

SEMI MF1048-0217 (Reapproved 1023) TEST METHOD FOR MEASURING REFLECTIVE TOTAL INTEGRATED SCATTER

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NOTICE: The section symbol (§) is used to reference a numbered section, paragraph, or header and all subordinate paragraphs, headers, and embedded material (i.e., EXCEPTIONs, lists) therein. The paragraph symbol (§) is used to reference a particular numbered paragraph and embedded material therein. When duplicated (i.e., §§ and §§) the symbols are used to reference more than one section or paragraph, respectively.

NOTICE: Paragraphs entitled 'NOTE:' are not an official part of this Standard or Safety Guideline and are not intended to modify or supersede the official Standard or Safety Guideline. These have been supplied by the global technical committee to enhance the usage of the Standard or Safety Guideline.

1 Purpose

- 1.1 The performance of optical components is affected by the degree to which they scatter optical radiation.
- 1.2 Under some conditions, bandwidth limited values of the rms microroughness, R_q , may be computed from measured values of total integrated scatter (TIS).
- 1.3 This Test Method may be used in manufacturing, quality control, metrology, and research.

2 Scope

- 2.1 This Test Method covers the measurement of scatter signals from surfaces into most of the reflective hemispherical collector above the surface. Calculation of the TIS, called Haze in some industries, is defined.
- 2.2 This Test Method is particularly applicable to clean, optically smooth, front surface reflectors, such as semiconductor wafers, computer disk substrates, and mirrors, because under certain conditions the measured signals can be related to bandwidth limited values of the rms microroughness of the surface.
- 2.3 This Test Method can be extended to measurements of TIS on other types of surfaces, but in this case, it is not possible to determine the rms microroughness from the measured TIS.
- 2.4 This Test Method is applicable to specimens ranging in size from 5 mm in diameter to as large as the supporting components can accommodate. The sampling area is typically 1 mm to 5 mm in diameter.
- 2.5 This Test Method is limited to specimens with optical surfaces that are flat or that are spherical with a radius of curvature greater than 10 m.
- 2.6 This Test Method determines the integrated scattering from an angle within 3° from the direction of specular reflection to an angle greater than 45° from the surface normal.
- 2.7 The Test Method is generally performed with a laser light source.
- 2.8 This Test Method includes procedures for establishing the repeatability of the test equipment under the conditions of measurement.
- 2.9 Repeated use of this Test Method on different areas of the specimen permits mapping of the surface TIS and computed rms microroughness.
- 2.10 This Test Method is nondestructive.
- 2.11 The maintenance of a control chart to monitor the long-term stability of the measurement process is required. This should be carried out by procedures normally in place in the testing organization. For organizations without such procedures, a suggested method for doing this is discussed in Related Information 1.

2.12 A discussion of background issues relevant to the conversion of the measured TIS to rms microroughness is included in Related Information 2.

2.13 This Test Method is based on the use of TIS instrumentation based on an integrating sphere. A discussion of TIS measurements using a Coblenz sphere to collect the scattered light, as was done in previous editions of this standard, is included in Related Information 3.

NOTE 1: This Test Method is consistent with, but not exactly the same, as the procedures given in ISO 13696.

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 Flaws or contaminants on the surface can produce scattering that is not characteristic of the microroughness of the surface.

3.2 Stray background radiation affects the precision and bias of measurement.

3.3 Detector offset voltages affect the precision and bias of measurement.

3.4 Degradation of the specular reflectance standard used for calibration degrades the precision of measurement.

3.5 Degradation of the specular reflectance standard can cause the control chart to indicate lack of experimental control.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI M59 — Terminology for Silicon Technology

4.2 ANSI® Standards¹

ANSI Z136.1 — American National Standard for Safe Use of Lasers

4.3 ISO® Standards²

ISO 13696 — Optics and Optical Instruments – Test Methods for Radiation Scattered by Optical Components

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

5 Terminology

5.1 Acronyms, terminology, and symbols used in silicon technology including those used in this Test Method may be found in SEMI M59.

6 Summary of Test Method

6.1 The background noise signal at the scatter signal detector is measured without a test specimen in the system so that the specular beam passes through the sphere and only stray light from the source is measured.

6.2 A specular reflectance standard is placed in the system at the position of the test specimen and the reflected light power is measured.

6.3 The specular reflectance standard is tilted so that the reflected beam is captured in the integrating sphere and the resulting power density is measured.

6.4 The test specimen is mounted and the specularly reflected light power is measured.

¹ American National Standards Institute, 25 West 43rd Street, New York, NY 10036, USA; Telephone: +1.212.642.4900, Fax: +1.212.398.0023, <http://www.ansi.org>. ANSI trademark is owned by American National Standards Institute.

² International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401-1214 Vernier, Geneva, Switzerland; Telephone: +41.22.749.01.11, Fax: +41.22.733.34.30, <http://www.iso.org>. ISO trademark is owned by International Organization for Standardization.

6.5 Under the same illumination conditions, the scattered light power density is measured.

6.6 The measurements are repeated an agreed upon number of times at each of an agreed upon number of locations on the test specimen.

6.7 The specular reflectance, the diffuse reflectance, the TIS, and the rms microroughness of the test specimen are calculated from the measured light powers and the various angles in the measurement system.

6.8 Averages and standard deviations of the TIS are calculated to monitor the repeatability of the instrument and the uniformity of the test specimens.

7 Apparatus

7.1 *Laser Source* — A light source (usually a laser) of power P_i , having a beam diameter of a few mm or less, a beam divergence of 5 mrad or less, an output power of a few mW and specified wavelength.

7.2 *Integrating Sphere* — A spherical chamber coated with a diffuse white reflector (the integrating sphere). Near the sphere waist is an aperture used for the scatter detector to view the far wall of the integrating sphere. Through a combination of baffles and/or detector optics the detector field of view is restricted to an area directly across from the detector.

7.2.1 The baffles shall be placed to eliminate any first reflections from the sample from entering either the detector field of view or the detector entrance aperture.

7.2.2 The exit aperture shall be on the order of 1° in diameter and shall be as close to the normal as possible, preferably within 8° .

7.2.3 The highest scatter angle allowed to reach the sphere shall be at least 45° and should be as large as possible.

7.2.4 The spatial bandwidth of the collection system shall be provided by the supplier of the instrument. If this information is not available to the user of the system, a rough procedure for computing it is given in ¶ 10.1.

7.2.5 A schematic view of the integrating sphere is given in Figure 1.

NOTE 2: High angle scatter from smooth optical surfaces is much smaller than near specular scatter; therefore the exact value of the highest scatter angle has relatively little effect on the magnitude of the TIS measured.

NOTE 3: Editions of this Standard prior to 2005 utilized a Coblenz sphere instead of an integrating sphere. A description of the Coblenz sphere arrangement and a discussion of the advantages and disadvantages of each type of collector sphere are given in Related Information 3.

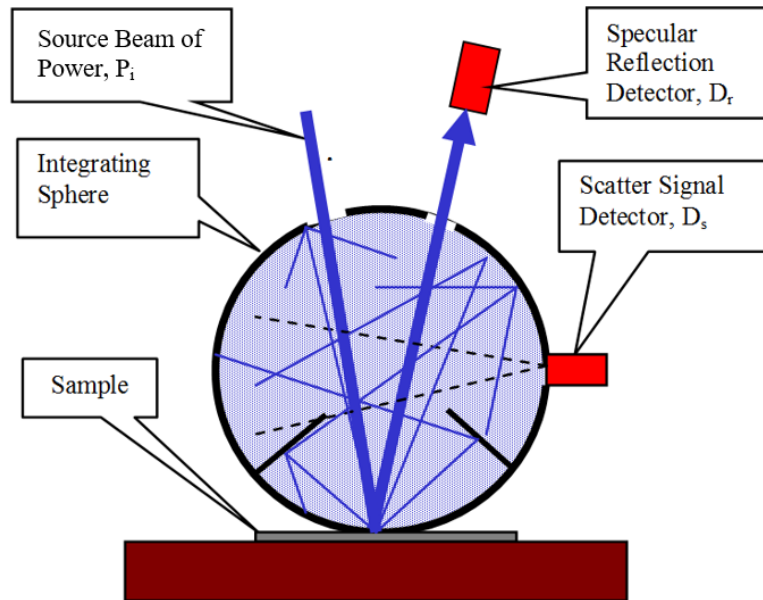


Figure 1
Schematic View of Integrating Sphere

7.3 Detectors — Silicon photovoltaic type having a dynamic range of 10^5 or greater, with a sensitive area of 2 mm^2 or greater, and in a housing less than 10 mm in diameter. One detector is used to detect the specular reflection and the other is used to collect the scatter signal. They are placed in relation to the integrating sphere as shown in Figure 1. The detectors shall be equipped with a diffuser or other means to minimize variation of signal with the position of the image on the detector, with angle of incidence, and with polarization of the radiation.

7.4 Filters — Attenuation type, of known transmittance T_r or T_s at the wavelength of the laser source, if required to prevent saturation of the specular reflection detector or the scatter signal detector, respectively.

7.5 Electronics Processing — Electronic circuits to transform the detected radiation into voltage signals proportional to the intensity of the detected radiation and display the results are required. The electronics may include circuits and/or software for making the required calculations and displaying the final, instead of intermediate, results.

7.6 Polished Reflectance Standard — An optically polished metallic mirror with known reflectance, R , at the wavelength of the incident laser beam, to be maintained in a protected environment to prevent degradation of polish.

NOTE 4: A polished stainless steel mirror preserved in a covered glass petri dish is adequate for the purposes of this Test Method.

8 Hazards

8.1 WARNING: Lasers with an output power on the order of 1 mW or greater can cause injury to personnel. The provisions of ANSI Z136.1 should be followed.

8.2 WARNING: Do not let the unexpanded laser beam impinge on the skin. In no case should the laser beam be viewed directly. Avoid looking directly into the beam or into a specularly reflected beam.

9 Sampling

9.1 The number of test specimens and their manner of selection from a given lot shall be agreed to by the parties to the test.

9.2 The location of each of the J measurement positions on each test specimen and K , the number of measurements made at each location, shall be agreed to by the parties to the test.

10 System Set Up and Control Chart Procedure

10.1 *Determination of Spatial Bandwidth* — If the spatial bandwidth of the collection system is not known, determine it in the following way:

10.1.1 Determine the angular radius of the exit aperture (usually 2.5° or less), θ_{apt} .

10.1.2 Determine the angle of incidence, θ_i .

10.1.3 Determine the lowest scatter angle $\theta_{min} = \theta_{apt} + \theta_i$.

10.1.4 Determine the highest scatter angle (usually 45° to 70°), θ_{max} .

10.1.5 Determine the wavelength of the incident radiation, λ .

10.1.6 Calculate and record the maximum spatial frequency as follows:

$$f_{max} = \frac{\sin \theta_{max} - \sin \theta_i}{\lambda} \quad (1)$$

10.1.7 Calculate and record the minimum spatial frequency as follows:

$$f_{min} = \frac{\sin \theta_{min} - \sin \theta_i}{\lambda} \quad (2)$$

NOTE 5: There is some asymmetry in the instrument caused by a nonzero incident angle. The result is that f_{max} and f_{min} found in the forward directions (as above in Equations 1 and 2) will be slightly different than the values found in the back scatter directions (scatter back toward the incident beam). These effects are minimized by using a small incident angle. Centering the reflected specular beam in the exit aperture minimizes the low angle/low spatial frequency issues. The high angle asymmetry is much less important as the high angle scatter contributions to the TIS are small. The values of f_{max} and f_{min} are usually reported in the forward scatter direction as in Equations 1 and 2.

10.1.8 Calculate and record the maximum and minimum spatial wavelengths, Λ_{max} and Λ_{min} respectively, as follows:

$$\Lambda_{max} = \frac{1}{f_{min}} \quad \text{and} \quad \Lambda_{min} = \frac{1}{f_{max}} \quad (3)$$

10.2 Control Chart Procedure

10.2.1 Each day during sustained operation, or at least every 60 days, perform the procedure of this Test Method (refer to §§ 11 and 12) to obtain TIS_{avg} and TIS_σ from five or more measurements at the center of the polished reflectance standard used as the test specimen to develop a control chart showing both the repeatability and stability of the measurement system. For this purpose, use the control charting procedures normally in place in the testing organization. For organizations without such procedures, a suggested method for carrying out the control charting is provided in Related Information 1.

11 Procedure

NOTE 6: The various calculations required may be performed automatically within the instrument. In this case it is not necessary to record the measured quantities. An outline of the calculation structures is provided here to indicate the nature of the procedure.

11.1 With no test specimen in place but with the source laser beam on at wavelength λ and incident power P_i , record the background noise signal at the scatter signal detector D_s as V_{sn} .

11.2 Place the specular reflectance standard in the position of the test specimen.

11.3 Align the source laser beam with the same incident power P_i so that it impinges on the surface of the specular reflectance standard and exits at the center of the exit aperture to the specular reflection detector, D_r . Record the resulting signal as V_{ref} .

11.4 Verify that the specular reflection detector signal has not exceeded a saturation value; if it has, insert the transmittance filter with transmittance T_r at wavelength λ in front of the detector.

11.5 Now with the identical incident power P_i tilt the specular reflectance standard so that the reflected beam is directed into the integrating sphere and record the signal at the scatter signal detector, D_s , as V_{sref} .

11.6 Verify that the detector signal has not exceeded a saturation value; if it has, insert the transmittance filter with transmittance T_s at wavelength λ in front of the detector.

11.7 Mount the test specimen so that location 1 is under the integrating sphere.

11.7.1 Align the source laser beam so that it impinges on the surface of the specular reflectance standard and exits at the center of the exit aperture to the specular reflection detector, D_r . Record the resulting signal as V_{r11} .

11.7.2 Under the same conditions, record the signal at the scatter signal detector as V_{s11} .

11.7.3 Repeat the measurements of both signals a total of K times, recording the signals as $V_{r12}, V_{s12}; V_{r13}, V_{s13}; V_{r14}, V_{s14}; \dots; V_{r1K}, V_{s1K}$.

11.8 Move the test specimen so that location 2 is under the integrating sphere and repeat ¶ 11.7.1 through 11.7.3 a total of K times, recording the signals as V_{r2k}, V_{s2k} .

11.9 Repeat ¶ 11.8 until measurements have been made at all J locations agreed upon for the test.

12 Calculations

12.1 Calculate and record the specular reflectance of the test specimen for each of the measured signals at the specular reflection detector as follows:

$$(R_{spec})_{jk} = \frac{P_{rjk}}{P_i} = \frac{T_r R V_{rjk}}{V_{rref}} \quad (4)$$

where:

$(R_{spec})_{jk}$ = specular reflectance of the test specimen for k^{th} measurement at j^{th} location,

P_{rjk} = light power of k^{th} measured reading of the specular reflection detector at j^{th} location on the test specimen,

P_i = incident power of the source laser beam (constant for all V_{rref} and V_{sref} measurements),

R = reflectance of the specular reflectance standard at wavelength λ ,

V_{rjk} = k^{th} measured reading of the specular reflection detector at j^{th} location on the test specimen,

T_r = transmittance of the filter for the specular reflection detector at wavelength λ ($= 1$ if no filter is used), and

V_{rref} = reference signal of the specular reflectance standard at the specular reflection detector (refer to ¶ 11.3).

12.2 Calculate and record the diffuse reflectance of the test specimen for each of the measured signals at the scatter signal detector as follows:

$$(R_{diff})_{jk} = \frac{P_{sjk}}{P_i} = \frac{T_s R (V_{sjk} - V_{sn})}{V_{sref}} \quad (5)$$

where:

$(R_{diff})_{jk}$ = diffuse reflectance of the test specimen for k^{th} measurement at j^{th} location,

P_{sjk} = light power of k^{th} measured reading of the scatter signal detector at j^{th} location on the test specimen,

P_i = incident power of the source laser beam (constant for all V_{rref} and V_{sref} measurements),

R = reflectance of the specular reflectance standard at wavelength λ ,

V_{sjk} = k^{th} measured reading of the scatter signal detector at j^{th} location on the test specimen,

V_{sn} = background noise signal (refer to ¶ 11.1),

T_s = transmittance of the filter for the scatter signal detector at wavelength λ ($= 1$ if no filter is used), and

V_{sref} = reference signal of the specular reflectance standard at the scatter signal detector (refer to ¶ 11.5).