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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Measuring Sori on Silicon Wafers by Automated Noncontact Scanning¹

This standard is issued under the fixed designation F 1451; 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 covers a noncontacting, nondestructive procedure to determine the sori of clean, dry semiconductor wafers.

1.2 The test method is applicable to wafers 50 mm or larger in diameter, and 100 μm (0.004 in.) approximately and larger in thickness, independent of thickness variation and surface finish, and of gravitationally-induced wafer distortion.

1.3 This test method employs a two-probe system that examines both external surfaces of the wafer simultaneously.

1.4 This test method measures sori of a wafer corrected for all mechanical forces applied during the test. Therefore, the procedure described gives the unconstrained value of sori. This test method includes a means of canceling gravity-induced deflection which could otherwise alter the shape of the wafer.² The resulting parameter is described by Sori in SEMI Specification M1, Appendix Shape Decision Tree (see Annex A1).

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.*

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

2. Referenced Documents

2.1 ASTM Standards:

D 4356 Practice for Establishing Consistent Test Method Tolerances³

F 1241 Terminology of Silicon Technology⁴

2.2 SEMI Standard:

M1 Specifications for Polished Monocrystalline Silicon Wafers⁵

3. Terminology

3.1 Definitions:

3.1.1 *mechanical signature, of an instrument*—that component of a measurement that is introduced by the instrument and which is systematic, repeatable and quantifiable.

3.1.2 *median surface, of a semiconductor wafer*—the locus of points equidistant from the front and back surfaces.

3.1.3 *quality area*—that portion of the wafer within which the specified parameter is determined.

3.1.4 *reference plane, of a semiconductor wafer*—a plane from which deviations are measured.

3.1.5 *reference plane deviation (RPD)*—the distance from a point on a reference plane to the corresponding point on a wafer surface. A dome-shaped wafer is considered to have positive RPD at its center; a bowl-shaped wafer is considered to have negative RPD at its center.

3.1.6 *sori, of a semiconductor wafer*—the difference between the maximum and minimum distances of the front surface of a free, unclamped wafer from a front-surface least squares reference plane.

3.1.6.1 *Discussion*—The front surface may contain regions with upward or downward curvature or both; under some conditions the front surface may be flat (see figures in Appendix X1).

3.1.7 *thickness, of a semiconductor wafer*—the distance through the wafer between corresponding points on the front and back surfaces.

3.1.8 Other definitions relative to silicon material technology can be found in Terminology F 1241.

4. Summary of Test Method

4.1 A calibration procedure is performed. This sets the instrument's scale factor and other constants. In the methods using representative wafer inversion this procedure also determines the mechanical signature of the instrument and the effect of gravity on the wafer (Z_{mg} – median surface; Z_{fg} – front surface).

4.2 The wafer is supported by a small-area chuck and is scanned along a prescribed pattern by both members of an opposed pair of probes.

4.3 One of two measurement methods is used. These are distinguished by their use of either a representative wafer or the sample wafer to calculate gravity effects, and in the application

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.

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² Poduje, N., "Eliminating Gravitational Effect in Wafer Shape Measurements," NIST/ASTM/SEMI/SEMATECH Technology Conference, Dallas, TX Technology for Advanced Materials/Process Characterization, February 1, 1990.

³ Annual Book of ASTM Standards, Vol 14.02.

⁴ Annual Book of ASTM Standards, Vol 10.05.

⁵ Available from SEMI, 805 East Middlefield Road, Mt. View, CA 94043.

of gravity correction to the median or top surface.

4.3.1 *Method 1—Median Surface, Representative Wafer (MR):*

4.3.1.1 The sample wafer is scanned in the normal orientation (front surface up) and data are taken.

4.3.1.2 The paired displacement values are used to construct a median surface.

4.3.1.3 The median surface is mathematically corrected for gravitational effects and for mechanical signature of the instrument, by subtracting Z_{mg} , which is obtained from a representative wafer during calibration.

4.3.1.4 One half the thickness at each point is added to the corrected median surface to construct the corrected front surface.

4.3.2 *Method 2—Median Surface, Sample Wafer (MS):*

4.3.2.1 The sample wafer is scanned in the normal orientation (front surface up) and data are taken.

4.3.2.2 The wafer is scanned in the inverted orientation (front-side down) and data are taken (see Note 3 in 11.2.1).

4.3.2.3 The two measurements at each point are subtracted and divided by two. This constructs a gravity-corrected median surface.

4.3.2.4 One half the thickness at each point is added to the corrected median surface to construct the corrected front surface.

4.4 A least-squares reference plane is constructed from the corrected front surface.

4.5 The reference plane deviation (RPD) is calculated at each measured point.

4.6 Sori is reported as the algebraic difference between the most positive RPD and the most negative RPD.

5. Significance and Use

5.1 Sori can significantly affect the yield of semiconductor device processing.

5.2 Knowledge of this characteristic can help the producer and consumer determine if the dimensional characteristics of a specimen wafer satisfy given geometrical requirements.

5.3 Changes in wafer sori during processing can adversely affect subsequent handling and processing steps. These changes can also provide an important process monitoring function.

5.4 This test method is suitable for measuring the sori of wafers used in semiconductor device processing in the as-sliced, lapped, etched, polished, epitaxial or other layer condition and for monitoring thermal and mechanical effects on the sori of wafers during device processing.

5.5 Until the results of a planned interlaboratory evaluation of this test method are established, use of this test method for commercial transactions is not recommended unless the parties to the test establish the degree of correlation that can be obtained.

6. Interferences

6.1 Any relative motion along the probe measuring axis between the probes and the wafer holding device during scanning will produce error in the measurement data. Vibration of the test specimen relative to the probe-measuring axis will introduce error. Such errors are minimized by system signature

analysis and correction algorithms. Internal system monitoring may also be used to correct nonrepetitive and repetitive system mechanical translations. Failure to provide such corrections may cause errors.

6.2 If a measured wafer differs substantially in diameter, thickness, fiducials or crystal orientation from that used for the gravitational compensation procedure, the results may be incorrect. Estimates of the errors for differences in diameter and thickness are shown in Appendix X2. If the crystal orientation of the sample to be measured differs from the crystal orientation of the gravity-compensation wafer, then the measured sori value may differ from the actual sori value by up to 15 %. Error tables for fiducial variation have not been generated.

6.3 Different methods for implementing gravitational compensation may give different results. Varying levels of completeness of implementing a method may also give different results.

NOTE 1—The recommended method for gravitational compensation is Representative Wafer Inversion,⁶ since it allows the use of a single wafer to establish the compensation that is subsequently applied to sample wafers. The sample wafer inversion method requires that every wafer be measured twice, once in a normal and once in an inverted position, which increases measurement time and subjects the sample to additional handling. Theoretical modeling requires only a single measurement per sample, however it does not address machine signature issues, nor is a rigorous theory presently known to exist.

6.4 Mechanical variations in wafer holding devices between systems may introduce measurement differences (see 7.1.1).

6.5 Most equipment systems capable of this measurement have a definite range of wafer thickness combined with sori (dynamic range) that can be accommodated without readjustment. If the sample moves outside this dynamic range during either calibration or measurement, results may be in error. An overrange signal can be used to alert the operator and measurement data examiners to this event.

6.6 The quantity of data points and their spacing may affect the measurement results (see 7.1.2).

7. Apparatus

7.1 *Sori-Measuring Equipment*, consisting of wafer holding device, multiple-axis transport mechanism, probe assembly with indicator, and system controller/computer, including data processor and suitable software. The system must be equipped with an overrange signal. Instrument data reporting resolution shall be 100 nm or smaller.

7.1.1 *Wafer-Holding Device*, for example a chuck whose face is perpendicular to the measurement axis, and on which the wafer is placed for the measurement scan. The diameter of the wafer holding device shall be 22 mm (0.9 in.) diameter, 33 mm (1.3 in.) diameter, or other value as agreed upon between using parties.

7.1.2 *Multiple-Axis Transport Mechanism*, which provides a means for moving the wafer-holding device, or the probe assembly, perpendicularly to the measurement axis in a controlled fashion in several directions. This motion must permit

⁶ The Representative Wafer method of gravitational correction is covered by a patent held by ADE Corporation, 77 Rowe Street, Newton, MA 02166. Alternate methods are described in 12.3.2.

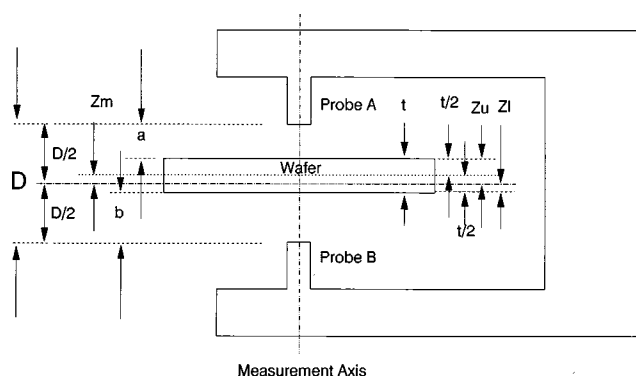


FIG. 1 Schematic View of Wafer, Probes, and Fixture

data gathering over a prescribed scan pattern covering the entire quality area. Maximum data point spacing to be used shall be 4 mm, or other value as agreed upon between using parties.

7.1.3 Probe Assembly with Paired Non-contacting Displacement-Sensing Probes, Probe Supports, and Indicator Unit. The probes shall be capable of independent measurement of the distance between the probed site on each surface of the sample wafer and the motion plane. The probes shall be mounted above and below the wafer in a manner so that the probed site on one surface of the wafer is opposite the probed site on the other. The common axis of these probes is the measurement axis (see Fig. 1). The probe separation D shall be kept constant during calibration and measurement. Displacement resolution shall be 0.1 μm or better. The probe sensor size shall be 4 by 4 mm, or other value to be agreed upon between using parties. Systems employing either representative wafer inversion or sample wafer inversion methods for gravity compensation must provide precise positioning in both measurement orientations so that measurements are taken at identical locations for each orientation of the sample.

7.1.3.1 The following equations are derived from Fig. 1.

$$D = a + t + b \quad (1)$$

$$Z_m = -\frac{D}{2} + b + \frac{t}{2} \quad (2)$$

$$Z_m = \frac{D}{2} - a - \frac{t}{2} \quad (3)$$

$$Z_m = \frac{b-a}{\gamma} \quad (4)$$

where:

D = the distance from Probe B to Probe A ,

a = the distance from the top surface of the wafer to Probe A,

b = the distance from Probe B to the bottom surface of the wafer,

t = wafer thickness (always a positive number),

Z_m = the distance between the wafer median surface and the point halfway between the upper and lower probes.

Z_1 = the distance between the wafer lower surface and the point halfway between the upper and lower probes, and

Z_u = the distance between the wafer upper surface and the point halfway between the upper and lower probes.

8. Materials

8.1 *Set-up Masters*, suitable to accomplish calibration and standardization as recommended by the equipment manufacturer.

8.2 *Reference Wafer*, with sori value $\leq 20 \mu\text{m}$ and with a data set that is used to determine the level of agreement between the system under test and the data set (see Annex A1).

8.3 Representative Wafer—if using the Representative Wafer Inversion Method, a wafer identical in nominal diameter, nominal thickness, nominal fiducials, composition and crystal-line orientation to those being measured is required for the calibration procedure. Its sori need not be known.

9. Suitability of Test Equipment

9.1 The suitability of the test equipment shall be determined with the use of a reference wafer and its associated data set in accordance with the procedures of Annex A1, or by performance of a statistically-based instrument repeatability study to ascertain whether the equipment is operating within the manufacturer's stated specification for repeatability.

NOTE 2—Subcommittee F1.95 is currently developing an instrument repeatability study format.

9.2 Determination of degree of suitability is currently under investigation.

10. Sampling

10.1 This test method is nondestructive and may be used on either 100 % of the wafers in a lot or on a sampling basis.

10.1.1 If samples are to be taken, procedures for selecting the sample from each lot of wafers to be tested shall be agreed upon between the parties to the test, as shall the definition of what constitutes a lot.

11. Calibration and Standardization

11.1 Calibrate in accordance with the manufacturer's instructions.

11.2 When using the representative wafer inversion method (Method 1), perform the following procedures to determine Z_{mg} , the representative effect of gravity and machine effects on the representative wafer.

11.2.1 *Method 1—MR (Median Surface, Representative Wafer)*—Scan the representative wafer in the normal orientation (front-side is upper surface) and record data. Invert the representative wafer and scan it in the inverted orientation (front-side is lower surface) and record data. The instrument performs the following functions: a median surface Z_{mn} is constructed using the paired displacement values from the normal orientation data (Eq 5). A median surface Z_{mi} is constructed using the paired displacement values from the inverted orientation data (Eq 6). In order to determine gravitational effects on the representative wafer's median surface, calculate Z_{mg} at each point.

$$Z_{mn} = \frac{b-a}{2} \text{ (normal position)}$$

$$Z_{mi} = \frac{b - a}{2} \text{ (inverted position)} \quad (6)$$

$$Z_{mg} = \frac{Z_{mn} + Z_{mi}}{2} \quad (7)$$

NOTE 3—Conventions for data sets: This procedure requires that sets of data taken at many points on the wafer be combined (added or subtracted). These data may be expressed as $d[x,y]$, where d is the data of interest and x,y is the location of datum in a coordinate system. The procedure requires that several sets of data be combined (that is added or subtracted) on a point by point basis. Two data points to be combined must be located at the same point on the wafer. If x,y are in the coordinate system of the wafer then the same x,y values are used for all data sets being combined. If x,y are in the coordinate system of the measuring system and the data sets to be combined were obtained with the wafer in different positions, then a transformation must be applied to one or more of the data sets. For instance, when data set d_1 is obtained with the wafer in the normal orientation and data set d_2 is obtained with the wafer in an inverted orientation, rotated about the x -axis, then $d_1[x,y]$ must be combined with $d_2[x_1 - y]$. In the test method, when data sets are combined, this convention must be used. For the sake of simplicity, the x,y notations are omitted from the calculations described in the method.

12. Procedure

12.1 Prepare the apparatus for measurement of wafers, including selection of diameter, peripheral fiducials, scan area and data display/output functions.

12.2 *Method 1: MR (Median Surface, Representative Wafer):*

12.2.1 Introduce the test specimen into the measurement mechanism with the front surface upward and initiate the measurement sequence.

12.2.2 *Calculations*—In this sequence, the displacements (distances) between each probe and the nearest surface of the wafer are determined (in pairs) at intervals along the scan pattern. The distance between probe A and the nearest surface of the wafer is displacement value a . The distance between probe B and the nearest surface of the wafer is displacement value b . The probes are separated by the distance D (see Fig. 1). The front surface is constructed as follows:

12.2.2.1 The difference of each pair of displacements is divided by 2 to yield the position Z_m (along the measurement axis) of the median surface of the wafer at each point with respect to a plane halfway between the upper and lower probes:

$$Z_m = \frac{b - a}{2} \quad (8)$$

12.2.2.2 Gravitational compensation is applied by subtracting z_{mg} from the median surface at each point.

$$Z_{mc} = Z_m - Z_{mg} \quad (9)$$

12.2.2.3 The sum of each pair of displacements is subtracted from D to yield the thickness at each point.

$$t = D - (a + b) \quad (10)$$

12.2.2.4 The corrected median surface position and one-half the thickness are added to yield the corrected position of the front surface.

$$Z_{uc} = Z_{mc} + \frac{t}{2} \quad (11)$$

12.3 *Method 2—MS (Median Surface, Sample Wafer):*

12.3.1 Introduce the test specimen into the measurement mechanism with the front surface upward and initiate the measurement sequence.

12.3.1.1 *Calculations*—In this sequence, the displacements (distances) between each probe and the nearest surface of the wafer are determined (in pairs) at intervals along the scan pattern. The distance between probe A and the nearest surface of the wafer is displacement value a . The distance between probe B and the nearest surface of the wafer is displacement value b . The probes are separated by the distance D (see Fig. 1). The front surface is constructed as follows:

12.3.1.2 With the wafer in the normal orientation (front side is upper), the difference of each pair of displacements is divided by 2 to yield the position Z_{mn} of the median surface of the wafer at each point with respect to a plane halfway between the upper and lower probes (Eq 12).

$$Z_{mn} = \frac{b - a}{2} \text{ (normal position)} \quad (12)$$

12.3.1.3 The sum of each pair of displacements is subtracted from D to yield the thickness at each point (Eq 13).

$$t = D - (a + b) \text{ (normal position)} \quad (13)$$

12.3.2 Invert the wafer and introduce it into the measurement mechanism with the front surface downward and initiate the measurement sequence, as in 12.3.1.1.

12.3.2.1 With the wafer in the inverted orientation (front side down), the difference of each pair of displacements is divided by 2 to yield the position Z_{mi} of the median surface of the wafer at each point with respect to a plane halfway between the upper and lower probes (Eq 14).

$$Z_{mi} = \frac{b - a}{2} \text{ (inverted position)} \quad (14)$$

12.3.3 The normal and inverted measurements are subtracted to yield Z_{mc} , the corrected median surface position at each point ((Eq 15) see Note 1).

$$Z_{mc} = \frac{Z_{mc} - Z_{mi}}{2} \quad (15)$$

12.3.4 The corrected median surface position and one-half the thickness are added to yield the corrected position of the upper surface (Eq 16) which is the corrected position of the front surface.

$$Z_{uc} = Z_{mc} + \frac{t}{2} \quad (16)$$

$$Z_{fc} = Z_{uc} \quad (17)$$

$$Z_{fc} = Z_c \quad (18)$$

NOTE 4—This method requires that every sample wafer be measured in both the normal and the inverted positions.

12.4 A reference plane is constructed that is a least-squares fit to the corrected front surface Z -position data at all points of the scan pattern. The Z -value of the reference plane ($Z_{f,ref}$) is subtracted from the measured Z -position at each point at all the points of the scan pattern to yield reference plane deviation (RPD) at each point.