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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Determining Net Carrier Density in Silicon Wafers by Miller Feedback Profiler Measurements With a Mercury Probe[1]

This standard is issued under the fixed designation F 1393; 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

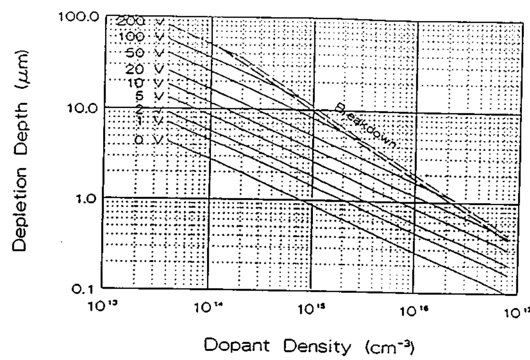
1.1 This test method[2] covers the measurement of net carrier density and net carrier density profiles in epitaxial and polished bulk silicon wafers in the range from about 4×10^{13} to about 8×10^{16} carriers/cm (resistivity range from about 0.1 to about 100 Ω-cm in *n*-type wafers and from about 0.24 to about 330 Ω-cm in *p*-type wafers).

1.2 This test method requires the formation of a Schottky barrier diode with a mercury probe contact to an epitaxial or polished wafer surface. Chemical treatment of the silicon surface may be required to produce a reliable Schottky barrier diode. **(1)**[3] The surface treatment chemistries are different for *n*- and *p*-type wafers. This test method is sometimes considered destructive due to the possibility of contamination from the Schottky contact formed on the wafer surface; however, repetitive measurements may be made on the same test specimen.

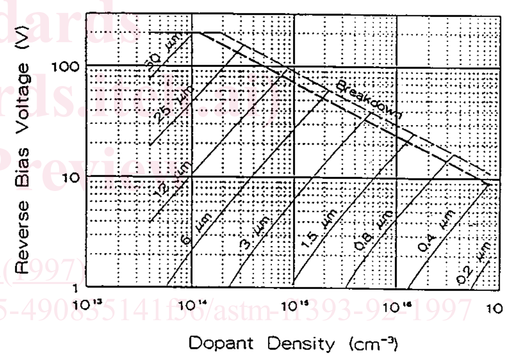
1.3 This test method may be applied to epitaxial layers on the same or opposite conductivity type substrate. This test method includes descriptions of fixtures for measuring substrates with or without an insulating backseal layer.

1.4 The depth of the region that can be profiled depends on the doping level in the test specimen. Based on data reported by Severin **(1)** and Grove **(2)**, Fig. 1 shows the relationship between depletion depth, dopant density, and applied voltage together with the breakdown voltage of a mercury silicon contact. The test specimen can be profiled from approximately the depletion depth corresponding to an applied voltage of 1 V to the depletion depth corresponding to the maximum applied voltage (200 V or about 80 % of the breakdown voltage, whichever is lower). To be measured by this test method, a layer must be thicker than the depletion depth corresponding to an applied voltage of 2 V.

1.5 This test method is intended for rapid carrier density determination when extended sample preparation time or high temperature processing of the wafer is not practical.



(a) Depletion Depth as a Function of Dopant Density with Applied Reverse Bias Voltage as a Parameter.



(b) Applied Reverse Bias Voltage as a Function of Dopant Density with Depletion Depth as a Parameter.

NOTE 1—The light dashed line represents the applied reverse bias voltage at which breakdown occurs in a mercury silicon contact; the heavy dashed line represents 80 % of this voltage, it is recommended that the applied reverse bias voltage not exceed this value. The light chain-dot line represents the maximum reverse bias voltage specified in this test method.

FIG. 1 Relationships between Depletion Depth, Applied Reverse Bias Voltage, and Dopant Density

NOTE 1—Test Method F 419 is an alternative method for determining net carrier density profiles in silicon wafers from capacitance-voltage measurements. This test method requires the use of one of the following structures: (*1*) a gated or ungated *p-n* junction diode fabricated using either planar or mesa technology or (*2*) an evaporated metal Schottky diode. Although this test method was written prior to consideration of the Miller Feedback Method, the Miller Feedback Method has been satisfactorily used in measuring the round robin samples.

1.6 This test method provides for determining the effective

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

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[2] DIN 50439, Determination of the Dopant Concentration Profile of a Single Crystal Semiconductor Material by Means of the Capacitance-Voltage Method and Mercury Contact, is the responsibility of DIN Committee NMP 221, with which Committee F-1 maintains close liaison. DIN 50439 is available from Beuth Verlag GmbH, Burggrafenstrasse 4-10, D-1000, Berlin 30, Germany.

[3] The boldface numbers in parenthesis refer to the list of references at the end of this test method.

area of the mercury probe contact using polished bulk reference wafers that have been measured for resistivity at 23°C in accordance with Test Method F 84 or Test Method F 673. This test method also includes procedures for calibration of the apparatus.

NOTE 2—An alternative method of determining the effective area of the mercury probe contact that involves the use of reference wafers whose net carrier density has been measured using fabricated mesa or planar *p-n* junction diodes or evaporated Schottky diodes is not included in this test method but may be used if agreed upon by the parties to the test.

1.7 *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.* Specific hazard statements are given in Note 4 in 7.2, 7.3, and 8.2.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specifications for Reagent Water[4]

F 26 Test Methods for Determining the Orientation of a Semiconductive Single Crystal[5]

F 42 Test Methods for Conductivity Type of Extrinsic Semiconducting Materials[5]

F 81 Test Method for Measuring Radial Resistivity Variation on Silicon Slices[5]

F 84 Test Method for Measuring Resistivity of Silicon Wafers with an In-Line Four-Point Probe[5]

F 419 Test Method for Determining Carrier Density in Silicon Epitaxial Layers by Capacitance Voltage of Measurements on Fabricated Junction or Schottky Diodes[5]

F 673 Test Method for Measuring Resistivity of Semiconductor Slices or Sheet Resistance of Semiconductor Films with a Noncontact Eddy-Current Gage[5]

F 723 Practice for Conversion Between Resistivity and Dopant Density for Boron-Doped and Phosphorus-Doped Silicon[5]

F 1241 Terminology of Silicon Technology[5]

2.2 *SEMI Standard:*

SEMI C1 Specifications for Reagents[6]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in silicon wafer technology refer to Terminology F 1241.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *breakdown voltage*—the reverse bias voltage at which the mercury probe contact exhibits a leakage current density of 3 mA/cm^2.

3.2.2 *compensation capacitance*, C_{comp}—the sum of the stray capacitance of the measurement system and the peripheral capacitance of the mercury probe contact (see 10.3).

3.2.3 *low-resistance contact*—an electrically and mechanically stable contact **(3)** in which the resistance across the contact does not result in excessive series resistance as determined in 11.4 (see also 6.2).

3.2.3.1 *Discussion*—A low-resistance contact may generally be achieved by using a metal semiconductor contact with an area much larger than that of the mercury probe contact.

3.2.4 *mercury probe contact*—a Schottky barrier diode formed by bringing a column of mercury into contact with an appropriately prepared polished or epitaxial silicon surface.

4. Summary of Test Method

4.1 A calibration procedure using polished bulk wafers of known carrier density is used to determine the mercury probe contact area.

4.2 The test specimen is placed on the mercury probe fixture. A column of mercury is brought into contact with an epitaxial or polished wafer surface by a pressure differential between the mercury and ambient to form a Schottky barrier diode (mercury probe contact).

4.3 A low-resistance return contact is also made to either the front or back surface of the wafer. This contact may be either a metal plate or a second mercury silicon contact with an area much larger (32 times or larger) than the mercury probe contact.

4.4 The quality of the Schottky barrier diode formed is determined by viewing the "delta *X* wave shape" on an oscilloscope and verifying that it is a good square wave per manufacturer's operating instruction. It can also be evaluated by measuring its series resistance and its reverse current characteristics.

4.5 A current is driven through the diode by a radio frequency (RF) generator. The current is compared to a reference current (magnitude of which is set by the dielectric constant and area controls) at the error summation point at the input of an amplifier in a servo-controlled feedback loop that (*a*) keeps the RF current amplitude constant and (*b*) generates an output d-c signal, *X*, that is proportional to the depletion depth. The reverse bias (*V*) on the diode is step-modulated at a low frequency and at an amplitude proportional to signal *X*, keeping dV/dX, the change in electric field, constant. The amplitude of the resulting modulation of the *X* signal (dX) is therefore proportional to the net carrier density. A d-c signal, 1/N, (net carrier density) proportional to dX is generated. The signal is used for read out information.

4.6 The net carrier density as a function of depth is determined by the profiler circuitry and computer data acquisition hardware and software.

NOTE 3—The net carrier density values obtained by this test method are frequently converted to resistivity, which is generally a more familiar parameter in the industry. If this is done, the conversion should be made in accordance with Practice F 723, using the tabular or computational methods given in paragraph 7.2 of this practice (conversion from dopant density to resistivity) in order to eliminate the self-consistency errors in the equations given in Practice F 723. The choice of conversion direction is based on the fact that the net carrier density of the reference wafer used for determination of the area of the mercury probe contact (see 8.4 and 10.2) is traceable to National Institute of Standards and Technology using the methods of paragraph 7.2 of Practice F 723 so that the more laborious iterative procedure is applied to the less frequently measured reference wafers and the direct conversion procedure is applied to material being evaluated by this test method. Note that in applying this conversion

[4] *Annual Book of ASTM Standards*, Vol 11.01.

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

[6] Available from Semiconductor Equipment and Materials International, 805 East Middlefield Road, Mountain View, CA 94043.