Designation: F 673 – 02

Standard Test Methods for Measuring Resistivity of Semiconductor Slices or Sheet Resistance of Semiconductor Films with a Noncontact Eddy-Current Gage[1]

This standard is issued under the fixed designation F 673; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This test method is intended to outline the principles of eddy-current measurements as they relate to semiconductor substrates and certain thin films fabricated on such substrates as well as requirements for setting up and calibrating such instruments for use particularly at a buyer-seller interface. Because such eddy-current measurements for semiconductor materials are made almost exclusively with commercial instrumentation from one of several suppliers, some details included here such as specific range limits and manner of entering slice/wafer 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. It is to be noted that an eddy-current instrument directly measures conductance of a specimen. Values of sheet resistance and resistivity are calculated from the measured conductance, with the resistivity values also requiring a measurement of specimen thickness.

1. Scope

1.1 These test methods cover the nondestructive measurement of bulk resistivity of silicon and certain gallium-arsenide slices and of the sheet resistance of thin films of silicon or gallium-arsenide fabricated on a limited range of substrates at the slice center point using a noncontact eddy-current gage.

1.1.1 The measurements are made at room temperature between 18 and 28°C.

1.2 These test methods are presently limited to single-crystal and polycrystalline silicon and extrinsically conducting gallium-arsenide bulk specimens or to thin films of silicon or gallium-arsenide fabricated on relatively high resistivity substrates but in principle can be extended to cover other semiconductor materials.

1.2.1 The bulk silicon or gallium-arsenide specimens may be single crystal or poly crystal and of either conductivity type (*p* or *n*) in the form of slices (round or other shape) that are free of diffusions or other conducting layers that are fabricated thereon, that are free of cracks, voids or other structural discontinuities, and that have (*1*) an edge-to-edge dimension, measured through the slice centerpoint, not less than 25 mm (1.00 in.); (*2*) thickness in the range 0.1 to 1.0 mm (0.004 to 0.030 in.), inclusive, and (*3*) resistivity in the range 0.001 to 200 Ω·cm, inclusive. Not all combinations of thickness and resistivity may be measurable. The instrument will fundamentally be limited to a fixed sheet resistance range such as given in 1.2.2; see also 9.3.

1.2.2 The thin films of silicon or gallium-arsenide may be fabricated by diffusion, epitaxial or ion implant processes. The sheet resistance of the layer should be in the nominal range from 2 to 3000 Ω per square. The substrate on which the thin film is fabricated should have a minimum edge to edge dimension of 25 mm, measured through the centerpoint and an effective sheet resistance at least 1000 × that of the thin film. The effective sheet resistance of a bulk substrate is its bulk resistivity (in Ω·cm) divided by its thickness in cm.

1.2.3 Measurements are not affected by specimen surface finish.

1.3 These test methods require the use of resistivity standards to calibrate the apparatus (see 7.1), and a set of reference specimens for qualifying the apparatus (see 7.1.2).

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

---

[1] This test method is under the jurisdiction of ASTM Committee F01 on Electronics and is the direct responsibility of Subcommittee F01.06 on Silicon Materials and Process Control.

Current edition approved Dec. 10, 2002. Published February 2003. Originally approved in 1980. Last previous edition approved in 1990 as F 673 – 90 (1996)$^{\epsilon 1}$.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 1 Specification for ASTM Thermometers[2]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[3]

F 81 Test Method for Measuring Radial Resistivity Variation on Silicon Slices[4]

F 84 Test Method for Measuring Resistivity of Silicon Slices with an In-Line Four-Point Probe[4]

F 374 Test Method for Sheet Resistance of Silicon Epitaxial, Diffused, and Ion-Implanted Layers Using an In-Line Four-Point Probe[4]

F 533 Test Method for Thickness and Thickness Variation of Silicon Slices[4]

F 1527 Guide for Application of Certified Reference Materials and Reference Wafers for Calibration and Control of Instruments for Measuring Resistivity of Silicon[4]

3. Summary of Test Method

3.1 There are two methods that may be used. They differ in calibration technique, sample measurement value range, data correction techniques, and suitability of instrumentation and are as follows:

Factors	Methods I	Methods II
Calibration	Ascertains linearity 5 samples Sheet or bulk	Ascertains slope 2 samples Sheet or bulk
Application range	Broad: 2 decades	Narrow: ± 25 %
Sample data	Direct reading, then correct for temperature.	Direct reading, then correct for slope.
Suitable instruments	Manual/Automatic	Automatic: computer-controlled

3.2 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.

3.2.1 The apparatus is first calibrated using standards of known resistivity or sheet resistance. 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.)

3.2.2 For subsequent measurements of bulk samples, the thickness of each sample (wafer) is measured and entered directly, or by the operator, according to the design of the instrument. The conductance of the specimen is then measured by the apparatus and converted to a resistivity value that is displayed. These measurements are subsequently corrected to 23°C-equivalents.

3.2.3 For subsequent measurement of thin film specimens, the sheet conductance is measured, converted to sheet resistance, and displayed. See 9.1.3 for relations between these quantitites.

3.3 Method II assumes instrument linearity between calibration standards whose values are narrowly separated (typically ±25 % of the anticipated sample range median point).

3.3.1 The apparatus is first calibrated using standards of known resistivity or sheet resistance. 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. These latter standards may be of either known bulk resistivity or sheet resistance; their material must be the same electrical type as the samples to be measured (see Note 8).

3.3.2 For subsequent measurements of bulk samples, the thickness of each sample (wafer) is measured and entered directly, or by the operator, according to the design of the instrument. 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.

3.3.3 For subsequent measurement of thin film specimens, the sheet conductance is measured, converted to sheet resistance and displayed. See 9.1.3 for relations between these quantities. These measurements are subsequently referred to the standard reference plot.

4. Significance and Use

4.1 Resistivity is a primary quantity for characterization and specification of material used for semiconductor electronic devices. Sheet resistance is a primary quantity for characterization, specification, and monitoring of thin film fabrication processes.

4.2 This test method requires no specimen preparation.

4.3 Method II is particularly well suited to computer-based systems where all measurements can be quickly and automatically corrected for value offset and for temperature coefficient of resistivity.

4.4 Method I has been evaluated by interlab comparison (see Section 11). Until Method II has been evaluated by interlaboratory comparison, it is not recommended that the test method be used in connection with decisions between buyers and sellers.

5. Interferences

5.1 Radial resistivity variations or other resistivity nonuniformity under the transducer are averaged by this test method in a manner which may be different from that of other types of resistivity or sheet resistance techniques which are responsive to a finite lateral area. The results may therefore differ from those of four-probe measurements depending on dopant density fluctuation and the four-probe spacing used.

NOTE 1—Test Method F 81 provides a means for measuring radial

[2] *Annual Book of ASTM Standards*, Vol 14.03.
[3] *Annual Book of ASTM Standards*, Vol 14.02.
[4] *Annual Book of ASTM Standards*, Vol 10.05.

resistivity variation of silicon slices.

5.2 Uncertainty of thickness values for the reference (bulk) wafers can introduce, in Method I, an uncertainty in the linearity plot; in Method II it can introduce a corresponding uncertainty in the reference line connecting the two reference wafer values, if calibration is performed in resistivity values.

5.3 Uncertainty of thickness value of sample (bulk) wafers can introduce an error in both measured and reported values for both Methods I and II. These uncertainties can be eliminated by executing the procedure using sheet resistance values for reference and sample wafers.

5.4 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.

5.5 Semiconductors have a significant temperature coefficient of resistivity. Temperature-correction factors for extrinsic silicon specimens are given in Test Method F 84. Temperature differences between any of the reference or sample wafers, during calibration or measurement, or both, will introduce a measurement error in Method II.

5.6 High levels of humidity may affect the indicated value.

6. Apparatus

6.1 *Electrical Measuring Apparatus*, with instructions for use and consisting of the following assemblies:

6.1.1 *Eddy-Current Sensor Assembly*, having a configuration of a fixed gap, between two opposed transducers, into which a specimen slice is inserted. The assembly shall include support(s) on which the slice rests, a device for centering the slice, and a high-frequency oscillator to excite the sensing elements. The frequency of the oscillator shall be chosen to provide a skin depth at least five times the thickness of the slice or thin film to be measured. The skin depth is a function of the resistivity of the specimen. The assembly shall provide an output signal proportional to sheet conductance. This assembly and associated apparatus are shown schematically in Fig. 1.

NOTE 2—A typical conductance apparatus is described in detail in a paper by Miller, Robinson, and Wiley.[5] This paper also discusses skin-depth as a function of thickness and resistivity.

6.1.2 *Signal Processor*— Means for electronically converting, by analog or digital circuitry, the sheet conductance signal to a sheet resistance value, and in the case of bulk substrate measurements, means for conversion to resistivity values using the measured thickness of the substrate. The processor shall incorporate a means for displaying sheet resistance or resistivity, a means of zeroing the conductance signal in the absence of a specimen and a means for calibrating the instrument with known calibration specimens.

NOTE 3—For Method I, the linearity of the apparatus is checked in an operational qualification test (see 9.1.3).

NOTE 4—A typical apparatus operates as follows. When a specimen is inserted into the fixed gap between the two colinear sensing elements, or transducers, in a special oscillator circuit, eddy currents are induced in the specimen by the alternating field between the transducers. The current needed to maintain a constant voltage in the oscillator is determined internally; this current is a function of the specimen conductance. The specimen conductance is obtained by monitoring this current. Sheet resistance or resistivity values are obtained from the specimen conductance by analog or digital electronic means; calculation of resistivity values also requires knowledge of specimen thickness.

6.2 *Thermometer*— ASTM Precision Thermometer having a range from − 8 to + 32°C and conforming to the requirements for Thermometer 63C as specified in Specification E 1.

6.3 *Thickness Gage*, as specified in 7.1 of Test Method F 533 (included for completeness).

6.4 Calibration and linearity checking must be done in consistent units, whether resistivity, sheet resistance or sheet conductance, according to the requirements of the given instrument. If resistivity values are used, knowledge of the specimen thickness is also required. For bulk calibration or linearity-check specimens, the thickness is the as-measured thickness in centimetres. For thin film specimens, the total thickness of the thin film plus substrate should be measured and used; if this cannot be done, an effective thickness of 0.0508 cm (0.020 in.) should be used. (See 9.1.3.)

7. Reagents and Materials

7.1 Resistivity standards or other reference specimens to check the accuracy and linearity of the instrument. Preferably, these are bulk silicon slices but may also be fabricated by ion implantation into silicon.

7.1.1 Bulk silicon standards or other reference specimens are to be measured for resistivity in accordance with Test Method F 84. The thickness of these specimens shall be within ±25 % of the specimens to be measured unless otherwise agreed to by the parties to the test.

7.1.2 Ion implant specimens are to be measured for sheet resistance by four point probe in accordance with Test Method F 374.

7.1.3 The standards and other reference specimens for Method I shall be at least five in number and should have a range of values that span the full range of the instrument. For Method II, where the specimens to be measured have a narrow range of resistivity or sheet resistance values, the standards and other reference specimens shall be two in number. Their values shall span a range at least as large as the specimens to be measured. Table 1 gives a list of values recommended for checking the full range of a typical instrument for Method I application; these values should be met within ±25 %.

NOTE 5—Resistivity standards are available from the National Bureau

[5] Miller, G. L., Robinson, D. A. H., and Wiley, J. D., "Contactless Measurement of Semiconductor Conductivity by Radio Frequency-Free-Carrier Power Absorption," *Review of Scientific Instruments*, Vol 47, No. 7, July 1976.

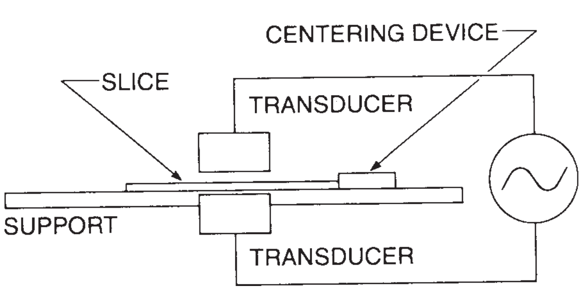

FIG. 1 Schematic of Eddy-Current Sensor Assembly