



Designation: F 2166 – 02

Standard Practices for Monitoring Non-Contact Dielectric Characterization Systems Through Use of Special Reference Wafers¹

This standard is issued under the fixed designation F 2166; 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 These practices describe the use of wafers with special electrical and physical characteristics for controlling and monitoring performance of non-contact dielectric characterization systems (NCDCS) that employ corona. Thermally oxidized wafers are not sufficient for this purpose because of parametric drift due to temperature-bias stressing and exposure to the atmosphere. Three methods are described to cover various experimental arrangements (see Appendix X1 for a discussion on the two different types of corona).

1.1.1 *Method A*—For systems that employ point source corona,

1.1.2 *Method B*—For systems that employ line source corona and can be programmed to obtain a full set of parameters, and

1.1.3 *Method C*—For systems that employ line source corona but can only determine mobile ion density.

1.2 Special reference wafers are used to determine selected performance of these dielectric characterization systems, including initial surface voltage (V_{surf} or V_{cpd}), flatband voltage (V_{fb}), effective charge (Q_{eff}), density of interface traps (D_{it}), mobile charge (Q_m), and electrical dielectric thickness (T_{ox}).

1.3 The results obtained by these measurements can also be used to expose problems with wafer handling and software algorithms.

1.4 The procedures in this practice can be used to ascertain that the dielectric characterization system(s) meet quality control requirements such as those in an ISO 9000 quality program.

1.5 *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 1241 Terminology of Silicon Technology²

2.2 *SEMI Standard:*

SEMI M20 Specification for Establishing a Wafer Coordinate System³

2.3 *ISO Standard:*

ISO 9000 International Standards for Quality Management⁴

3. Terminology

3.1 *accumulation condition*—the condition in which majority carriers predominate at the semiconductor surface. In this condition, the slope of the capacitance-voltage (C-V) curve diminishes with an increasingly negative voltage for *p*-type material, or an increasingly positive voltage for *n*-type material.

3.2 *bias temperature stress, (BTS)*—a voltage applied to the top surface of a dielectric on a wafer whose temperature is maintained at a defined level for a specified time.

3.3 *contact potential difference, (V_{cpd})*—the potential measured by a Kelvin or Monroe probe that results from the potential difference between two metals or between a semiconductor and a metal, due to their difference in work function. Also called surface voltage (V_{surf}); see 3.16.

3.4 *corona temperature stress, (CTS)*—a BTS in which bias voltage is supplied by a corona discharge of known charge and voltage applied to the top surface of a dielectric on a wafer whose temperature is maintained at a defined level for a specified time.

3.5 *density of interface traps, (D_{it})*—the calculated interface charge per unit area that accounts for the difference in gradient between the measured and theoretical Q_{bias} versus SPV curve or equivalent “Q-Q” plot, in the band gap region.

3.6 *depletion condition*—the condition that exists in the semiconductor surface region when the free carrier density is

¹ These practices are under the jurisdiction of ASTM Committee F01 on Electronics and is the direct responsibility of Subcommittee F01.06 on Silicon Materials and Process Control.

Current edition approved Jan. 10, 2002. Published March 2002.

² *Annual Book of ASTM Standards*, Vol 10.05.

³ Available from Semiconductor Equipment and Materials International, 3081 Zanker Road, San Jose, CA 95134.

⁴ In the U.S., ISO documents may be obtained from ANSI, www.ansi.org or from the International Organization for Standardization, www.iso.ch.



insufficient to neutralize the fixed dopant charge density of donors and acceptors.

3.7 *dielectric (oxide) electrical thickness*, (T_{ox})—the silicon dioxide equivalent thickness (when the silicon dioxide dielectric constant is assumed) calculated from electrical measurement of Q_{bias} versus V_{surf} (or V_{cpd}) for the capacitor.

3.8 *effective charge*, (Q_{eff})—the oxide charge/cm² in the capacitor that gives the measured flatband voltage.

3.9 *flatband condition*—the point at which an external applied voltage causes there to be no internal potential difference across the MOS structure.

3.9.1 *Discussion*—In the flatband condition, the SPV is zero.

3.10 *flatband voltage*, (V_{fb})—the applied voltage necessary to produce the flatband condition.

3.11 *inversion condition*—the condition in which a minority carrier layer is formed at the semiconductor surface separated from the bulk by a depletion region.

3.12 *Kelvin probe*—a reference electrode that vibrates perpendicular to the wafer surface and generates an AC signal by varying the electrode-wafer capacitance.

3.13 *Monroe probe*—a reference electrode that is stationary and generates an AC signal by the horizontal vibration of a grounded fork which shields the probe from the wafer.

3.14 *mobile charge density*, (Q_m)—the calculated charge/cm² that moves in the oxide under temperature and electrical field stress, creating shifts in SPV, V_{fb} , and V_{cpd} (or V_{surf}).

3.15 *surface photovoltage*, (SPV)—the change of the electrostatic potential of the silicon surface caused by illumination.

3.16 *surface voltage*, (V_{surf})—the potential measured by the Kelvin or Monroe probe that results from the potential difference between two metals or between a semiconductor and a metal, due to their difference in work function. Also called contact potential difference (V_{cpd}); see 3.3.

3.17 Other terms related to testing of semiconductor materials may be found in Terminology F 1241.

4. Summary of Practices

4.1 Method A:

4.1.1 A special reference wafer is loaded into the NDCS.

4.1.2 A series of tests, which must include CTS, is executed to position mobile ions into a consistent pre-test condition.

4.1.3 Three additional identical test sequences are executed to collect data to evaluate performance of the instrument.

NOTE 1—The bias, temperature and time used for the last CTS prior to carrying out the above tests should be employed for these test sequences.

4.1.4 Performance of the NDCS and its selected components is checked by measuring the following characteristics: initial surface voltage (V_{surf}), flatband voltage (V_{fb}), effective charge (Q_{eff}), density of interface traps (D_{it}), mobile charge (Q_m), and electrical dielectric thickness (T_{ox}).

4.1.5 Measurements are made at three points on the surface of the wafer and the mean, standard deviation and relative standard deviation of the results obtained in the three identical sequences (4.1.3) are computed and recorded.

4.1.6 The results are compared with the values supplied with the special reference wafer to evaluate the NDCS performance.

4.1.7 If it is desired to check system linearity, this procedure is repeated using two or more additional special reference wafers with parameters that cover the typical parameter ranges in 7.4.

4.2 Method B:

4.2.1 First any remaining residual charge on a special reference wafer is neutralized by immersing it in DI water.

4.2.2 Then the special reference wafer is loaded into the NSCDS and the surface voltage (contact potential difference) is zeroed to within ± 0.3 V.

4.2.3 Then the steps in 4.1.2–4.1.4 and 4.1.6 are followed.

4.2.4 If it is desired to check system linearity, this procedure is repeated using two or more additional special reference wafers with parameters that cover the typical parameter ranges in 7.4.

4.3 Method C:

4.3.1 The steps in 4.2.1 and 4.2.2 are followed.

4.3.2 Then a dummy mobile ion run is performed to position the mobile ions into a consistent pre-test condition.

4.3.3 Then three additional mobile ion runs are made and the average, standard deviation, and relative standard deviation of the mobile ion density are determined.

4.3.4 The results are compared with the mobile ion density data supplied with the special reference wafer to evaluate the system performance.

4.3.5 If it is desired to check system linearity, this procedure is repeated using two or more additional special reference wafers with parameters that cover the typical parameter ranges in 7.4.

5. Significance and Use

5.1 The procedures in these practices are designed to ensure that the NDCS being evaluated provides reliable data for selected device-related parameters.

5.1.1 Flatband voltage is an important parameter in the fabrication of MOS devices. Its value is dependent on the charge structure within and on the dielectric as well as at the silicon dielectric (Si-SiO₂) interface. These charges consist of interface and bulk trapped and fixed charge, mobile charge distributed within the dielectric, and charge residing on the top of the dielectric. The total charge in and on the oxide determines flatband voltage, but the charge near the silicon has the most effect on flatband voltage. In order for this measurement to be useful, the charges at and near the silicon-dielectric interface of the wafer used to check the tester must be repeatable and stable over a period of at least six months. Most device applications require that the mobile charge be minimized to provide stable threshold voltage. Stability of the charges at elevated temperatures is a measure of mobile charge density within the dielectric. Tools used to produce dielectrics can become contaminated in various ways. When these tools become contaminated, they usually introduce an increased level of mobile ions into the dielectric.

5.1.2 Measuring V_{surf} or V_{cpd} , the contact potential between the probe and the semiconductor, with a Kelvin or Monroe probe allows a quantitative measurement of the charges associated with the semiconductor surface and the dielectric, independent of top (contact) electrode variations as in MOS C-V measurements. A special reference wafer has been used to



ions confined to the top half of the dielectric. It is therefore a good check of the Kelvin or Monroe probe, which is most sensitive to charges near the top of the dielectric.

5.2 The parameters determined relate to the properties of the NDCS subsystems in the following way:

5.2.1 V_{fb} and Q_{eff} data are used to check the surface photovoltage (SPV) probe, SPV strobe and corona biasing subsystems, by monitoring behavioral changes through accumulation and around the flat band condition.

5.2.2 D_{it} data are used to check the same subsystems as in 5.2.1, by monitoring behavioral changes through the depletion region of the Q_{bias} versus SPV curve.

5.2.3 Q_m data are used to check the temperature-stress subsystem, the corona subsystem, the Kelvin or Monroe probe.

5.2.4 T_{ox} data are used to check the corona stepping and voltage bias on the dielectric under test.

6. Interferences

6.1 The presence of light on the wafer surface during the measurements can affect results and should be controlled according to the system manufacturer's recommendations.

6.2 Relative humidity in the measurement environment above 60 % may affect measurement values.

6.3 Stray electromagnetic fields external to the NDCS may affect measurement results and should be limited according to the system manufacturer's recommendations.

6.4 Wafer handling should be done in accordance with accepted clean room practices, because surface contamination can affect the measurement results.

6.5 Change in the characteristics of the special reference wafers due to handling and other effects may affect measurement results. The special reference wafers must be checked periodically, for example once every six months, to assure consistent performance.

7. Special Reference Wafers

7.1 Fabricate the special reference wafers (SRW) from *p*-type silicon with a multi-layer dielectric including an embedded layer of mobile ions confined to the top portion of the dielectric. These mobile ions drift during temperature-bias stressing. Since the drift occurs only in the top of the dielectric, the Kelvin (Monroe) probe easily senses a shift in V_{surf} (V_{cpd}) for the mobile ion concentration calculation. Confining the mobile ions to the top of the dielectric also ensures that measurements associated with the silicon-dielectric interface are left unchanged after the mobile ion test.

7.2 Limit the thickness of the dielectric on the special reference wafers to between 30 and 70 nm, to provide sufficient distance for the mobile ions to drift while remaining clear of the interface.

7.3 Ensure the dielectric is rugged enough so that repeated use, for example, once a day for six months, of the same test sites does not result in shifts in electrical parameters.

7.3.1 Check parameter drift every 6 months. Parameter drift over time should be less than 10 % in six months. If drift exceeds this value, replace the special reference wafers.

7.3.2 Test wafers must be re-calibrated and documented semi-annually by testing the wafers on two documented NDCSs that have been maintained using this Practice. The

results must match within 10 %. If the results exceed this value, replace the special reference wafers.

7.4 *Test Parameter Ranges*—*p*-type special reference wafers should have parameters appropriate for the test application. Parameters in the following ranges cover all anticipated applications of the SRWs.

7.4.1 $V_{fb} = -0.1$ to -5.0 V,

7.4.2 $Q_{eff} = 0.5$ to 10×10^{11} charge/cm²,

7.4.3 $Q_m = 0.7$ to 20×10^{10} charge/cm²,

7.4.4 $D_{it} = 0.5$ to 50×10^{11} charge/cm², and

7.4.5 $T_{ox} = 2$ to 200 nm.

7.5 *Supporting Data*:

7.5.1 Data collected using the appropriate method shall be supplied with each special reference wafer.

7.5.2 Provide appropriate reference data for each wafer on a data sheet similar to that in Fig. 1 (Methods A or B) or Fig. 2 (Method C).

7.5.3 These values are the targets against which the system is evaluated.

7.6 To determine the linearity of the system, select a set of at least three special reference wafers with values of each parameter that span the ranges given in 7.4.

8. Calibration Data Sheet

8.1 A test plan shall be agreed upon among all parties to the test. Data shall be recorded on a Test Certification Sheet similar to that supplied with the special reference wafers. Examples are shown in Figs. 1 and 2.

9. Procedure

9.1 Observe and record the temperature and relative humidity of the room where the testing is taking place.

9.2 *Method A*—for NDCSs that employ a point source corona:

9.2.1 Place a special reference wafer in the NDCS.

9.2.2 Program the NDCS to measure the following parameters of *p*-type wafers: initial V_{surf} , T_{ox} , Q_{eff} , V_{fb} , D_{it} , and Q_m .

9.2.3 Align the point probe over position A, then execute a dummy measurement to stabilize the mobile ions. Repeat this procedure at two other locations. An example would be the locations (0,0; -40,40; and 40,-40), where the *x* and *y* locations are expressed in millimeters, relative to the wafer center, using a Cartesian wafer coordinate system as defined in SEMI M20. (See Fig. X1.1)

9.2.4 Execute three additional, identical runs. Determine and record the parameters listed in 9.2.2.

9.2.5 Calculate and record the average, standard deviation, and % deviation for each parameter measured at each location in runs 2 through 4.

9.2.6 To check NDCS linearity, repeat 9.2.1-9.2.5 using at least two additional special reference wafers with parameter values that span the typical parameter ranges in 7.4.

9.3 *Method B*—For NDCSs that employ a line source corona and can be programmed to obtain a full set of parameters:

9.3.1 Rinse a special reference wafer in a DI water bath for 10 min then dry for 10 min to naturalize any residual charge.

9.3.2 Place the special reference wafer in the NDCS.

9.3.3 Measure the voltage on the wafer surface (V_{cpd})