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Designation: F 1392 – 00

Standard Test Method for Determining Net Carrier Density Profiles in Silicon Wafers by Capacitance-Voltage Measurements With a Mercury Probe [1]

This standard is issued under the fixed designation F 1392; 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^3 (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 relationships 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.

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.

1.6 This test method provides for determining the effective 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 (Note 2). This test method also includes procedures for calibration of the apparatus for measuring both capacitance and voltage.

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 7.1, (7.2, 7.10.3 (Note 7), 8.2, 11.5.1, 11.6.3, and 11.6.5.

2. Referenced Documents

2.1 *ASTM Standards:*

D 5127 Guide for Ultra Pure Water Used in the Electronics and Semiconductor Industry [4]

D 4356 Practice for Establishing Consistent Test Method Tolerances [5]

E 691 Practice for Conducting an Interlaboratory Study to

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

Current edition approved June 10, 2000. Published August 2000. Originally published as F 1392 – 92. Last previous edition F 1392 – 93.

[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 technically equivalent to this test method. DIN 50439 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 parentheses refer to the list of references at the end of this test method.

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

[5] *Annual Book of ASTM Standards*, Vol 14.02.

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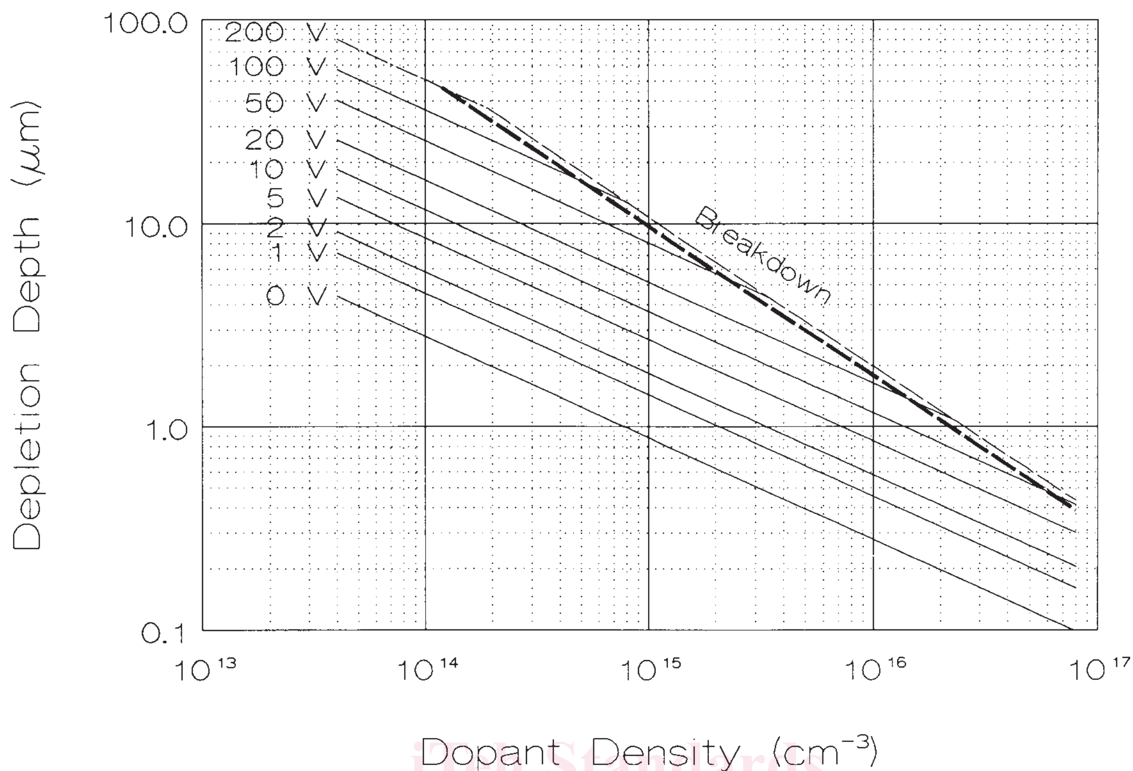
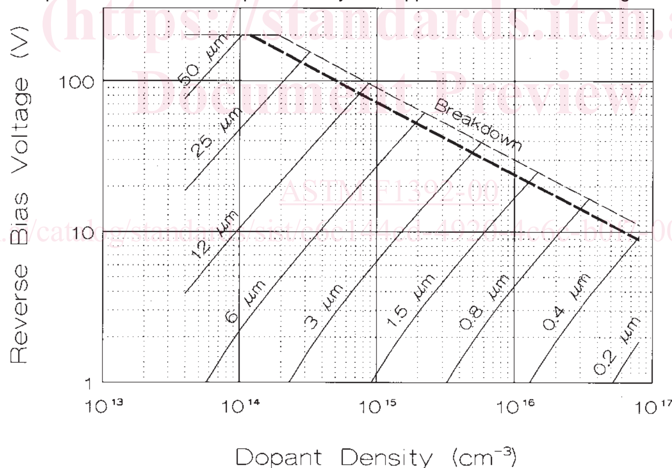


(a) Depletion Depth as a Function of Dopant Density with Applied Reverse Bias Voltage as a Parameter.



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

Determine the Precision of a Test Method [5]

F 26 Test Methods for Determining the Orientation of a Semiconductive Single Crystal [6]

F 42 Test Methods for Conductivity Type of Extrinsic Semiconducting Materials [6]

F 81 Test Method for Measuring Radial Resistivity Variation on Silicon Wafers [6]

F 84 Test Method for Measuring Resistivity of Silicon Wafers with an In-Line Four-Point Probe [6]

F 419 Test Method for Determining Carrier Density in Silicon Epitaxial Layers by Capacitance-Voltage Measurements on Fabricated Junction or Schottky Diodes [6]

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

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F 672 Test Method for Measuring Resistivity Profiles Perpendicular to the Surface of a Silicon Wafer Using a Spreading Resistance Probe [6]

F 723 Practice for Conversion Between Resistivity and Dopant Density for Boron-Doped, Phosphorus-Doped, and Arsenic-Doped Silicon [6]

F 1153 Test Method for Characterization of Metal-Oxide-Silicon (MOS) Structures by Capacitance-Voltage Measurements [6]

F 1241 Terminology of Silicon Technology [6]

2.2 *SEMI Standards:*

SEMI C28 Specifications for Hydrofluoric Acid [7]

SEMI C29 Specification for Hydrofluoric Acid, 4.9 % [7]

SEMI C30 Specification for Hydrogen Peroxide [7]

3. Terminology

3.1 *Definitions:*

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

3.1.2 Definitions of the statistical terms *repeatability* and *reproducibility* are given in Practice E 691.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *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).

3.2.2 *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 6.4).

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

3.2.3 *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 The compensation capacitance and effective mercury probe contact area are determined using a reference wafer.

4.2 The test specimen is placed in the mercury probe fixture. A column of mercury is brought into contact with the epitaxial or polished surface of the specimen 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 than the mercury probe contact.

4.4 The quality of the Schottky barrier diode formed by the mercury probe contact is evaluated by measuring its series resistance and its reverse current characteristics.

4.5 The small-signal, high frequency capacitance of the mercury probe contact is measured as a function of the voltage applied between the mercury probe column and the return contact. The polarity of the applied voltage is such that the mercury probe contact is reverse biased and the low-resistance return contact is forward biased.

4.6 The net carrier density profile (net carrier density as a function of depth from the surface) is calculated from the measured values of capacitance and applied voltage by one of two equivalent methods.

NOTE 3—Net carrier density values obtained by this test method are often 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 the computational methods given in 7.2 of Practice F 723 (conversion from dopant density to resistivity). Note that in applying this conversion procedure in either direction it is assumed that the net carrier density is equal to the dopant density.

5. Significance and Use

5.1 This test method can be used for research and development, process control, and materials specification, evaluation, and acceptance purposes. However, in the absence of interlaboratory test data to establish its reproducibility, this test method should be used for materials specification and acceptance only after the parties to the test have established reproducibility and correlation.

6. Interferences

6.1 A poor Schottky contact, which is generally indicated by an excessively high leakage current (see 11.5) is the most common problem in capacitance-voltage measurements made with mercury probe instruments. It must be emphasized that the use of a poor Schottky contact does not actually prevent a carrier density determination but produces an erroneous result.

6.2 Improper determination of the compensation capacitance, C_{comp}, (see 10.3) can cause significant errors in the capacitance measurement. In homogeneous material, improper zeroing or use of an improper value for C_{comp} results in an apparent monotonic increase or decrease of carrier density with distance from the Schottky barrier. In some fixtures, inherently large stray capacitances exist; in such cases, the value of C_{comp} may depend both on the diameter of the wafer and on the position of the wafer on the chuck. If these dependencies are observed, they may be reduced or eliminated by shielding the mercury probe column. If shielding is not practical, probe calibration procedures should be carried out with wafers of the same diameter as the wafers being tested and care should be taken to ensure that the geometry of wafer and probe is the same during calibration and measurement.

6.3 Alternating frequency test signals greater than 0.05 V rms may lead to errors in the measured capacitance.

6.4 Excessive series resistance in the capacitance measurement circuit can cause significant errors in the measured capacitance values. Series resistance values greater than 1 kΩ have been reported to cause measurement error in some cases **(4, 5)**. The primary source of excessive series resistance is generally a high-resistance return contact; other possible sources are bulk resistance in the wafer and wiring defects in the mercury probe fixture or the test cables (see 11.4).

6.5 When exposed to air, a scum tends to form on the exposed surface of the mercury used to form the mercury probe contact. When freed from the surface, this scum floats to the top of the mercury column. It is necessary to make certain that

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

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the mercury that contacts the wafer surface is clean by changing the mercury periodically or by otherwise removing the scum from the exposed surface.

6.6 A dirty or damaged capillary tube containing the mercury column may also result in unstable measurements (see 10.4.2.2).

6.7 If the reference wafer is not sufficiently uniform throughout its thickness, the value of net carrier density, N_{ref}, determined by the four-point probe measurement (see 8.4.3) may differ from the value of net carrier density at the surface where the mercury probe measurement is made. Use of erroneous values of N_{ref} results in incorrect values for effective probe contact area (see 10.3). Further, if the resistivity profile of the reference wafer is not uniform near the surface, an incorrect value of C_{comp} may be obtained (see 10.2). Incorrect values of probe contact area and C_{comp} result in incorrect values for the average net carrier density of the test specimen.

7. Apparatus

7.1 *Mercury Probe Fixture*—one of the following fixtures depending on the type of test specimen to be measured. **Warning:** Mercury is a toxic material. Refer to the appropriate Material Safety Data Sheet prior to use. Avoid physical contact with mercury and breathing of its vapor.

7.1.1 *Back-Surface-Return-Contact Fixture*, for use in measuring polished wafers or epitaxial layers deposited on substrates of the same conductivity type. A probe fixture that holds the treated wafer and provides a single mercury column contained in a capillary tube with nominal inside diameter of 0.4 to 2.0 mm. The fixture shall be capable of forming a mercury probe contact area on the front polished or epitaxial surface of the wafer with a repeatability of ±1 % or better. The fixture must also provide a low-resistance return contact to the back surface of the wafer.

7.1.2 *Front-Surface-Return-Contact Fixture*, for use in measuring epitaxial wafers deposited on substrates of the opposite conductivity type or on substrates with insulating back surface films. A probe fixture that holds the treated wafer and provides two contacts to the front polished or epitaxial surface of the wafer. One contact is the mercury probe contact as described in 7.1.1, and the other is a low-resistance return contact. The latter may be either a second mercury column or a metal plate. Its area shall be such that its capacitance is not less than 32 times the capacitance of the smaller mercury column. In addition, it is recommended that this fixture also provide a low-resistance return contact to the back surface of the wafer to permit the apparatus also to be used in the back-surface-return-contact configuration (see 7.1.1).

7.2 *Equipment for Handling Mercury*— hypodermic needle or other means for transferring mercury from a storage bottle to the mercury column and equipment for neutralizing and picking up spilled mercury (**Warning**—see 7.1).

7.3 *Capacitance Bridge or Meter*, with ranges from 1 to 1000 pF full scale or greater, in range multiples of 10 or less. The accuracy shall be 1.0 % of full scale or better for each range, and the rated reproducibility shall be 0.25 % of full scale or better. The internal a-c voltage signal shall not exceed 0.05 V rms. The measurement frequency shall be in the range from 0.9 to 1.1 MHz inclusive. The instrument shall be capable of sustaining an external d-c bias of up to 200 V. Provision shall be made to compensate a compensation capacitance of up to 10 pF.

NOTE 4—Capacitance meters or bridges capable of measuring the phase angle, equivalent series resistance, conductance or total impedance in addition to the capacitance may be used.

NOTE 5—Capacitance meters with nominal frequencies from 100 kHz to 1 MHz have been used for measurements of the type covered by this test method. If an instrument with a nominal frequency other than 1 MHz is employed, the user shall demonstrate that it obtains results equivalent to the specified instrument.

7.4 *Dc Power Supply*, continuously variable from 0 V to the maximum expected reverse bias (Note 6) or 200 V, whichever is less, capable of supplying voltages of either polarity with a peak-to-peak noise of 25 mV or less. This power supply may be integrated with the capacitance meter, if desired.

NOTE 6—The maximum reverse bias depends on the net carrier density in the wafer under test, see Fig. 1.

7.5 *Digital Voltmeter*, with a minimum of four digits, ranges from ±1 to ±200 V full scale or greater in range multiples of 10 or less, a sensitivity of 1 mV or less, and an accuracy of 0.5 % of full scale or better, a rated reproducibility of 0.25 % of full scale or better, an input impedance of 100 MΩ or more, and a common-mode rejection ratio of 100 dB or greater at 60 Hz. This voltmeter may be integrated with the capacitance meter and power supply, if desired.

7.6 *Curve Tracer*, or other apparatus, capable of monitoring the reverse and forward current-voltage characteristics of the mercury probe contact. It shall be capable of applying 200 V at 0.1 mA in the reverse direction and 1.1 V at 1 mA in the forward direction and have a sensitivity of 10 µA/division or better.

7.7 *Shielded Cables*, as required, for making electrical connections between the probe fixture, power supply, capacitance bridge or meter, and digital voltmeter.

7.8 *Precision Capacitors*, with an accuracy of 0.25 % or better at 1 MHz, the measurement frequency, required only for capacitance meter adjustment and verification (see 10.5). If used, at least two precision capacitors with values differing by at least a factor of 10 and lying within the expected capacitance ranges to be measured are required.

7.9 *Precision Voltage Source*, capable of providing output voltages from 0 to ±200 V with an accuracy of 0.1 % of the output voltage or better, required only for voltmeter verification (see 10.6).

7.10 *Facilities for Wafer Surface Treatment*, if required (see 8.5, 10.3.5, 10.4.3.1 and 11.5.6):

7.10.1 *Fume Hood*, equipped with tanks to hold hydrofluoric acid at room temperature and, for n-type wafers only, hydrogen peroxide at 70° to 90°C. The tanks shall be of sufficient size to allow complete immersion of the cassettes holding the desired size wafers.

7.10.2 *Cassettes*, for holding the wafers in hydrofluoric acid.

7.10.3 *Additional Cassettes*, for holding n-type wafers in hydrogen peroxide at 70°C. **Warning:** When using a cassette that has been previously used in hydrofluoric acid in hydrogen peroxide without prior cleaning make sure that the cassette is

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clean because of the likelihood of contamination of the hydrogen peroxide bath.

NOTE 7—A cassette that has been previously used in hydrofluoric acid may be cleaned for the hydrogen peroxide treatment by boiling in water for 1 h.

7.10.4 *Dump Rinser*, with air atmosphere.

7.10.5 *Spin Dryer*, for drying the wafers in an air atmosphere.

7.10.6 *Hot Plate*, for *p*-type wafers or other means for baking the wafer at 120± 10°C in air may also be required.

7.10.7 *Interval Timer*, for controlling treatment times.

7.10.8 *Nonmetallic Tweezers or Vacuum Wand*, for holding and manipulating wafers.

8. Reagents and Materials

8.1 *Purity of Reagents*—All chemicals for which such specifications exist shall adhere to Grade 1 specifications for those specific chemicals. Other grades may be used, provided it is first determined that the chemical is of sufficiently high purity to permit its use without lessening the accuracy of the test.

8.2 *Mercury* shall be triple distilled and conform to reagent grade, as specified in *Reagent Chemicals*. [8] It shall be changed regularly or otherwise maintained in a clean state to avoid interference from surface scum (see 6.5) (**Warning**—see 7.1).

8.3 *Purity of Water*—Reference to water shall be understood to mean deionized water (DI) meeting the resistivity and impurity specifications of Type I Reagent Water in Specifications D 5127.

8.4 *Reference Wafers*—One or more polished bulk silicon wafers of the same conductivity type as the layer or wafer to be tested. If one reference wafer is used, its net carrier density shall lie between one-half and two times the net carrier density of the layer or wafer to be tested. If several reference wafers are used, their net carrier densities shall cover the range of net carrier densities of the layers or wafers to be tested. Bulk reference wafers shall have the following characteristics:

8.4.1 Flat spreading resistance profile over a depth equal to or greater than that to be profiled in this test method. The flat profile is required to ensure correct determination of C_{comp} (see 6.7, 10.2). Determine that the spreading resistance profile is flat in the following manner:

8.4.1.1 Measure the spreading resistance profile in accordance with Test Method F 672 on a small chip from a portion of the wafer. Use a minimum of 10 spreading resistance values in constructing the spreading resistance profile.

8.4.1.2 Fit the spreading resistance data to a straight line by a least-squares method.

8.4.1.3 For the profile to be considered flat, the fitted values at the beginning and end of the profile shall be equal to within ±2 % and the maximum deviation of any measured value from the fitted line shall not exceed 5 %.

8.4.2 Resistivity variation over the central region of the wafer ≤5 %. Resistivity variation over this region should be as small as possible to obtain maximum accuracy of the determination of the net carrier density of the reference wafer; accurate determination of the net carrier density is required for accurate determination of the probe contact area (see 10.3).

8.4.2.1 Determine radial unformity from resistivity measurements taken at 2.0 mm intervals along two perpendicular diameters for a distance of 6 mm from the center of the wafer in each direction. Analyze the data in accordance with the maximum/minimum convention of Sample Plan D of Test Method F 81.

8.4.2.2 Establish axial uniformity (see 6.7) by spreading resistance measurements across a cleaved portion of the wafer or by some other method agreed upon by the parties to the test.

8.4.3 *Known Net Carrier Density:* Determine the net carrier density as follows:

8.4.3.1 Measure the resistivity at the center of the wafer and correct it to 23°C in accordance with Test Method F 84.

8.4.3.2 Convert the resistivity value to net carrier density using the computational methods given in 7.2 (conversion from dopant density to resistivity) of Practice F 723.

NOTE 8—The appropriate equation given in this section for resistivity must be solved iteratively for the net carrier density. It is necessary to use the same equation for conversion from net carrier density to resistivity and vice versa in order to eliminate the self-consistency errors in Practice F 723. The choice of conversion direction in this test method was made 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 procedure in either direction it is assumed that the net carrier density is equal to the dopant density.

8.4.3.3 Record the net carrier density just obtained, as N_{ref}, in cm^{-3}.

NOTE 9—The advantage of using bulk reference wafers is that the net carrier density can be related to that of resistivity standard reference materials issued by the National Institute of Standards and Technology. However, material inhomogeneity may make it difficult to obtain accurate values of net carrier density from bulk reference wafers (see 6.7). As an alternative, epitaxial wafers may be used as reference wafers. In this case, the epitaxial layer thickness must be large enough that the resistivity profile in the near-surface region may be obtained from spreading resistance measurements through the use of a calibration curve only, without the need for using correction factors. Since the procedures for characterizing such reference wafers are still under development by ASTM Subcommittee F01.95 on Reference Materials, use of epitaxial wafers as reference wafers shall be permitted only if agreed upon between the parties to the test. If used, the epitaxial reference wafer shall meet the requirements of 8.4.1 for a flat spreading resistance profile. Net carrier density shall be determined using an metal oxide silicon (MOS) capacitor structure in accordance with Test Method F 1153 or by another mutually acceptable method.

8.5 *Reagents for Surface Treatment*—If surface treatment is required, the following chemicals may be needed. Grade 1 chemcials are to be preferred (see Appendix X1).

8.5.1 *Hydrofluoric Acid*, HF, concentrated, 49.00 ± 0.25 %, or dilute, 4.9± 0.1 %.

8.5.1.1 Once a week, fill the hydrofluoric acid tank with fresh HF, either concentrated or dilute.

8.5.2 *Hydrogen Peroxide*, H_2O_2, unstabilized, 30 %.

8.5.2.1 Every eight hours, fill the hydrogen peroxide tank with a fresh 15 % H_2O_2 solution by mixing equal volumes of

[8] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC.

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H_2O_2(30 %) and water. Wait until the freshly poured bath reaches 70 ± 5°C before using to treat wafer surfaces.

8.5.2.2 During use, approximately every two h (or when the H_2O_2 level falls below the wafers being treated), replenish the tank by adding 30 % H_2O_2.

9. Sampling

9.1 It is generally impractical to measure every wafer in a particular lot owing to the potential for contamination from the handling and chemical treatments involved. A wafer sampling plan shall therefore be agreed upon between the parties to the test.

9.2 Locations on the wafer where measurements are to be made shall also be agreed upon between the parties to the test.

10. System Calibration and Control

10.1 *Frequency of Calibration and Control Procedures*:

10.1.1 Calibrate the capacitance meter and voltmeter in accordance with manufacturer's instructions on initial installation and following hardware or software modifications. Calibration of the capacitance meter and voltmeter may be carried out in-house or by a qualified testing laboratory.

10.1.2 Determine the compensation capacitance and effective area of the mercury probe in accordance with the procedures of this section on initial installation and after any corrective action has been carried out to bring the system back into control.

10.1.3 Conduct periodic tests and maintain control charts in accordance with the procedures in this section to demonstrate that the instruments are in control and that the variability is within the requirements of this test method.

10.2 *Determination of Compensation Capacitance*, C_{comp}:

10.2.1 Measure a series of capacitance-voltage pairs on the reference wafer carrier density of 1×10^{14} cm^{-3} or less or, if such a reference wafer is not available, on the reference wafer with the lowest value of net carrier density (see 8.4) in accordance with Procedure (Section 11), using either the front- or back-surface-return-contact configuration depending on the type of wafer to be tested (see 7.2). Be certain that the series resistance of the diode circuit formed with the reference wafer meets the requirements of 11.4.1.7 or 11.4.2.7 before proceeding with the measurement of the capacitance-voltage pairs. Record each measured capacitance, C_i, and its associated voltage, V_i. Determine the value of C_{comp} either from the net carrier density profile (10.2.2) or from V_i as a function of C_i^{-2}(10.2.3).

10.2.2 *Net Carrier Density Profile*:

10.2.2.1 Measure a total of n pairs, sufficient to calculate at least five values of net carrier density, N_i, and depth, W_i.

NOTE 10—If the incremental method of calculation (see 12.3) is used, $n \geq k + 5$, where k is an integer chosen such that C_{i+k} is between 80 and 85 % of C_i; if the curve-fitting method of calculation (see 12.4) is used $n \geq 5$.

10.2.2.2 Calculate the net carrier density profile in accordance with the incremental method (see 12.3) or the curve-fitting method (see 12.4) taking $C_{comp} = 0$ (see 12.1).

NOTE 11—If an approximate value of C_{comp} is known, this procedure may be shortened by starting with this approximate value. In this case, if the slope of the net carrier density profile is positive, increase C_{comp} as directed in 10.2.2.3 and 10.2.2.4 and decrease it after the first slope change as directed in 10.2.2.5; if the slope is negative, decrease C_{comp} initially and increase it after the first slope change.

10.2.2.3 Increase C_{comp} by 0.1 pF and recalculate the net carrier density profile (Note 11). For the recalculation, correct each of the C_i to C'_i as follows:

$$C'_i = C_i + C_{comp}. \qquad (1)$$

NOTE 12—On some instruments, it may be necessary to enter a new value for C_{comp} and remeasure the reference wafer each time the value of C_{comp} is changed.

10.2.2.4 Repeat 10.2.2.3, increasing the value of C_{comp} by 0.1 pF each time until the slope of the calculated net carrier density profile changes sign.

10.2.2.5 After the slope of the calculated net carrier density profile changes sign, repeat 10.2.2.3., decreasing the value of C_{comp} by 0.02 pF each time until the slope of the calculated net carrier density profile changes sign again.

10.2.2.6 Record as C_{comp} the value obtained just before and just after the sign change of the slope.

10.2.3 V_i *as a Function of* C_i^{-2}.

10.2.3.1 Measure at least 50 capacitance-voltage pairs over the entire range to be measured.

10.2.3.2 Taking $C_{comp} = 0$, fit a straight line to the $V_i - C_i^{-2}$ data by the least-squares method, and compute the sum of the squares of the normalized residuals as follows:

$$R_N = \sum_{i=1}^{n} \left(\frac{V_i}{\hat{V}_i} - 1 \right)^2 \qquad (2)$$

where:

R_N = the sum of the squares of the normalized residuals,
V_i = the measured voltage corresponding to the capacitance C_i,
$\hat{V}_i$ = the voltage corresponding to the capacitance C_i, calculated from the least-squares fit, and
n = the number of measured capacitance-voltage pairs.

10.2.3.3 Set $C_{comp} = 0.1$ pF.

10.2.3.4 Correct each of the C_i to C'_i using Eq 1, fit a straight line to the new data, and recompute the sum of the squares of the normalized residuals using Eq 2.

10.2.3.5 If the sum of the squares of the normalized residuals is less than the sum obtained from the previous case, increase C_{comp} by 0.1 pF, and repeat 10.2.3.4.

10.2.3.6 Repeat 10.2.3.5, increasing the value of C_{comp} by 0.1 pF each time until the sum of the squares of the normalized residuals increases.

10.2.3.7 At this point, decrease the value of C_{comp} by 0.02 pF.

10.2.3.8 Correct each of the C_i to C'_i using Eq 1, fit a straight line to the new data, and recompute the sum of the squares of the normalized residuals using Eq 2.

10.2.3.9 If the sum of the squares of the normalized residuals is less than the sum obtained from the previous case, decrease C_{comp} by 0.02 pF, and repeat 10.2.3.8.

10.2.3.10 Repeat 10.2.3.9, decreasing C_{comp} by 0.02 pF each time until the sum of the squares of the normalized residuals again increases.

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