Designation: F 43 – 99

DIN 50431

Standard Test Methods for Resistivity of Semiconductor Materials [1]

This standard is issued under the fixed designation F 43; 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.

1. Scope

1.1 The resistivity of a semiconductor material is an important materials acceptance requirement. Resistivity determinations made during device fabrication are also widely used for quality control purposes.

1.2 These test methods [2] cover two procedures which are widely used for making routine measurements. These procedures apply directly to both silicon and germanium. Application of these procedures to other semiconductor materials may require the use of different probe material and probe attachment.

1.2.1 *Method A, Two-Probe*— This test method requires a bar specimen of measurable cross section and with cross-sectional dimensions small in comparison with the length of the bar. For materials for which no specific ASTM referee method has been developed, this test method is recommended for materials acceptance purposes.

1.2.2 *Method B, Four-Probe*— This test method is rapid and does not require a specimen of regular cross section. This test method may be used on irregularly shaped specimens, provided a flat region is available for the contacting probes. As described in this standard, this test method is applicable only to specimens such that the thickness of the specimen and the distance from any probe point to the nearest edge are both at least four times the probe spacing (Note 1). For the special case of specimens of circular cross section with thickness more than one, but less than four, times the probe spacing, measurements by this test method are possible; the required application of approximate geometric corrections will result in improved accuracy (see 9.1.3).

1.2.3 In general, resistivity measurements are most reliable when made on single crystals, since with such material local variations in impurity which affect the resistivity are less severe. Localized impurity segregation at grain boundaries in polycrystalline material may result in large resistivity variations. Such effects are common to either of the measurement test methods but are more severe with the four-probe test method, and its use, therefore, is not recommended for polycrystalline material.

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

1.4 *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:*

F 76 Test Methods for Measuring Resistivity and Hall Coefficient and Determining Hall Mobility in Single-Crystal Semiconductors [3]

F 84 Test Method for Measuring Resistivity of Silicon Wafers with an In-Line Four-Point Probe [3]

F 374 Test Method for Sheet Resistance of Silicon Epitaxial, Diffused, Polysilicon, and Ion-Implanted Layers Using an In-Line Four-Point Probe [3]

F 397 Test Method for Resistivity of Silicon Bars Using a Two-Point Probe [3]

F 533 Test Method for Thickness and Thickness Variation of Silicon Slices [3]

F 613 Test Method for Measuring Diameter of Semiconductor Wafers [3]

2.2 *American National Standard:*

B 74.10 Specification for Grading of Abrasive Microgrits [4]

NOTE 1—Other ASTM methods are preferred for use in various special circumstances. For measurements on thin slices, use Test Method F 84; this method is preferred for referee measurements on silicon slices. For measurements on specimens for which point contacts are unsatisfactory, use a procedure in Test Methods F 76. For two-probe referee measurements on cylindrical single crystal bars, use Test Method F 397. For four-probe referee measurements of sheet resistance on epitaxial layers deposited on or diffused or implanted into opposite conductivity-type

[1] These test methods are under the jurisdiction of ASTM Committee F-1 on Electronics and are the direct responsibility of Subcommittee F01.06 on Silicon Materials and Process Control.

Current edition approved Dec. 10, 1999. Published February 2000. Originally published as F 43 – 64 T. Last previous edition F 43 – 93.

[2] DIN 50431 is an equivalent method. It is the responsibility of DIN Committee NMP 221, with which Committee F-1 maintains close technical liaison. DIN 50431, Testing of Inorganic Semiconductor Materials: Measurement of the Specific Electrical Resistance of Monocrystals of Silicon or Germanium by the Four-Point Direct-Current Technique with Linearly Arranged Probes, is available from Beuth Verlag GmbH Burggrafenstrasse 4-10, D-1000 Berlin 30, Federal Republic of Germany.

[3] *Annual Book of ASTM Standards*, Vol 10.05.

[4] Available from American National Standards Institute, 11 West 42nd St., 13th Floor, New York, NY 10036.

substrates, use Test Method F 374.

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *resistivity,* ρ*[Ω·cm] of a semiconductor,*— the ratio of the potential gradient (electric field) parallel with the current to the current density.

4. Summary of Test Methods

4.1 *Two-Probe Method*—A direct current is passed through ohmic contacts at the ends of a bar specimen and the potential difference is determined between two probes placed along the current direction (Fig. 1). The resistivity is calculated from the current and potential values and factors appropriate to the geometry.

4.2 *Four-Probe Method*—An in-line four-point probe is placed on a flat surface of a solid specimen which can be approximated as semi-infinite. A direct current is passed through the specimen between the outer probes and the resulting potential difference is measured between the inner probes (Fig. 1). The resistivity is calculated from the current and potential values and factors appropriate to the geometry.

5. Interferences

5.1 In making resistivity measurements, spurious results can arise from a number of sources. The following must be guarded against:

5.1.1 Photoconductive and photovoltaic effects can seriously influence the observed resistivity, particularly with nearly intrinsic material. Therefore make all determinations in a dark chamber unless experience has shown that the material is insensitive to ambient illumination.

5.1.2 Spurious currents can be introduced in the testing circuit when the equipment is located near high-frequency generators. If equipment is located near such sources, adequate shielding must be provided.

5.1.3 Minority carrier injection during the measurement can occur due to the electric field in the specimen. With material possessing high minority carrier lifetime and high resistivity, such injection can result in a lowering of the resistivity for distance of several centimetres. Carrier injection can be detected by repeating the measurements at lower current. In the absence of injection no increase in resistivity should be observed. It is recommended that the current used in a resistivity measurement be as low as possible, consistent with the required precision.

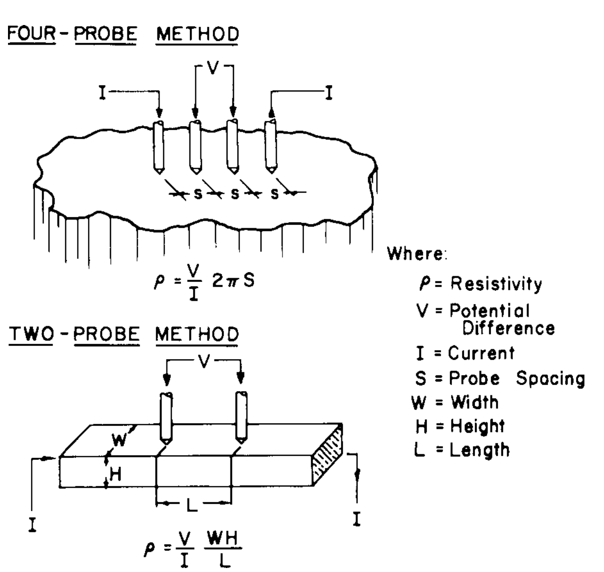

FIG. 1 Specimen and Probe Arrangement for Two-Probe and Four-Probe Measurements on a Rectangular Bar

5.1.4 Semiconductors have a significant temperature coefficient of resistivity. Consequently, the temperature of the specimen should be known at the time of the measurement and the current used should be small to avoid resistive heating. If resistive heating is suspected, it can be detected by a change in readings as a function of time starting immediately after the current is applied. Temperature correction factors for extrinsic germanium are plotted in Fig. 2 and Fig. 3. For referee purposes, it is recommended that the test be performed at 23 ± 0.5°C . Temperature correction factors for silicon are plotted in Fig. 4 and Fig. 5, and are given in tabular form in Test Method F 84 along with an equation for applying the correction.

5.1.5 Vibration of the probes sometimes causes troublesome changes in the contact resistance. If difficulty is encountered, shock mount the apparatus.

6. Apparatus

6.1 *Jigs* suitable for mounting the specimens and contacting them with either two or four probes as required. The probes shall be individually spring mounted and shall be loaded with a force of 1.5 ± 0.5 N. The probe mountings shall be furnished with appropriate guides to ensure that the probes contact the specimen reproducibly with a probe spacing tolerance of ±0.5 %. The probes may be made from hardened tool steel, tungsten carbide, or other conducting metal and may be chisel shaped for measurement of curved surfaces or pointed for measurement on flat sections. In the case of point probes, the nominal radius of the tips should be initially 25 to 50 µm. With all probing devices, frequent checking of the probe spacing with a calibrating microscope is desirable. Probes should be replaced or resharpened when necessary to maintain the required spacing tolerance. Isolation resistance between the probes should be at least 10^9 Ω.

NOTE 2—Detailed procedures for in situ determination of the spacing between adjacent probes of an in-line four-point probe are given in the Probe Assembly paragraph of the Suitability of Test Equipment section, of Test Method F 84. These procedures, for which equipment described in the Probe Alignment and Separation paragraph of the Apparatus section, of Test Method F 84 is required, can be used to establish probe spacings and their repeatability for both two- and four-probe assemblies. The probe spacing correction factor, F_{sp}, in Equation 5 of the Suitability of Test Equipment section, of Test Method F 84 should be replaced by:

$$F = 1 + 1.25\,[1 - (\bar{S}_2/\ \bar{S})],$$

where:

$\bar{S}_2$ = spacing between inner pair of probes, cm, and
$\bar{S}$ = average probe spacing, cm,

when four-probe measurements are made on semi-infinite solids. In general, however, the correction for unequal probe spacing is neglected.

6.2 The recommended electrical circuit, connected as shown in Fig. 6, consists of the following:

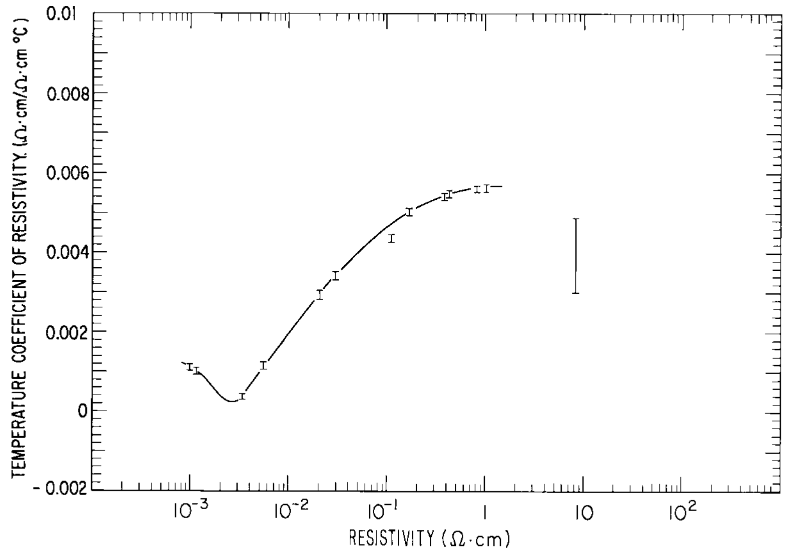

FIG. 2 Temperature Coefficient (C_T) Versus Specimen Resistivity (ρ_{av}) for *N*-Type Germanium

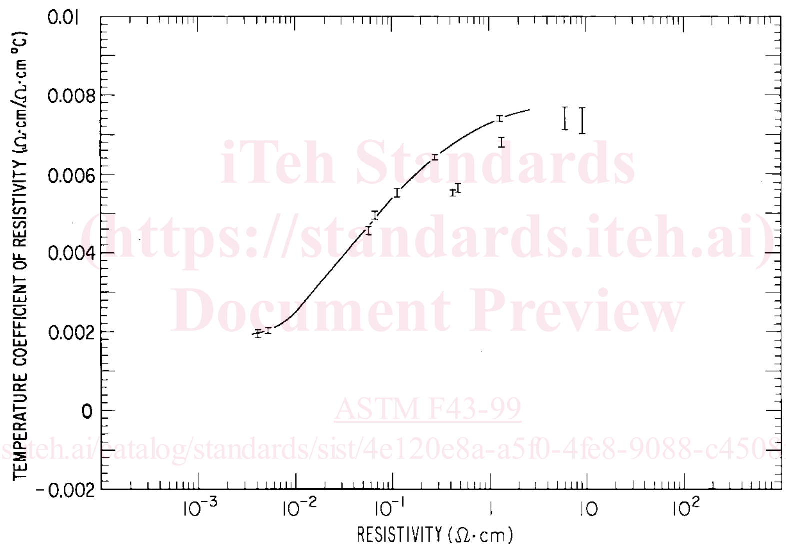

FIG. 3 Temperature Coefficient (C_T) Versus Specimen Resistivity (ρ_{av}) for *p*-Type Germanium

6.2.1 *Constant Current Source* capable of supplying currents between 10^{-1} and 10^{-5} A. The current must be known and maintained constant to ±0.5 % during the measurement.

6.2.2 *Current Reversing Switch.*

6.2.3 *Standard Resistor* with a resistance within a factor of 100 of that of the specimen.

6.2.4 *Double-Throw, Double-Pole Potential Selector Switch.*

6.2.5 *Potentiometer-Galvanometer or Electronic Voltmeter*—capable of measuring potential differences between 10^{-4} and 1 V of either polarity to ±0.5 %. The input impedance must exceed 1000 times the total contact plus bulk resistance of the specimen.

NOTE 3—The electrical measuring circuit may also measure either resistance or current directly. Any electrical circuit that meets the requirements of the Electrical Equipment part of the Suitability of Test Equipment section, of Test Method F 84 is acceptable for use in this test method. If the procedures of Test Method F 84 are used to evaluate the adequacy of the electrical equipment, an appropriate analog test circuit as described in the Analog Test Circuit paragraph of the Apparatus section, of Test Method F 84 is required.

6.3 *Lapping or Sandblasting Facilities* to provide a flat, abraded surface on which the measurement is made.

6.4 *Micrometer or Vernier Caliper* to determine the cross-sectional area normal to the current in the two-probe method to ±0.5 % or for measuring the dimensions of circular specimens with thickness more than one, but less than four, times the probe spacing in the four-probe method.

6.5 *Thermometer* or other temperature measuring instrument to determine the ambient temperature to ±0.5°C.

7. Test Specimen

7.1 *Two-Probe Method*—The test specimen for the two-probe test method may be in the form of a strip, rod, or bar. The ratio of the length to the larger cross-sectional dimension of the specimen shall be not less than 3 to 1. The cross section of the specimen must be of measurable shape and should be as uniform as possible. Prior to measurement, ohmic contact shall