SEMI MF1390-0218 (Reapproved 1023)
TEST METHOD FOR MEASURING BOW AND WARP ON SILICON WAFERS BY AUTOMATED NONCONTACT SCANNING

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NOTICE: Paragraphs entitled 'NOTE:' are not an official part of this Standard or Safety Guideline and are not intended to modify or supersede the official Standard or Safety Guideline. These have been supplied by the global technical committee to enhance the usage of the Standard or Safety Guideline.

1 Purpose

1.1 Bow and warp can significantly affect the yield of semiconductor device processing.

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

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

1.4 This Test Method is suitable for measuring the bow and warp 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 bow and warp of wafers during device processing.

2 Scope

2.1 This Test Method covers a noncontacting, nondestructive procedure to determine the bow and warp of clean, dry semiconductor wafers.

2.2 This Test Method employs a two-probe system that examines both external surfaces of the wafer simultaneously.

NOTE 1: Although bow and 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. In all cases, warp is a zero or positive quantity while bow is a signed quantity (positive or negative).

2.3 The Test Method is applicable to wafers 50 mm or larger in diameter, and approximately 100 µm and larger in thickness, independent of thickness variation and surface finish, and of gravitationally induced wafer distortion.

2.4 This Test Method is not intended to measure the flatness of either exposed silicon surface. Bow and warp are measures of the distortion of the median surface of the wafer.

2.5 This Test Method measures bow and warp of a wafer corrected for mechanical forces applied during the test. Therefore, the procedure described gives the unconstrained value of bow and warp.

2.6 This Test Method includes several methods for canceling gravity-induced deflection which could otherwise alter the shape of the wafer.[1]

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

[1] 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.

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3 Limitations

3.1 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 non-repetitive and repetitive system mechanical translations. Failure to provide such corrections may cause errors.

3.2 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 in gravity induced deflection for differences in diameter and thickness are shown in Related Information 1. If the crystal orientation of the sample to be measured differs from the crystal orientation of the gravity-compensation wafer, then the measured bow and warp values may differ from the actual bow and warp values by up to 15%. Error tables for fiducial variation have not been generated.

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

3.4 Mechanical variations in wafer holding devices between systems may introduce measurement differences. This test method allows the use of a variety of wafer holding devices (refer to ¶ 7.1.4.1); results obtained with different geometrical configurations of wafer holding device on the same test samples may differ.

3.5 Most equipment systems capable of this measurement have a definite range of wafer thickness combined with bow or warp (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 over-range signal can be used to alert the operator and measurement data examiners to this event.

3.6 The quantity of data points and their spacing may affect the measurement results. This Test Method does not specify the data point spacing (refer to ¶ 7.1.4.2); results obtained with different data point spacings on the same test samples may differ.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI M1 — Specification for Polished Single Crystal Silicon Wafers

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI M59 — Terminology for Silicon Technology

SEMI MF1530 — Test Method for Measuring Flatness, Thickness, and Thickness Variation on Silicon Wafers by Automated Noncontact Scanning

4.2 *ASTM® Standards*[2]

ASTM E691 — Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

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

5 Terminology

5.1 Terms relating to silicon and other semiconductor are defined in SEMI M59.

5.2 *Definitions*

5.2.1 Bow_{BF} — the algebraic difference between the corrected median surface at the center of the wafer to a least squares reference plane.

5.2.2 Bow_{3P} — the algebraic difference between the corrected median surface at the center of the wafer to a 3-point reference plane.

[2] ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA; Telephone: +1.610.832.9585, Fax: +1.610.832.9555, http://www.astm.org. ASTM trademark is owned by ASTM International.

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6 Summary of Test Method

6.1 A calibration procedure is performed to set the instrument's scale factor and other constants. If the representative wafer inversion method is used for gravity correction, the calibration procedure also determines the mechanical signature of the instrument and the effect of gravity on the wafer.

6.2 The wafer is supported by a small-area chuck with front surface up.

6.3 Both external surfaces are simultaneously scanned along a prescribed pattern by an opposed pair of probes to obtain a set of values of the distances between each surface and the nearest probe. In each case, both members of the pair of distances is taken at the same value of the x and y coordinates.

6.4 The paired displacement values are used to construct the median surface.

6.5 A correction for gravity effects on the median surface is made either by subtracting a gravity correction obtained (1) from measurements on a representative wafer or (2) from theoretical considerations or by repeating the scan with the wafer inverted.

6.6 A least-squares reference plane is constructed from the corrected median surface.

6.7 The reference plane deviation (RPD) is calculated at each measured pair of points.

6.8 Warp is reported as the algebraic difference between the most positive RPD and the most negative RPD to a least squares reference plane.

6.9 Bow_{BF} is reported as the RPD at the center of the wafer to a least squares reference plane.

6.10 A 3-point reference plane is constructed from the corrected median surface.

6.11 Bow_{3P} is reported as the algebraic difference between the corrected median surface and the 3-point reference plane at the center of the wafer.

7 Apparatus

7.1 *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.

7.1.1 The equipment shall be direct reading with all necessary calculations performed internally and automatically as outlined in ¶ 11.2.

7.1.2 The equipment shall be equipped with an over-range signal.

7.1.3 Instrument data reporting resolution shall be 100 nm or smaller.

7.1.4 The measuring equipment contains the following subsystems:

7.1.4.1 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 nature and size of the wafer holding device shall be agreed upon between the parties to the test.

7.1.4.2 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 data gathering over a prescribed scan pattern covering the entire fixed quality area. Data point spacing to be used shall be agreed upon between the parties to the test.

7.1.4.3 Probe assembly with paired noncontacting displacement-sensing probes, probe supports, and indicator unit (refer to Figure 1).

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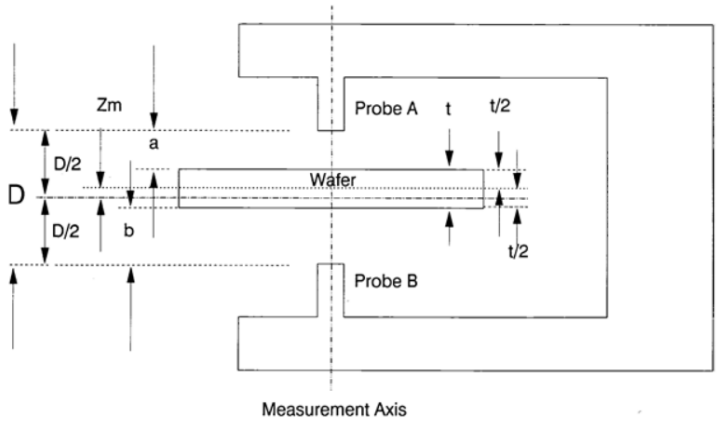

Figure 1
Schematic View of Wafer, Probes, and Fixture

7.1.4.3.1 The probes shall be capable of independent measurement of the distances *a* and *b* between the probed site on each surface of the sample wafer and the nearest probe surface.

7.1.4.3.2 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.

7.1.4.3.3 The common axis of these probes is the measurement axis.

7.1.4.3.4 The probe separation *D* shall be kept constant during calibration and measurement.

7.1.4.3.5 Displacement resolution shall be 100 nm or smaller.

7.1.4.3.6 The probe sensor size shall be 4 mm × 4 mm, or other value to be agreed upon between the parties to the test.

7.1.4.3.7 Measuring equipment employing either the Representative Wafer Inversion Method or the Sample Wafer Inversion Method 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.

8 Materials

8.1 *Set-Up Masters* — Suitable to accomplish calibration and standardization as recommended by the equipment manufacturer.

8.2 *Reference Wafer* — With a reference warp value ≤20 µm that is used to determine the level of agreement between the warp value obtained by the measuring equipment under test and the reference warp value (refer to § 9).

8.3 *Representative Wafer* — Required only if the Representative Wafer Inversion Method is used for the gravity correction. A representative wafer shall be identical in nominal diameter, nominal thickness, fiducials, composition, and crystalline orientation to those being measured. Its warp need not be known.

9 Suitability of Measuring Equipment

9.1 Determine the suitability of the measuring equipment with the use of a reference wafer and its reference warp value in accordance with the procedures of § 9.2, 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.

9.1.1 The reference warp value is the average of a number of values obtained for that wafer over a number of 'passes' (repeat measurements). The reference wafer is measured on the measuring equipment under test and its reference warp value is compared against the measured warp value. The acceptable level of the agreement between the reference and measured warp values is to be agreed upon by the parties to the test.

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