SEMI MF81-1105 (Reapproved 0611)
TEST METHOD FOR MEASURING RADIAL RESISTIVITY VARIATION ON SILICON WAFERS

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NOTICE: This document was reapproved with minor editorial changes.

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1 Purpose

1.1 The radial resistivity variation of bulk semiconductor material is an important materials acceptance requirement for semiconductor device fabrication and is also used for quality control purposes.

1.2 The four-point probe method provides a test that requires little specimen preparation and that is nondestructive in that the wafer is left intact. The method can be applied to wafers using the resistivity-measuring apparatus and procedures of SEMI MF84 if provisions are made for making measurements at several sites on the wafer (see ¶ 7.1). Appropriate correction factors must be applied to compensate for effects of the wafer geometry (see ¶ 12.1).

1.3 Radial resistivity variations are a function of the crystal growth process and dopant, in both characteristic shape and magnitude. Because no single sampling plan is adequate to characterize the resistivity variations of all crystal types or for all applications, four sampling plans are included in this test method.

2 Scope

2.1 This test method[1] provides procedures for the determination of relative radial variation of resistivity of semiconductor wafers cut from silicon single crystals grown either by the Czochralski or floating-zone technique.

2.2 This test method provides procedures for using SEMI MF84 for the four-point probe measurement of radial resistivity variation.

2.3 This test method yields a measure of the variation in resistivity between the center and selected outer regions of the specimen. The amount of information obtained regarding the magnitude and form of the variation in the intervening regions when using the four-point probe array depends on the sampling plan chosen (see ¶ 8.2). The interpretation of the variations measured as radial variations may be in error if azimuthal variations on the wafer or axial variations along the crystal length are not negligible.

2.4 This test method can be applied to single crystals of silicon in circular wafer form, the thickness of which is less than one-half of the average probe spacing, and the diameter of which is at least 15 mm (0.6 inch). Measurements can be made on any specimen for which reliable resistivity measurements can be obtained. The resistivity measurement procedure of SEMI MF84 has been tested on specimens having resistivities between 0.0008 and 2000 Ω·cm for *p*-type silicon and between 0.0008 and 6000 Ω·cm for *n*-type silicon. Geometrical correction factors required for these measurements are included for the case of standard wafer diameters, and are available in tabulated form for other cases.[2]

NOTE 1: In the case of wafers whose thickness is greater than the average spacing of the measurement probes, no geometrical correction factor is available except for measurement at the center of the wafer face.

2.4.1 Several sampling plans are given that specify sets of measurement sites on the wafers being tested. The sampling plans allow differing levels of detail of resistivity variation to be obtained. One of these sampling plans is selected and agreed upon by the parties to the measurement (see ¶ 8.1).

[1] DIN 50435, Determination of the Radial Resistivity Variation of Silicon or Germanium Slices by Means of a Four-Point DC-Probe, is an equivalent method. It is the responsibility of DIN Committee NMP 221 and 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] Swartzendruber, L. J., "Correction Factor Tables for Four-Point Probe Resistivity Measurements on Thin Circular Semiconductor Samples," NBS Technical Note 199, National Bureau of Standards, April 15, 1964. Available as AD 683 408 from National Technical Information Service, Springfield, Va. 22161.

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NOTE 2: The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

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 *Current Level* — The current levels as a function of resistivity recommended in SEMI MF84 have been found satisfactory for the specified probe spacing and specimen size range. However, should smaller than recommended probe spacing be used, or very long lifetime specimens be measured, the suitability of the recommended currents should be established by doubling and halving the recommended current and checking for a resulting doubling and halving of measured specimen voltage. It is then recommended that a current near the middle of the range giving a constant measure of resistivity be used.

3.2 *Longitudinal Resistivity Variations* — The local fluctuations in dopant density that cause resistivity variations on a cross section of a semiconductor crystal also cause axial resistivity variations down the length of the crystal. The four-point probe method measures averaged local resistivity values, and these averaged values are influenced by resistivity changes through the thickness of the specimens. The extent of this influence depends on probe spacing. Radial variation measurements on the front and back surfaces of a wafer may differ because of longitudinal variations.

3.3 *Accuracy of Probe Placement* — The position of the probe head may have a noticeable effect on the measured voltage-to-current ratio because of the proximity of the probe tips to a wafer boundary. Geometrical correction factors used to calculate the local resistivity from the measured voltage and current values are calculated for a particular position and orientation of the probe head with respect to the wafer center and wafer boundaries. Related Information 1 gives magnitudes of the error in the geometrical correction factor and in resulting local resistivity values if the position of a probe with a 1.59 mm probe tip spacing is shifted the maximum allowed value, 0.15 mm (0.006 inch), toward the edge of the wafer. These errors decrease with decreasing probe spacing for all wafer sizes and measurement sites.

3.4 *Wafer-Geometry Related Errors*

3.4.1 The geometrical correction factors used to calculate the local resistivity from the measured voltage and current ratios depend on the assumptions of full circular wafer geometry and of non-conducting wafer back surface and edges. As a result, some error is introduced if measurements are made in proximity to a flat on a wafer, or if the wafer back surfaces and/or edges are conducting.

3.4.2 Additional errors in the correction factor are encountered if the true wafer diameter is not used in calculating the correction factor. Use of the nominal diameter for all wafers of standard dimensions with diameter tolerances allowed by SEMI M1 introduces negligible error if measurements are made no closer to the edge of the wafer than 6 mm. Related Information 1 gives magnitudes of the error in the geometrical correction factor and in the resulting local resistivity values that result when the nominal wafer diameter is used in the calculation for specimens that have the smallest diameter allowed by SEMI M1.

3.4.3 The wafer thickness enters directly into the calculation of resistivity from the measured voltage-to-current ratio. Related Information 1 gives magnitudes of the error in the local resistivity values when the nominal wafer thickness is used in the calculation for wafers with the smallest center-point thickness allowed by SEMI M1 and a local thickness that deviates from the nominal value by the maximum allowed by SEMI M1. If more accurate determinations of local resistivity are required, (1) the thickness at each measurement site should be determined and used in calculating the resistivity at that site, (2) wafers with smaller thickness variation should be employed, or (3) thicker wafers should be employed.

3.5 *Polished Surfaces* — Measurements on a polished rather than a lapped wafer surface as required in this method generally gives satisfactory measurement results.[3] However, the possibility of measurement errors due to surface

[3] Ehrstein, J. R., Brewer, F. H., Ricks, D. R., and Bullis, W. M.," Effects of Current, Probe, Force and Wafer Surface Condition on Measurement of Resistivity of Bulk Silicon Wafers by the Four-Probe Method," Appendix E, *Methods of Measurement for Semiconductor Materials, Process Control, and Devices, Quarterly Report, October 1 to December 31, 1972*, NBS Technical Note 773, National Bureau of Standards, June 1973, pp. 43–49. Available as COM 73-50534 from National Technical Information Service, Springfield, Va. 22161.

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conduction or to low surface recombination velocity requires the use of lapped wafer surfaces for referee measurements.

3.6 Temperature fluctuations of specimen temperature during the measurement time affect the measurement. This can be corrected if the specimen temperature is known (see ¶ 12.1.4).

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI M1 — Specifications for Polished Single Crystal Silicon Wafers

SEMI M59 — Terminology for Silicon Technology

SEMI MF84 — Test Methods for Measuring Resistivity of Silicon Slices with a Collinear Four-Probe Array

SEMI MF2074 — Guide for Measuring Diameter of Silicon and Other Semiconductor Wafers

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 Method

6.1 Resistivity measurements are made in accordance with SEMI MF84 at specified sites along one or two diameters of a silicon wafer in accordance with a sampling plan selected from the four given. Choice among the sampling plans is made on the basis of the extent of information required regarding possible resistivity variations.

6.2 The measured resistivity values are corrected for specimen geometry and, if desired, for temperature, and suitable differences are taken to obtain the resistivity variation.

7 Apparatus

7.1 Apparatus as specified in SEMI MF84 is required for four-point probe measurement, except that the specimen support shall include an *x-y* or *r-θ* stage with micrometer adjustment capable of positioning the probe head at specified points on the specimen with an accuracy of ±0.15 mm; it shall also include provision for rotating the specimen through 360 degrees with a rotational accuracy of ±5 degrees.

8 Sampling

8.1 The sampling plan for selection of wafers from a lot shall be agreed upon by the parties to the measurement.

8.2 This test method provides four sampling plans (see Figure 1) for the selection of the sites where measurements are to be made on a specimen and from which radial resistivity variations can be determined. A sampling plan shall be chosen from those given on the basis of device application, growth process, and dopant, and of the consequent level of resistivity information desired.

8.2.1 *Sampling Plan A, Small-Area Cross Pattern* — Six measurements are made: two at the center of the wafer and four at half radius (*r*/2) points.

8.2.2 *Sampling Plan B, Large-Area Cross Pattern* — Six measurements are made: two at the center of the wafer and four 6.0 mm (0.24 inch) from the wafer edge.

8.2.3 *Sampling Plan C, Small-Area and Large-Area Cross Patterns* — Nine measurements are made: one at the center of the wafer, four at half radius (*r*/2) and four at 6.0 mm (0.24 inch) from the wafer edge.

8.2.4 *Sampling Plan D, Single-Diameter, High-Resolution Pattern* — Measurements are made at the center of the wafer and at as many additional sites as possible along a diameter at intervals of 2 mm between the center and each edge with the exclusion of the outer 3 mm of the sample at each end of the diameter.

NOTE 3: Because of the extent of the area over which the four-point probe array samples resistivity, little additional information is gained by using an interval smaller than 2 mm.

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9 Test Specimen

9.1 Prepare the surface to be measured in accordance with the Preparation of Test Specimen Section of SEMI MF84. If the wafer does not have a primary flat or notch as specified in SEMI M1, place a reference mark on the periphery of the back surface. Use this mark for purposes of wafer alignment during measurement.

9.2 Measure and note the diameter of the specimen along three diameters as specified in SEMI MF2074. If each of these diameter values is within the range specified in SEMI M1, record as the diameter the nominal value. If not, record as the diameter the average of the three measured values.

9.3 Using the thickness gage specified in the Apparatus Section of SEMI MF84, measure and record the specimen thickness at the nine sites of Sampling Plan C (see Figure 1). Accept a specimen for measurement if the total thickness variation is less than that specified in SEMI M1 (see ¶ 3.4.3).

10 Suitability of Test Equipment

10.1 Determine the suitability of the four-point probe and electronics for use in measuring resistivity in accordance with the Suitability of Test Equipment Section of SEMI MF84.

11 Procedure

11.1 Align the specimen so that the first measurement diameter is located 30 degrees counterclockwise from the diameter perpendicular to the primary flat or from the diameter through the notch or reference mark (see ¶ 9.1 and Figure 1). For referee measurements, record the orientation of the measurement sites with respect to this diameter (see ¶ 13.5).

11.2 Choose one of the sampling plans (see ¶ 8.2 and Figure 1).

11.3 Measure and record the temperature of the specimen if absolute values of resistivity are desired.

11.4 For each site indicated for measurement on the chosen plan:

11.4.1 Place the four-point probe array on the surface of the specimen so that (1) the imaginary line joining the probe points is perpendicular to the specimen radius that passes through the site, and (2) the midpoint of the line is within ±0.15 mm (±0.006 inch) of the site.

11.4.2 Measure the forward and reverse resistance once in accordance with the Procedure Section of SEMI MF84.

11.4.3 If the wafer has a nonstandard diameter, determine and record Δ, the distance from the center of the specimen to the midpoint of the probe pins.

12 Calculations

12.1 For each measurement site:

12.1.1 Calculate and note the mean value of resistance in accordance with the Calculation Section of SEMI MF84.

12.1.2 If the wafer has a standard diameter (see ¶ 9.2) and if the probe spacing is 1.59 mm, determine the value of the correction factor, F_2, from Table 1 or Table 2 depending on the sampling plan chosen. In Table 2, the values below the underlined entry in each column correspond with measurement sites 6 mm or closer to the wafer edge.

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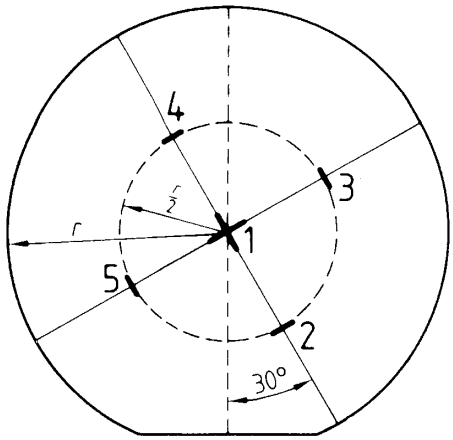
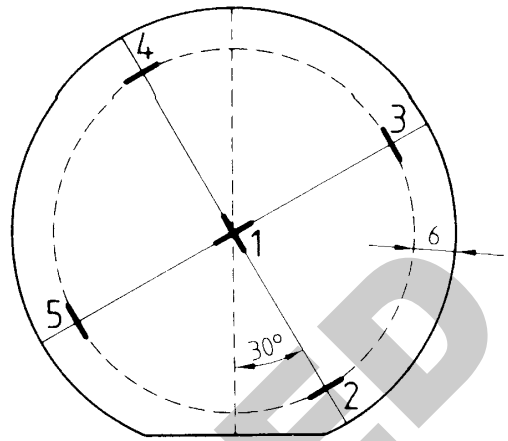


Sampling Plan A



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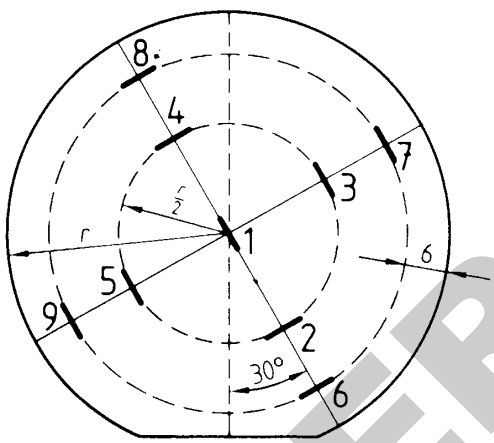

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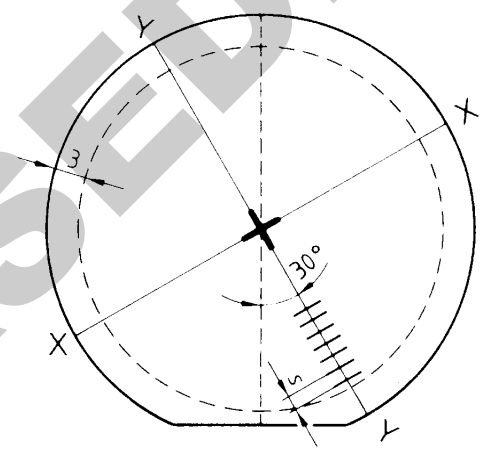

Sampling Plan D

NOTE: The flat shown at the bottom of each wafer represents the primary flat, notch or reference mark (see ¶ 9.1). Each of the small line segments is perpendicular to a wafer diameter and shows the location and orientation of the four-point probe for resistivity measurement at the site. In sampling plans A through C, the sites are identified by the adjacent number.

Figure 1
Sampling Plans for Four-Point Probe Measurement of Radial Resistivity Variation

Table 1 Correction Factor F_2 for Circular Wafers with Standard Diameters and Probe-Tip Spacing of 1.59 mm (0.0625 inch) for Use with Sampling Plan A, B, or C

Measurement Site	*Nominal Wafer Diameter*						
	2 in.	*3 in.*	*100 mm*	*125 mm*	*150 mm*	*200 mm*	*300 mm*
Center	4.494	4.515	4.522	4.526	4.528	4.530	4.531
Half Radius	4.465	4.502	4.515	4.521	4.525	4.528	4.530
6 mm from Edge	4.328	4.345	4.352	4.357	4.360	4.363	4.367

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