_i at the top of the scattered light detector. The reflected light scattered from the film is collected by the scattered light collector (C_i).

7.2.2 In the case of transmissive haze measurement, the adjustable mirror is rotated $\frac{1}{2}(90 - \alpha_i)^\circ$ clockwise so that the beam is deflected along the dashed path in Figure 1, so that the source beam is reflected by the fixed mirror to pass through the transparent substrate and strike the bottom of the TCO film. Again the transmitted light scattered from the film is collected by the scattered light collector (C_i).

¹ Available from the Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826, USA; Telephone: +1.800.345.2737, Fax: +1.407.380.1553, <http://www.lia.org>