

SEMI MF2166-1110 (Withdrawn 1015) PRACTICES FOR MONITORING NONCONTACT DIELECTRIC CHARACTERIZATION SYSTEMS THROUGH USE OF SPECIAL REFERENCE WAFERS

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NOTICE: This Document was balloted and approved for withdrawal in 2015.

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1 Purpose

1.1 Noncontact dielectric characterization systems (NDCS) that supply surface charge by means of a corona instead of an electrode are frequently used to determine the oxide characteristics of MOS device structures. These instruments can measure a number of characteristic parameters, including:¹

1.1.1 initial surface voltage (V_{surf} or V_{cpd}),

1.1.2 flatband voltage (V_{fb}),

1.1.3 effective charge (Q_{eff}),

1.1.4 interface trap density (D_{it}),

1.1.5 mobile oxide charge (Q_m), and

1.1.6 electrical dielectric thickness (t_{ox}).

1.2 To determine that the NDCS is performing correctly, it is necessary to test the tester. These practices provide procedures for testing these systems with the use of special reference wafers with specified characteristics.

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

1.4 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 oxide charge distributed within the dielectric, and charge residing on the top of the dielectric. Although the total charge in and on the oxide determines flatband voltage, the charge near the silicon has the greatest effect.

1.4.1 Most device applications require that the mobile oxide charge be minimized to provide stable threshold voltage. Stability of the charges at elevated temperatures is a measure of mobile oxide charge density within the dielectric. The mobile oxide charge changes location under temperature and electric field stress. The mobile oxide charge density can be calculated from the resulting change in flatband voltage.

1.4.2 Equipment used to produce dielectrics can become contaminated in various ways. When such equipment becomes contaminated, it usually introduces an increased level of mobile ions into the dielectric.

¹ Names and symbols for *interface trapped charge density* and *mobile oxide charge* are taken from Deal, B. E. “Standardized Terminology for Oxide Charges Associated with Thermally Oxidized Silicon.” *IEEE Trans. Electron Devices*, **ED-27** (1980): pp. 606–608.

1.4.3 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 the mobile 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.

1.5 The procedures in these practices can be used to ascertain that the dielectric characterization system(s) meet quality control requirements. They can be used as a training tool for tester applications.

1.6 The results obtained by these measurements can also be used to expose and troubleshoot tester problems including wafer handling and software issues.

2 Scope

2.1 These practices describe the use of wafers with special electrical and physical characteristics for controlling and monitoring performance of non-contact dielectric characterization systems (NCDs) that employ corona. They apply in general to dielectrics with charge structure that can be measured by the characterization system. Their applicability to dielectrics of less than 3-nm electrical oxide thickness depends on the capability of the NCDs. A thickness correlation between the reference wafer(s) and thin-dielectric monitor wafers must be established.

2.1.1 The reference wafers must be designed to check the repeatability and functionality of all the parts and subsystems of the characterization system. Thermally oxidized wafers are not sufficient for this purpose because of parametric drift due to temperature-bias stressing and exposure to the atmosphere.

2.2 Three methods are described to cover various experimental arrangements (see Related Information 1 for a discussion on the two different types of corona).

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

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

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

2.3 For each of the three methods, the total testing time can be reduced by using a short-cycle-time modification.

2.4 Special reference wafers are used to determine selected performance characteristics 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 trap density (D_{it}), mobile oxide charge (Q_m), and electrical dielectric thickness (t_{ox}).

2.5 The parameters determined relate to the properties of the NCDs subsystems in the following way:

2.5.1 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.

2.5.2 D_{it} data are used to check the same subsystems as in ¶ 2.5.1, by monitoring behavioral changes through the depletion region of the Q_{bias} vs SPV curve.

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

2.5.4 t_{ox} data are used to check the corona stepping and voltage bias and the Kelvin or Monroe probe air-gap setting.

2.6 Methods for determination of various oxide characteristics are outside the scope of these practices. Information on this can be found in SEMI MF1153 and in the technical literature.²

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² Refer to, for example, Schroder, D. K. *Semiconductor Material and Device Characterization*, Wiley Interscience, New York 1990, Chapter 4.

3 Limitations

- 3.1 The presence of light on the wafer surface during the measurements can affect the results obtained and should be controlled according to the system manufacturer's recommendations.
- 3.2 Relative humidity in the measurement environment above 60% may affect measurement values.
- 3.3 Stray electromagnetic fields external to the NCDSCS may affect measurement results and should be limited according to the system manufacturer's recommendations.
- 3.4 Wafer handling should be done in accordance with accepted clean room practices, because surface contamination can affect the measurement results.
- 3.5 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 at least once every six months, to assure consistent performance.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI M59 — Terminology for Silicon Technology

SEMI MF1153 — Test Method for Characterization of Metal-Oxide-Silicon (MOS) Structures by Capacitance-Voltage Measurements

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 Acronyms, terms, and symbols related to silicon technology, including those used in these practices, are listed and defined in SEMI M59.

6 Summary of Practices

6.1 Method A

6.1.1 A special reference wafer is loaded into the NCDSCS.

6.1.2 A series of tests, which must include CTS, is executed to position mobile ions into a consistent pre-test condition. All CTS times must be at least 4 minutes to allow full movement of the mobile ions.

6.1.3 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.

6.1.4 Performance of the NCDSCS 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 trap density (D_{it}), mobile oxide charge (Q_m), and electrical dielectric thickness (t_{ox}).

6.1.5 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 (§ 6.1.3) are computed and recorded.

6.1.6 The results are compared with the values supplied with the special reference wafer to evaluate the NCDSCS performance.

6.1.7 If it is desired to check the system over its full range of operation, this procedure is repeated using two or more additional special reference wafers with parameters that cover the typical parameter ranges in § 7.4.

6.1.8 *Short-cycle Time Modification of Method A* — The short-cycle time modification is performed in the same manner except that the measurement of Q_m is carried out first, in order to assure consistent alignment of the mobile ions prior to the other measurements. The Q_m measurement is followed by the measurement of the other parameters. No repetitions are required; the test sequence in this modification is only run once.

6.2 Method B

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

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

6.2.3 Then the steps in ¶¶ 6.1.2 through 6.1.4 and ¶ 6.1.6 are followed.

6.2.4 If it is desired to check the system over its full range of operation, this procedure is repeated using two or more additional special reference wafers with parameters that cover the typical parameter ranges in ¶ 7.4.

6.2.5 *Short-cycle Time Modification of Method B* — The short-cycle time modification is performed in the same manner except that the measurement of Q_m is carried out first, in order to assure consistent alignment of the mobile ions prior to the other measurements. The Q_m measurement is followed by the measurement of the other parameters. No repetitions are required; the test sequence in this modification is only run once.

6.3 Method C

6.3.1 The steps in ¶¶ 6.2.1 and 6.2.2 are followed.

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

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

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

6.3.5 If it is desired to check the system over its full range of operation, this procedure is repeated using two or more additional special reference wafers with parameters that cover the typical parameter ranges in ¶ 7.4.

6.3.6 *Short-cycle Time Modification of Method C* — The short-cycle time modification is performed in the same manner except that the first CTS time is 4 minutes and the second is 8 minutes. Only a single mobile ion run is carried out.

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 NCDCSs that have been maintained using these practices. 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