Designation: F 657 – 92 (Reapproved 1999)

Standard Test Method for
Measuring Warp and Total Thickness Variation on Silicon Wafers by Noncontact Scanning [1]

This standard is issued under the fixed designation F 657; 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 warp and total thickness variation (TTV) of clean, dry silicon wafers in a free (unclamped) condition. The procedure uses a three-point back surface reference plane for determining warp.

1.2 The test method is applicable to circular silicon 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. The test method is applicable to wafers of semiconductors other than silicon with these same physical characteristics.

1.3 This test method is not intended to measure surface flatness; warp, which is not to be confused with flatness, is a bulk property of the wafer.

1.4 This test method measures warp or TTV of a wafer with no mechanical force applied during the test. Therefore, the procedure described gives the unconstrained value of warp or TTV. Gravity-induced deflection alters the shape of the wafer and is included in the measurement.

1.5 For silicon wafers of diameter 3 in. or smaller, the values stated in inch-pound units are to be regarded as standard; the values stated in acceptable metric units in parentheses are for information only. For silicon wafers of diameter larger than 3 in., the values stated in acceptable metric units are to be regarded as standard whether or not they appear with parentheses; inch-pound units are for information only.

1.6 *This standard does not purport to address 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 *ASME Standard:*

B 46 Surface Texture [2]

2.2 *SEMI Standard:*

M 1 Specifications for Polished Monocrystalline Silicon Wafers [3]

2.3 *Federal Standard:*

GGG-P 463 C Surface Plate, Granite [4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

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

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

3.1.3 *total thickness variation, TTV— of a semiconductor wafer,* the difference between the maximum and minimum values of the thickness of the wafer.

3.1.4 *warp—of a semiconductor wafer,* the difference between the maximum and minimum distances of the median surface of a free, unclamped wafer from a reference plane.

3.1.4.1 *Discussion*—Although warp may be caused by unequal stresses on the two exposed surfaces of the wafer, it cannot be determined from measurements on a single exposed surface. The median surface may contain regions with upward or downward curvature or both; under some conditions the median surface may be flat (see 6.4 and Appendix X1).

4. Summary of Test Method

4.1 The wafer is supported by three hemispherical points on a reference ring, and both surfaces are simultaneously scanned along a prescribed pattern by both members of an opposed pair of probes.

4.2 The displacements (distances) between each probe and the nearest surface of the wafer are determined (in pairs) at intervals along the scan pattern.

4.3 Half the difference between the largest and smallest of the differences of the paired displacements is taken as a measure of the warp.

4.4 The difference between the largest and smallest of the sums of the paired displacements is taken as a measure of the total thickness variation.

---

[1] This test method is under the jurisdiction of ASTM Committee F-1 on Electronicsand is the direct responsibility of Subcommittee F01.06 on Electrical and Optical Measurement.

Current edition approved Nov. 15, 1992. Published March 1993. Originally published as F 657 – 80. Last previous edition F 657 – 91.

[2] Available from the American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

[3] Available from the Semiconductor Equipment and Materials International, Inc., 805 E. Middlefield Rd., Mountain View, CA 94043.

[4] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094.

5. Significance and Use

5.1 Warp and thickness variation can significantly affect the yield of semiconductor device processing.

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

5.3 Changes in wafer warp during processing can adversely affect subsequent handling and processing steps.

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

6. Interferences

6.1 Any change in the reference plane during scanning will produce error in the indicated measurement equal to the axial vector value of the deviation at the probe axes at the points of largest and smallest differences. If such changes occur, there is the possibility that an incorrect location may be identified as an extremum.

6.2 Non-parallelism of the reference plane to the granite base surface will produce an error in the indicated measurement proportional to the non-parallelism.

6.3 Foreign particles (dirt) between the measuring ring and surface plate will introduce error.

6.4 This test method does not completely separate thickness variation from warp. In some cases, the median surface may be flat but still show a non-zero value for warp.

6.5 Vibration of the test specimen relative to the probe-measuring axis will introduce error.

6.6 Running probes off the test specimen during the scan sequence will give false readings.

6.7 Most equipment systems capable of this measurement have a definite range of wafer thickness combined with warp which can be accommodated without readjustment. Any values observed while in an over-range condition are invalid (see 7.1.2.3).

6.8 In this test method, both TTV and warp are determined using a specified partial scan pattern; thus, the entire surface is not sampled and use of another scan pattern may not yield the same result.

7. Apparatus

7.1 *Warp—Measuring Equipment*, consisting of movable reference ring, fixed probe assembly with indicator, guide, and surface plate as follows:

7.1.1 *Reference Ring*, consisting of a closed base and three hemispherical support pads; a different size ring is required for use with each diameter of wafer to be measured (see Fig. 1). Each reference ring shall be fabricated of a metal whose thermal coefficient of expansion shall not exceed 6×10^{-6}/°F at laboratory temperatures; be at least 0.75 in. (or 19 mm) thick, with the bottom surface lapped flat to within 10 µin. (0.25 µm); have an outside diameter approximately 2 in. (or 50 mm) larger than the diameter of the specimen wafer with which it is intended to be used; and incorporate the following features:

7.1.1.1 *Three Hemispherical Support Pads*, used to define the plane of the reference ring and equally spaced within ±0.005 in. (±0.13 mm) on the circumference of a circle whose diameter is 0.250 in. (6.35 mm) less than the nominal diameter of the wafer as given in SEMI Specifications M 1. The support pads shall be fabricated from tungsten carbide, or from a material of the same or greater hardness, have a nominal diameter of 0.125 in. (3.18 mm), and project 0.0625 ± 0.0050 in. (1.59 ± 0.13 mm) above the upper surface of the reference ring. The upper bearing surface of each support pad shall be polished, with a maximum surface roughness R_A of 10-µin. (0.25-µm) measured with 0.31-in. (0.8-mm) cutoff in accordance with ASME B 46.

7.1.1.2 *Three Cylindrical Guide Pins*, used to assist the operator to position the specimen wafer by eye, spaced approximately equally on the circumference of a circle whose diameter is nominally equal to the sum of the diameter of the pin and the maximum allowable wafer diameter as given in SEMI Specifications M 1. The guide pins shall be at least 0.015 in. (0.38 mm) higher than the support pads (see Fig. 1).

7.1.1.3 *Probe Parking Position*, cut-out area in the reference ring outside the nominal wafer diameter to permit the ring to be positioned so that the probe assembly is out of the way for specimen or precision flat insertion and removal (see Fig. 1).

NOTE 1—The plane defined by the reference ring is the plane tangent to the three pads.

NOTE 2—It is recommended that the guide pins be fabricated from a hard plastic material.

7.1.2 *Probe Assembly with Indicator*, 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 specimen slice and the plane of the reference ring. The probes shall be mounted above and below the specimen position in a manner so that the probe site on one surface of the specimen is opposite the probed site on the other. The common axis of mounting shall be perpendicular (±2°) to the plane defined by the reference ring. The upper probe mount shall incorporate a positioning adjustment to accommodate the wafer thickness range desired. The indicator unit shall be capable of displaying the output from each probe individually and of being manually reset. The assembly shall satisfy the following requirements:

7.1.2.1 Probe-sensing area (probed site) diameter shall be in the range from 0.062 to 0.225 in. (1.57 to 5.72 mm), inclusive,

7.1.2.2 Displacement resolution of 10 µin. (0.25 µm) or better from a probed site,

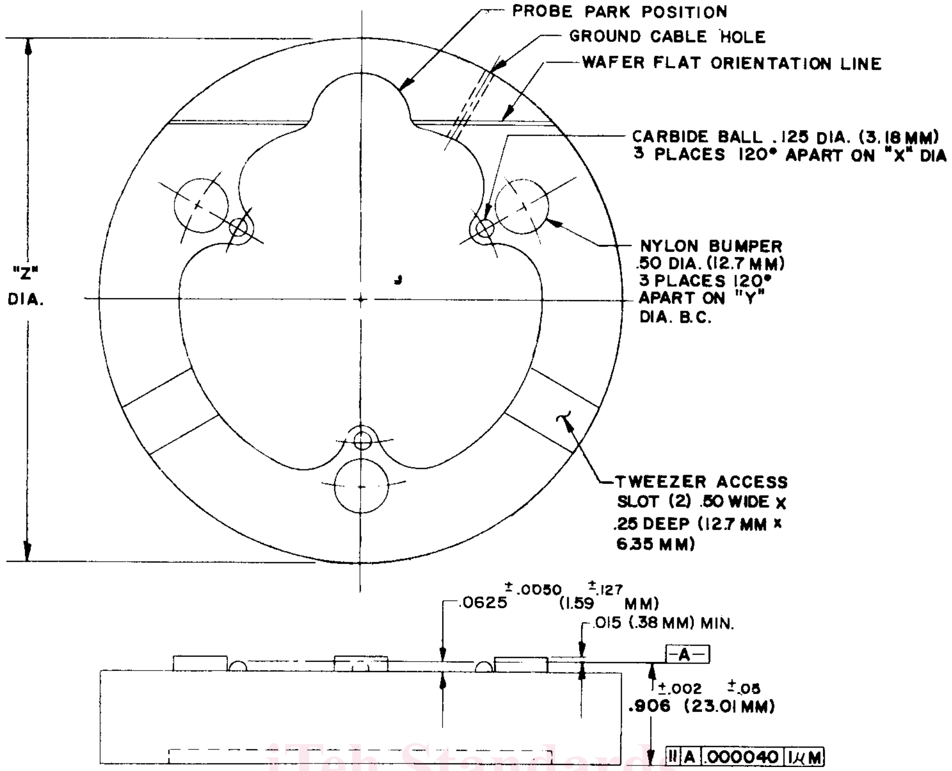
7.1.2.3 Displacement range (for each probe) of at least ± 0.010 in. (±0.25 mm) about the nominal zero position,

7.1.2.4 Linearity within 0.5 % of the full-scale reading, and

7.1.2.5 For instruments operating in an automatic data-sampling mode during scan, sampling capability of at least 100 data points per second.

NOTE 3—The probe-sensing principle may be capacitive, optical, or any other noncontacting means suitable for determinating the separation between probe and silicon surface; noncontacting is specified to prevent the probe from deflecting the specimen wafer.

NOTE 4—The indicator unit may conveniently incorporate (*1*) means



	Dimensions, inches (mm)		
Nominal Slice Diameter	*X*	*Y*	*Z*
2.000 (50.80)	1.750 (44.45)	2.515 (63.88)	4.00 (101.6)
3.000 (76.20)	2.750 (69.85)	3.525 (89.54)	5.00 (127.0)
3.150 (80.00)	2.900 (73.65)	3.669 (93.20)	5.15 (130.8)
3.543 (90.00)	3.293 (83.65)	4.063 (103.20)	5.54 (140.8)
3.937 (100.00)	3.687 (93.65)	4.457 (113.20)	5.94 (150.8)
4.921 (125.00)	4.671 (118.65)	5.441 (138.20)	6.92 (175.8)
5.906 (150.00)	5.656 (143.65)	6.425 (163.20)	8.00 (203.2)
7.874 (200.00)	7.624 (193.65)	8.394 (213.20)	10.25 (260.4)

FIG. 1 Reference Ring

for calculating and storing sums or differences of paired displacement measurements and for identifying the maximum and minimum values of these quantities, (*2*) means for zero-reading adjustment, and (*3*) switch-selectable display of stored calculated values, individual probe measurements, and the like. The display may be digital or analog (dial); digital readout is recommended to eliminate interpolative errors on the part of the operator.

7.1.3 *Guide*—Means for restricting the motion of the reference ring so that the probe mounting axis does not approach closer to the edge of the specimen slice than 0.267 in. (6.78 mm) except at the parking position.

NOTE 5—Depending on the design of the apparatus, a matching guide may be required for each reference ring.

7.1.4 *Surface Plate*, granite, with a working surface at least large enough to accommodate the largest ring to be used, meeting the requirements of Laboratory Grade AA as given in Federal Specification GGG-P 463C, and with provision for accommodating the lower probe mount.

7.2 *System Mechanical Parallelism*—With the reference ring in position on the surface plate, the distance between the top of each pad and the upper surface of the plate shall be equal to within 40 μin. (1.0 μm).

7.3 *Set-up Thickness Masters*, covering a range equal to the nominal thickness of the wafer to be tested ±0.005 in. (or 125 μm), in approximately 0.002-in. (or 50-μm) steps (a total of 6 masters). Each master shall have surfaces flat to within 10 μin. (0.25 μm) and a thickness variation no greater than 50 μin. (1.25 μm). The thickness of each master shall be known to within 50 μin. (1.25 μm). The diameter of each master shall be suitable for the ring with which it will be used.

NOTE 6—Silicon wafers satisfying the above requirements may be used as set-up thickness masters.

7.4 *Precision Metal Flat*, of the same nominal diameter as the wafer to be tested and with one surface flat to 8 μin. (or 0.2μm) TIR, maximum. The thickness of the flat shall be such as to permit the flat to be placed and measured in the specimen position (see 9.2).

8. Sampling

8.1 This test method is nondestructive and may be used on either a 100% or a sampling basis.

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

9. Calibration and Standardization

9.1 Through measurements on set-up thickness masters sized according to the nominal diameter of the intended specimen wafer (see 7.2), calibrate and qualify the apparatus as follows:

9.1.1 If not already assembled, assemble the apparatus with the selected reference ring, corresponding to the intended specimen size, on the surface plate and the guide (Note 5) in position to limit ring movement. Make sure that the probes are in the parking position and that the position is away from the operator (see Fig. 2).

9.1.2 Make, record, and analyze measurements on each selected setup thickness master in turn, in accordance with the manufacturer's instructions or in accordance with the sections on procedure and calculations (Sections 10 and 11). Position the ring so that the probes are in the parking position before inserting or removing a master.

9.1.3 Construct a plot of measured thickness of each master as a function of known thickness. Draw a straight line through the end points. At each end point, plot two additional points representing values of + 0.5 % and − 0.5 % of the end point values. Draw a limit line through the two + 0.5 % values. Draw another limit line through the two − 0.5 % values. Observe the plotted points. If all points fall on or within the limit lines, accept the apparatus as satisfying the linearity requirement for the test (see Fig. 3).

9.2 Verify that the specified requirement is met for parallelism of the plane defined by the reference ring and the working surface of the surface plate.

9.2.1 Set up the equipment to accept the flat. Insert the precision metal flat in the specimen position (if one side of the flat is known to be flatter than the other, insert the flat with that side facing the surface plate).

9.2.2 Measure and record the distance between the bottom probe and the bottom surface of the precision flat as the flat is scanned in accordance with the pattern shown in Fig. 3. Remove the flat.

9.2.3 Inspect the recorded distance values and calculate the difference between the maximum and minimum value.

9.2.4 If the difference calculated in 9.2.3 is less than or equal to 60 µin. (1.5 µm), accept the apparatus as satisfying the parallelism requirement.

NOTE 7—The value 60 µin. (1.5 µm) represents the total system transfer error of the reference ring together with the surface plate and is intentionally greater than the tolerance of 40 µin. (1.0 µm) given for the parallelism of the defined plane of the reference ring and the bottom surface of the ring.

10. Procedure

10.1 If not already assembled, assemble the apparatus with the selected reference ring corresponding to the intended specimen size on the surface plate and the matching guide in position to limit ring movement. Make sure that the probes are in the parking position and that the position is away from the operator (see Fig. 2).

10.2 Place the test specimen on the support pads with the primary flat parallel with the flat orientation line and with the periphery of the test specimen against the two guide pins closest to the probe parking position.

10.3 Move the ring on the surface plate until the probes are at the starting position of the scan.

10.4 Reset the indicator.

10.5 Move the reference ring on the surface plate to scan the probes along the curved and straight segments 1 through 7 (see Fig. 4).

10.6 Record, in inches or micrometres, the individual displacements of the top and bottom surfaces at selected points along the scan pattern or, for direct-reading instruments, the difference between the largest and smallest of the differences or sums of the paired displacements, depending on whether warp (differences) or TTV (sums) is being measured.

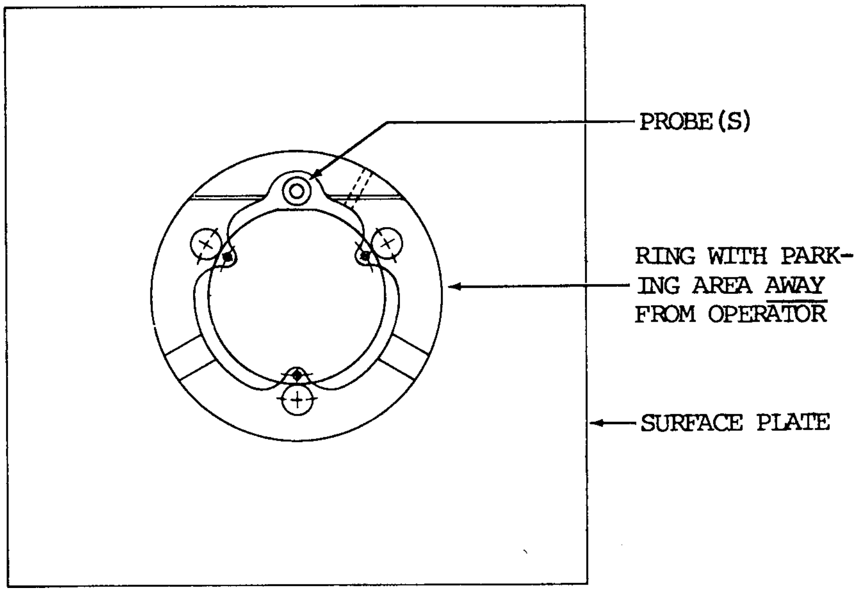


FIG. 2 Orientation of Reference Ring

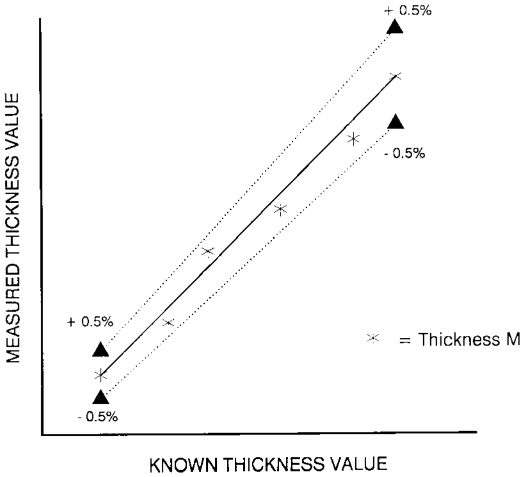


FIG. 3 Thickness Gage Linearity Check

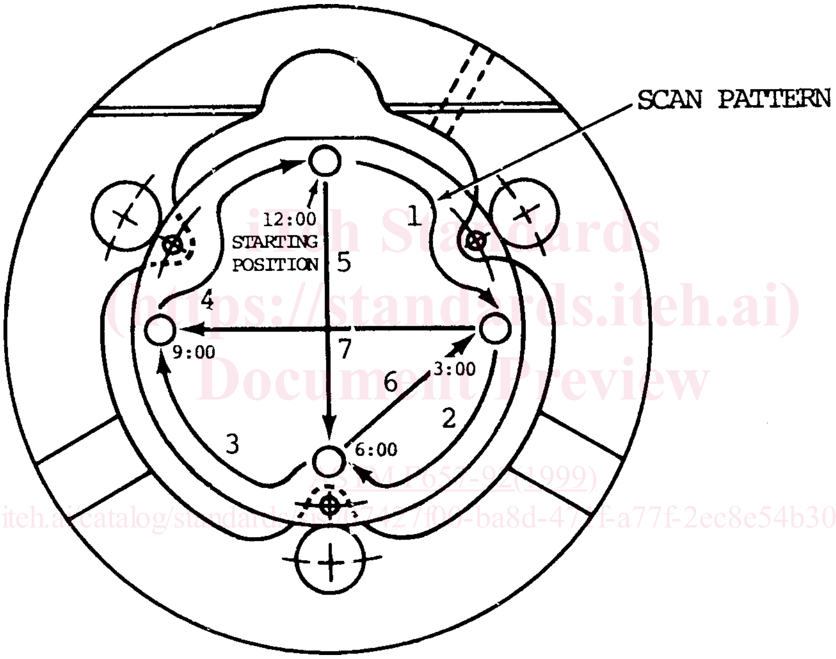


FIG. 4 Measurement Scan Pattern

10.7 For referee measurements only, repeat 10.4 through 10.6 nine more times.

10.8 Position the ring so that the probes are in the parking position and remove the specimen.

10.9 Repeat 10.2 through 10.8 for each wafer to be measured.

11. Calculation

11.1 Unless the instrument is direct reading, calculate for each wafer the difference between each pair of displacement values a and b and inspect the differences to identify the maximum and minimum difference values. Calculate the warp or TTV in inches or micrometres according to the relation:

$$\text{warp} = \frac{1}{2}[(b - a)_{\max} - (b - a)_{\min}] \quad (1)$$

$$TTV = (b + a)_{\max} - (b + a)_{\min} \quad (2)$$

where:

a = distance between the top surface of the wafer under test and the upper probe, in. (or µm),

b = distance between the bottom surface of the wafer under test and the lower probe, in. (or µm),

max denotes the largest value of the difference or sum, and min denotes the smallest value of the difference or sum.

11.2 For routine measurements, record the calculated warp or TTV.

11.3 For referee measurements, calculate each measured warp or TTV from Eq 1 or Eq 2, respectively, and then calculate the mean value and standard deviation. Record the mean value as the warp or TTV, as appropriate.

12. Report

12.1 Report the following information:

12.1.1 Date of test,

12.1.2 Identification of operator,

12.1.3 Identification of measuring instruments,

12.1.4 Lot identification, including nominal diameter and thickness,

12.1.5 Description of sampling plan, and

12.1.6 Warp or TTV (or both) of each wafer measured, in. (or µm).

12.2 For referee tests the report shall also include the standard deviation of the warp or TTV (or both) of each wafer measured, in. (or µm).

13. Precision and Bias

13.1 A round-robin experiment was conducted to estimate the precision of this test method.[5] Each of 11 laboratories was to perform three measurements on five 100-mm and five 125-mm diameter polished wafers. The wafers in each set of five had warp values from about 6 to about 40 µm, and TTV values from about 1 to about 5 µm.

13.2 Three laboratories used warp measuring equipment that did not conform to the requirements of this test method and one additional laboratory did not supply warp data. Two laboratories used TTV measuring equipment that did not conform to the requirements of this test method. Data from these laboratories were excluded from the analysis.

13.3 Based on warp results from seven laboratories and TTV results from nine laboratories, the repeatability (within laboratory) is estimated to be 1.45 ± 0.42 µm and 0.92 ± 0.20 µm for warp and TTV, respectively. No significant difference was noted between measurements on 100- and on 125-mm diameter wafers. There was no significant trend in repeatability with measured value (see Fig. 4). The reproducibility (between laboratories) is estimated to be 5.25 ± 3.19 µm and 3.25± 0.92 µm for warp and TTV, respectively. In this case, there was some increase in the value of warp reproducibility as the warp value increased and a less pronounced increase in the value of TTV reproducibility as the TTV value increased (see Fig. 5).

13.4 No statement of bias can be made because there are no reference standards against which the result of this measurement can be compared.

14. Keywords

14.1 measurement of warp and total thickness variation, (TTV); noncontact scanning; silicon wafers; thickness variation; warp

---

[5] Supporting data are available from ASTM Headquarters. Request RR: F-1-1005.