

SEMI PV28-0212

TEST METHODS FOR MEASURING RESISTIVITY OR SHEET RESISTANCE WITH A SINGLE-SIDED NONCONTACT EDDY-CURRENT GAUGE

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1 Purpose

1.1 Resistivity is a primary quantity for characterization and specification of material used for photovoltaic devices. Sheet resistance is a primary quantity for characterization, specification, and monitoring of thin films. An eddy-current gauge directly measures conductance of a specimen. Values of resistivity or sheet resistance are calculated from the measured conductance, with the resistivity values also requiring a measurement of specimen thickness.

1.2 These test methods outline the principles of eddy-current measurements as they relate to silicon bricks and ingots or silicon films on nonconductive substrates that are used in photovoltaic sensors. These test methods are very similar to those in SEMI MF673, which covers the principles of eddy-current measurements as they relate to silicon wafers and certain thin films fabricated on such substrates, but the nature of the apparatus is significantly different to accommodate the bricks and ingots. Such an instrument can also be used for measurements on thin silicon or other thin conducting films on nonconductive substrates. SEMI MF673 should be referred to for measurements on silicon wafers and certain thin films fabricated on such substrates.

NOTE 1: A single-sided noncontact eddy current gauge can also be used to measure silicon wafers.

2 Scope

2.1 In addition to providing the procedures for eddy-current measurements on both single crystalline and multicrystalline silicon bricks and ingots as well as silicon or other thin conducting films on nonconductive substrates, these test methods cover the requirements for setting up and calibrating such instruments for use, particularly at a buyer-seller interface.

2.1.1 For measurements on thin conducting films, the sheet resistance of the film shall be in the nominal range from 0.04 to 3,000 Ω per square. The substrate on which the thin film is fabricated shall have a minimum edge to edge dimension of 25 mm, measured through the center point and an effective sheet resistance at least 1,000 times that of the thin film.

NOTE 2: The effective sheet resistance of a bulk substrate is its bulk resistivity (in $\Omega \cdot \text{cm}$) divided by its thickness in cm.

2.2 These test methods require no specimen preparation. Measurements are not affected by specimen surface finish or crystallinity of the test specimen.

2.3 For measurements on silicon specimens, these test methods require the use of single crystal silicon resistivity standards to calibrate the apparatus (see ¶ 7.1), and a set of similar reference specimens for qualifying the apparatus (see ¶ 7.1.1). For measurements on transparent conducting oxide (TCO) films, it is possible to use TCO film standards, calibrated by four-point probe sheet resistance measurements.

2.4 Two test methods are covered by this Standard.

2.4.1 Method I ascertains the conformance of the apparatus to linearity and slope limits (± 1 digit) over a broad range (2 decades) of calibration standard values. It qualifies apparatus for use over a wide range of sample values.

2.4.2 Method II, for use on silicon specimens only, assumes instrument linearity between calibration standards whose values are narrowly separated (typically $\pm 25\%$ of the anticipated sample range median point). Method II is particularly well suited to computer-based systems where all measurements can be quickly and automatically corrected for value offset and for the temperature coefficient of the resistivity of silicon.

2.4.3 These methods differ in calibration technique, sample measurement value range, data correction techniques, and suitability of instrumentation as indicated in Table 1. Either method may be applied to brick or ingot specimens

with resistivity in the range from 0.1 to 10,000 $\Omega\cdot\text{cm}$ or to silicon or other thin films of sheet resistance 2 to 3,000 Ω/square provided that suitable calibration standards can be obtained.

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.

Table 1 Characteristics of Eddy-Current Methods

<i>Factors</i>	<i>Method I</i>	<i>Method II</i>
Calibration	Ascertains linearity with five samples	Ascertains slope with two samples
Application range	Broad: 2 decades	Narrow: $\pm 25\%$
Sample data	Direct reading, then correct for temperature	Direct reading, then correct for slope
Suitable instruments	Manual/Automatic	Automatic: computer-controlled

3 Limitations

3.1 Because eddy-current measurements for semiconductor materials are made almost exclusively with commercial instrumentation from one of several suppliers, some details included in these test methods, such as specific range limits and manner of entering specimen thickness values to obtain resistivity values may not apply strictly to all instruments. In all such cases, the owner's manual for the particular instrument shall be considered to contain the correct information for that instrument.

3.2 Radial resistivity variations or other resistivity non-uniformities (such as those occurring in multicrystalline materials) under the transducer are averaged by these test methods in a manner which may be different from that of other types of resistivity or sheet resistance measurements that are responsive to a finite lateral area. The results may therefore differ from those of four-point probe measurements depending on dopant density fluctuation and the probe spacing used.

3.3 Spurious currents can be introduced in the test equipment when it is located near high-frequency generators. If equipment is located near such sources, adequate shielding must be provided. Power line filtering may also be required.

3.4 Silicon has a significant temperature coefficient of resistivity. Temperature-correction factors for extrinsic silicon specimens are given in SEMI MF84, but these may not provide sufficient accuracy for use with multicrystalline or heavily compensated material. Note that they should apply accurately to the single crystal reference wafers. Temperature differences between any of the silicon reference wafers or test specimens, during calibration or measurement, or both, introduce a measurement error in Method II.

3.5 High levels of humidity may affect the indicated value and should be avoided.

3.6 Photoconductive and photovoltaic effects can seriously influence the observed resistivity. Therefore, all determinations should be made in a dark chamber unless experience shows that the material is insensitive to ambient illumination.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI M59 — Terminology for Silicon Technology

SEMI MF43 — Test Methods for Measuring Resistivity of Semiconductor Materials

SEMI MF84 — Test Method for Measuring Resistivity of Silicon Wafers with an In-Line Four-Point Probe

SEMI MF374 — Test Method for Sheet Resistance of Silicon Epitaxial, Diffused, Polysilicon, and Ion-Implanted Layers Using an In-Line Four-Point Probe with the Single-Configuration Procedure

SEMI MF533 — Test Method for Thickness and Thickness Variation of Silicon Wafers

SEMI MF673 — Test Method for Measuring Resistivity of Semiconductor Wafers or Sheet Resistance of Semiconductor Films with a Noncontact Eddy-Current Gauge

SEMI MF1527 — Guide for Application of Certified Reference Materials and Reference Wafers for Calibration and Control of Instruments for Measuring Resistivity of Silicon

4.2 ASTM Standards¹

ASTM E2251 — Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids

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 those used in this Test Method, are listed and defined in SEMI M59.

5.2 The following term and symbol are also used in this Standard:

5.2.1 *transparent conducting oxide (TCO)* — a transparent conducting film, consisting of a metal-oxide compound such as indium-tin-oxide, used for electrically contacting the active semiconducting regions of a PV solar cell and for improving the spectral response of the cell.

6 Summary of Test Methods

6.1 Method I

6.1.1 The temperature of the apparatus during the measurement is determined.

6.1.2 The apparatus is first calibrated using standards of known resistivity or sheet resistance with the sensor located the same measured distance above each calibration specimen. Then the apparatus is subjected to a test for linearity that involves measuring a set of five reference specimens. As a part of the linearity test, a plot is made of the indicated values as a function of the known values; two limiting curves are also plotted on the same graph. If all the plotted points fall within the limit curves, the apparatus is regarded as satisfactory.

6.1.3 For subsequent measurements of bulk test specimens placed with the sensor at the same distance above the test specimen as used for the calibration specimens, the conductance of the specimen is then measured by the apparatus and converted to a resistivity value that is displayed. The resistivity is subsequently corrected to its 23°C equivalent.

6.1.4 For subsequent measurement of thin film specimens again placed with the sensor at the same distance above the test specimen as used for the calibration specimens, the sheet conductance is measured, converted to sheet resistance, and displayed.

6.2 Method II (For Measurements on Silicon Test Specimens Only)

6.2.1 The temperature of the apparatus during the measurement is determined.

6.2.2 The apparatus is first calibrated using two single crystal silicon standards of known bulk resistivity with in each case the sensor located the same measured distance above the calibration specimen. These standards should be the same electrical type as the test specimens to be measured (see Note 3). The apparatus is then subjected to a test that quantifies apparatus slope at two points, and provides a means of correcting subsequent sample measurements, for values between these two points, to a calibration line established between the two standards employed.

NOTE 3: The maximum error derived from calibrating on one conductivity type and measuring the other is less than or equal to 0.12%/°C in the resistivity range 0.01Ω to 1,000 Ω·cm.

6.2.3 For subsequent measurement of test specimens placed with the sensor at the same distance above the test specimen (see ¶ 6.2.2), the conductance is measured, converted to Resistivity and displayed. These measurements are subsequently referred to the standard reference plot. The corrected values are known to a greater precision than those obtained following Method I, and in most instances are also 23°C equivalents.

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