SEMI MF42-0316 (Reapproved 0921)
TEST METHOD FOR CONDUCTIVITY TYPE OF EXTRINSIC SEMICONDUCTING MATERIALS

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1 Purpose

1.1 The determination of conductivity type and the presence of junctions in semiconductors is important in processing or inspection of semiconducting materials for device fabrication as well as in research and development.

1.2 This Test Method covers four procedures that are widely used for making routine measurements.

2 Scope

2.1 This Test Method[1] covers the determination of the conductivity type of extrinsic semiconductors. While explicit details are given for germanium and silicon, inclusion of other extrinsic materials such as gallium arsenide and indium antimonide should be feasible. For the latter compounds, however, applicability has not been formally verified by round-robin tests. Determinations can be made most reliably on homogeneous bulk material, but these test methods may also be used to map regions of different conductivity type on the surfaces of inhomogeneous specimens. These test methods have not been tested on layered structures, such as epitaxial layers. Measurements on these structures may give erroneous indications of conductivity type.

2.2 Four test methods are described:

2.2.1 *Test Method A* — Hot-Probe Thermal EMF Conductivity-Type Test.

2.2.2 *Test Method B* — Cold-Probe Thermal EMF Conductivity-Type Test.

2.2.3 *Test Method C* — Point-Contact Rectification Conductivity-Type Test.

2.2.4 *Test Method D* — Type-All[2] system operating in either of two modes:

2.2.4.1 Rectification Conductivity-Type Mode.

2.2.4.2 Thermal EMF Conductivity-Type Mode.

2.3 Experience has shown that Test Method A (hot-probe) gives dependable results in *n*- and *p*-type silicon having room-temperature resistivity up to 1000 Ω·cm.

NOTE 1: Resistivity of germanium specimens may be measured in accordance with SEMI MF43 and resistivity of silicon specimens may be measured in accordance with SEMI MF43 or SEMI MF84.

[1] DIN 50432, Testing of Inorganic Semiconductor Materials: Determining the Conductivity Type of Silicon or Germanium by Means of the Rectification Test or Hot Probe, includes methods equivalent to Test Methods A and C. It does not include Test Methods B and D. DIN 50432, the responsibility of DIN Committee NMP 221, is available in both German and English editions from Beuth Verlag GmbH, Burggrafenstrasse 6, 10787 Berlin, Germany, Telephone: 49.30.2601-0, Fax: 49.30.2601.1263, Website: www.beuth.de.

[2] Keenan, W. A., Schneider, C. P., and Pillus, C. A., "Type-All System for Determining Semiconductor Conductivity Type," *Solid State Technology*, Volume 14, March 1971.

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2.4 Test Method B (cold-probe) gives dependable results for *n*- and *p*-type germanium having a room-temperature resistivity of 20 Ω·cm or less and for *n*- and *p*-type silicon having a resistivity up to 1000 Ω·cm (Note 1). This technique has the advantage over the hot-probe test method in that the signal amplitude can be increased by developing a greater temperature difference between the two probes.

2.5 Test Method C (rectification) is a simple convenient technique that gives dependable results for *n*- and *p*-type silicon with room-temperature resistivity between 1 and 1000 Ω·cm. This Test Method is not recommended for germanium.

2.6 Test Method D (type-all rectification mode) is appropriate for use on *n*- and *p*-type silicon having room-temperature resistivity between 0.1 and 1000 Ω·cm, inclusive.

2.7 Test Method D (type-all thermal emf mode) is appropriate for use on *n*- and *p*-type silicon having a room-temperature resistivity between 0.002 and 0.1 Ω·cm, inclusive (Note 1).

2.8 These test methods may apply outside the limits given above, but their suitability outside these limits has not been verified experimentally.

2.9 It is recommended that if satisfactory results cannot be obtained with the use of these test methods that conductivity type be determined from Hall-effect measurements as described in ASTM F76.

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 *Test Method A (Hot-Probe)*

3.1.1 Some high-resistivity silicon and germanium specimens may be nearly intrinsic at the hot-probe temperature; since the mobility of the electrons exceeds that of holes, the thermoelectric power is always negative at these temperatures.

3.1.2 Oxide coating buildup on the hot probe can produce unreliable measurements.

3.1.3 *n*-type germanium with room-temperature resistivity greater than 40 Ω·cm can show *p*-type conductivity due to insufficient probe force.

3.2 *Test Method B (Cold-Probe)*

3.2.1 The cold-probe should be maintained free of ice. Ice formed during prolonged periods of usage in ordinary ambient air has been found to give erratic results.

3.2.2 Oxide coating buildup on the cold-probe can produce unreliable measurements.

3.2.3 Specimens of *n*-type germanium with room-temperature resistivity greater than 20 Ω·cm can show *p*-type conductivity due to insufficient probe force.

3.3 *Test Method C (Rectification)*

3.3.1 Since this test method indicates primarily the surface-conductivity type, extreme care must be taken in proper surface preparation. A surface oxide can act as an insulator so that no voltage is indicated by the meter.

3.3.2 Reversed readings can sometimes occur if the large-area contact is not held firmly. In such cases, a heavy force on the point contact can cause the large-area contact to become the effective rectifying contact and give reversed meter readings.

3.3.3 Erroneous readings may arise from stray pickup caused by touching the specimen with hands or objects other than the probe.

3.3.4 An etched surface is not recommended because various etchants and etching techniques may introduce uncontrolled variations in surface characteristics.

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3.4 *Test Method D (Type-All)*

3.4.1 Erroneous indications may result if the rectification mode is used with very low-resistivity material, which results in a low output signal. For silicon, use of the rectification mode in cases where the output is less than 0.5 V is not recommended.

3.4.2 Erroneous indications may result if the thermal emf mode is used with high-resistivity material.

3.5 All four described test methods may give erroneous readings if excessive light falls on the specimen, especially with high-resistivity material.

3.6 Ambient radio-frequency energy may cause spurious rectification and erroneous indications.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI M59 — Terminology for Silicon Technology

SEMI MF43 — Test Method for Resistivity of Semiconductor Materials

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

4.2 *ASTM Standards*[3]

ASTM D5127 — Guide for Ultra-Pure Water Used in the Electronics and Semiconductor Industry

ASTM F76 — Test Methods for Measuring Resistivity and Hall Coefficient and Determining Hall Mobility in Single-Crystal Semiconductors

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

5 Terminology

5.1 Terms relating to silicon and other semiconductor technology are defined in SEMI M59.

6 Summary of Test Methods

6.1 *Test Methods A and B* — In both of these test methods, the sign of the thermal emf generated between two metal probe contacts to the specimen held at different temperatures is used to determine conductivity type. One of the probes is maintained at room temperature while the other is heated (Test Method A) or cooled (Test Method B). The warmer probe is positive with respect to the cooler probe when the specimen is *n*-type and negative when the specimen is *p*-type.[4] The polarity is observed on a center-zero meter that may be either voltage or current sensitive. Because most of the temperature difference occurs in the region of the probe that is not at room temperature, the sign observed is governed by the conductivity type of the portion of the specimen at this probe contact.

6.2 *Test Method C* — In this test method, the direction of the current through a point contact is used to determine the conductivity type of the specimen. A metal point contact to a *p*-type semiconductor passes current when the semiconductor is positive while a metal point contact to an *n*-type semiconductor passes current when the semiconductor is negative. An alternating potential is applied between the point contact and a second large area contact. The direction of current is observed on a zero-center current sensitive meter, an oscilloscope, or a curve tracer. Since rectification occurs at the point contact rather than at the large area contact, the direction of current is governed by the conductivity type of the portion of the specimen at the point contact.

6.3 *Test Method D, Rectification Mode* — In this test method, the polarity of the voltage required to reverse-bias a point contact is used to determine the conductivity type of the specimen. An alternating potential is applied between two point contacts to the specimen. During one-half cycle, a given contact is reverse-biased and experiences the major portion of the voltage drop. During the following half cycle, this junction is forward-biased and the voltage drop is

[3] ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA; Telephone: +1.610.832.9585, Fax: +1.610.832.9555, http://www.astm.org

[4] Scaff, J. H., and Theuerer, H. C., in *Transistor Technology*, Volume 1, Edited by Scaff, J. H., Bridgers, H. E., and Shive, J. N., D. Van Nostrand Co., Inc., New York, 1958, p. 12.

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