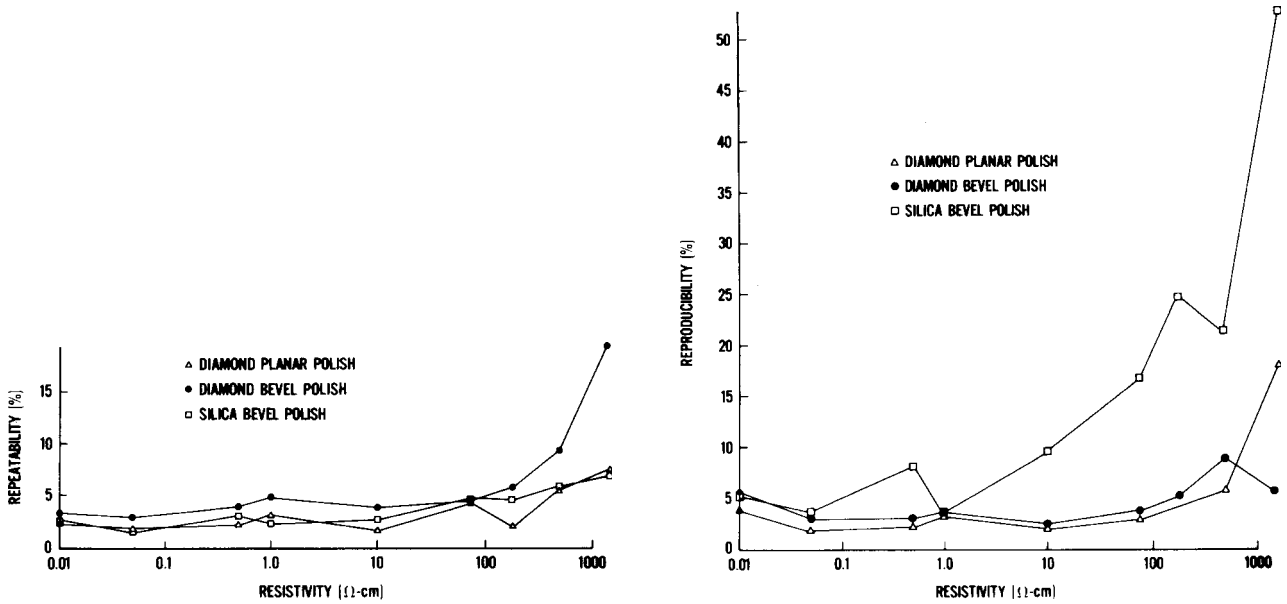
Lab #	*Specimen Identification*													
	C	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*N*	*P*	*R*	*T*
3 20 g	2.09 kΩ 7.3% 2.3%	22.1 kΩ 4.7% 2.4%	749 kΩ 95.0% 7.1%	327 kΩ 20.0% 8.3%	857 Ω 3.7% 2.4%	22.4 kΩ 13.6% 1.5%	28.4 kΩ 8.7% 3.4%	43.9 Ω 2.3% 1.2%	5.88 Ω 1.6% 1.7%	21.8 kΩ 13.5% 3.0%	270 kΩ 4.9% 5.7%	20.4 Ω 1.6% 1.0%	904 Ω 2.6% 1.8%	291 kΩ 11.4% 4.4%
3 20 g baked	1.73 kΩ 9.8% 2.4%	15.3 kΩ 6.7% 1.7%	606 kΩ 27.0% 8.0%	439 kΩ 27.0% 4.0%	75.6 Ω 7.6% 2.6%	18.7 kΩ 9.5% 1.8%	16.8 kΩ 6.9% 1.7%	45.9 Ω 4.5% 1.5%	6.01 Ω 1.1% 2.3%	20.0 kΩ 8.7% 1.8%	403 kΩ 40.0% 5.1%	20.5 Ω 2.5% 1.0%	803 Ω 5.5% 1.1%	229 kΩ 9.7% 6.5%
7 Instru- ment 1	2.07 kΩ 5.4% 3.5%	15.6 kΩ 2.4% 2.4%	1.38 MΩ 38.0% 7.8%	665 kΩ 25.0% 5.7%	1.31 kΩ 14.0% 4.7%	20.6 kΩ 14.7% 2.1%	22.1 kΩ 5.3% 4.7%	69.4 Ω 9.7% 4.4%	10.5 Ω 14.0% 5.8%	22.9 kΩ 7.8% 4.7%	337 kΩ 24.0% 3.6%	30.7 Ω 12.0% 1.9%	1.61 kΩ 1.1% 4.6%	181 kΩ 13.0% 3.7%
7 Instru- ment 2	2.43 kΩ 4.7% 2.5%	14.2 kΩ 4.9% 2.1%	1.40 MΩ 30.0% 5.6%	734 kΩ 18.0% 3.4%	1.11 kΩ 5.3% 3.9%	22.4 kΩ 7.66% 1.8%	14.4 kΩ 5.3% 3.5%	58.2 Ω 1.5% 1.8%	9.64 Ω 20.0% 4.1%	23.8 kΩ 7.5% 2.2%	303 kΩ 23.0% 3.5%	35.0 Ω 4.2% 3.2%	832 Ω 0.7% 3.3%	186 kΩ 4.90% 2.9%
15	1.95 kΩ 4.4% 2.3%	13.5 kΩ 6.2% 2.5%	29.7 MΩ 73.0% 6.0%	2.02 MΩ 33.0% 3.2%	641 Ω 11.0% 2.6%	16.0 kΩ 3.5% 0.8%	8.00 kΩ 5.6% 1.2%	31.9 Ω 2.3% 1.8%	4.64 Ω 1.2% 0.6%	22.1 kΩ 3.8% 2.1%	608 kΩ 16.9% 2.7%	15.6 Ω 1.2% 0.7%	647 Ω 4.7% 2.3%	304 kΩ 16.5% 2.6%
11	3.51 kΩ 11.0% 3.5%	1.37 MΩ 18.0% 9.0%	2.66 MΩ 49.0% 10.0%	1.42 MΩ 50.0% 6.0%	260 kΩ 22.0% 4.6%	33.8 kΩ 16.0% 2.7%	235 kΩ 16.0% 5.8%	1.19 kΩ 26.0% 6.5%	22.6 Ω 36.0% 7.4%	27.5 kΩ 5.1% 2.9%	585 kΩ 33.0% 8.1%	89.9 Ω 33.0% 5.0%	5.67 kΩ 28.0% 4.4%	327 kΩ 14.0% 3.5%
Aluminum-Oxide Lap[#1]														
10	1.22 kΩ 3.3% 6.6%	9.79 kΩ 1.6% 12.0%	5.26 MΩ 18.0% 36.0%	981 kΩ 7.9% 8.9%	53.0 Ω 8.2% 10.0%	13.0 kΩ 2.8% 5.3%	10.7 kΩ 4.8% 10.0%	41.6 Ω 2.3% 7.3%	4.48 Ω 6.6% 6.2%	10.5 kΩ 0.8% 6.8%	191 kΩ 3.6% 8.7%	17.1 Ω 2.1% 7.2%	588 Ω 2.4% 6.2%	89.1 kΩ 4.2% 7.2%

[#1] In each box, the first value is grand average spreading resistance value (for the record only, not used in analysis of test); second entry is "reproducibility," σ_R, that is, the percent relative standard deviation of four averages (of 25 measurements each), the third entry is the "repeatability," σ_r, that is, the average of four relative standard deviations (of sets of 25 measurements).

[#2] Reported graphical data and averages; σ_r could not be calculated.



(b) Reproducibility

(a) Repeatability

Figure R1-1
Round-Robin Averages as a Function of Resistivity and Specimen Preparation

RELATED INFORMATION 2
PROCEDURE TO ESTIMATE TOTAL RANDOM ERROR

NOTICE: This related information is not an official part of SEMI MF525. It was derived from information developed during the original preparation of the standard in ASTM Committee F-1 on Electronics in 1977. This related information was approved for publication by full letter ballot procedures.

R2-1 Estimates of repeatability, σ_r, and reproducibility, σ_R, may be combined as follows to estimate the total random error, σ_t, to be experienced in the spreading resistance measurements of a single test specimen by a laboratory in control of the measurement process.

$$\sigma_t = \sqrt{\frac{\sigma_R^2}{n_p} + \frac{\sigma_r^2}{n_p n_r}} \tag{R2-1}$$

where:

σ_r = repeatability for the chosen specimen preparation (see Table 1),

σ_R = reproducibility for the chosen specimen preparation (see Table 1),

n_p = number of specimen preparations, and

n_r = number of measurement replications that are performed by the laboratory after each specimen preparation.

R2-2 An additional source of random error, due to the variability of the four-point probe measurement of resistivity, must be considered when determining the total random error uncertainty, σ_c, of a point on the spreading resistance calibration relation. Although this additional term is an error in resistivity value, not in spreading resistance value, it is a small additional error, and a reasonable simplifying approximation for the combined random error uncertainty for a calibration specimen is:

$$\sigma_c = \sqrt{\frac{\sigma_R^2}{m_p} + \frac{\sigma_r^2}{m_p m_r} + s^2} \tag{R2-2}$$

where:

σ_r = repeatability for the chosen specimen preparation (see Table 1),

σ_R = reproducibility for the chosen specimen preparation (see Table 1),

s = estimate of four-point probe measurement precision given in SEMI MF84 and summarized in Table R2-1,

m_p = number of preparation replications on the calibration specimens, and

m_r = number of spreading resistance measurement replications on the calibration specimens.

Table R2-1 Precision (Random Error) of Four-Point Probe Resistivity Measurement that Contributes to Spreading-Resistance Calibration Error

Specimen Resistivity, Ω·cm	*Three-Sigma Four-Point Probe Precision from SEMI MF84*	*One-Sigma Precision to be used for* s *in Equation R2-2*
0.0008 to 120	2%	0.7%
120 to 500	5%	1.7%
500 to 2000	15%	5%

R2-3 *Propagation of Random Error and Uncertainty of Resistivity Values When Determining Test Specimen Resistivity by Calibrated Spreading Resistance Measurements*

R2-3.1 If the entire calibration procedure (or just a part containing specimens of a limited range of resistivity values of interest) is performed once for each test specimen measured, the random errors for the measurement of both test and calibration specimens are statistically independent and can be added in root-mean-square fashion to estimate the total random error uncertainty, s_T, in the derived resistivity value of a test specimen:

$$s_T = \sqrt{\sigma_t^2 + \sigma_c^2} \tag{R2-3}$$

R2-3.1.1 The associated 95% confidence interval for resistivity values derived from spreading resistance measurements, considering only random sources of error, is given by $S_T = 1.96\ s_T$, or approximately by $2s_T$.

R2-3.2 If the calibration procedure is performed once, and a number of test specimens are then measured before calibration is performed again, the random errors are not independent and the errors cannot be combined in the above fashion. In this case, the "random" errors on the calibration specimen act as short-term systematic errors: the errors for some calibration specimens are on the high side, the errors for others are on the low side, and they will be fixed until the next calibration. If this situation obtains, a reasonable estimate of the 95% confidence interval for derived resistivity values, due to what are normally random errors, is given by:

$$S'_T \approx 2(\sigma_t + \sigma_c) \tag{R2-4}$$

where σ_t and σ_c are obtained from Equations R2-1 and R2-2.

R2-4 *Examples of Use of Propagation of Error Equations to Estimate the 95% Confidence Limits (Due to Random Error Only) for the Resistivity Values of a Test Specimen*

R2-4.1 *Assumptions* — One preparation each of test specimens and of calibration specimens ($n_p = m_p = 1$); ten measurements are taken and averaged on the calibration specimens closest in resistivity to the test specimen ($m_r = 10$; five measurements are taken and averaged on the test specimen ($n_r = 5$); the test specimen has a resistivity of approximately 1 Ω·cm: $s = 0.7\%$; diamond bevel polishing is used ($\sigma_r = 6.3\%$, $\sigma_R = 6.2\%$).

R2-4.2 *Case I* — Calibration measurements are *always* taken prior to measurement of each test specimen.

$$\sigma_t = \sqrt{\frac{0.063^2}{1} + \frac{0.062^2}{1\times 5}} = 0.0688 = 6.88\%$$

$$\sigma_c = \sqrt{\frac{0.063^2}{1} + \frac{0.062^2}{1\times 10} + 0.007^2} = 0.0664 = 6.64\%$$

$$S_T \approx 2\sqrt{0.0688^2 + 0.0664^2} = 0.191 = 19.1\%$$

R2-4.3 *Case II* — Calibration measurements are not taken prior to each test specimen measurement.

$$S'_T \approx 2(0.0688 + 0.0664) = 0.270 = 27.0\%$$

R2-5 Equations R2-1 through R2-4 may also be used to estimate the random error in the measurement process based only on measurements in a single laboratory. In this case the values of σ_r and σ_R to be used must be determined through appropriate replicate experiments using the desired measurement conditions in that laboratory.

RELATED INFORMATION 3
SOURCES OF SYSTEMATIC ERROR

NOTICE: This related information is not an official part of SEMI MF525. It was derived from information developed during the original preparation of the standard in ASTM Committee F-1 on Electronics in 1977. This related information was approved for publication by full letter ballot procedures.

R3-1 In addition to random errors, there are a number of sources of systematic error which can be identified but which cannot be estimated here; their estimation must be done by the individual laboratory.

R3-2 *Calibration Specimen Nonuniformity* — The four-point probe method for measuring the resistivity of the calibration specimens responds to the average resistivity of a specimen over an area which is several times the total spacing of the four-point probe. Within this area there may be significant variation of resistivity. Spreading resistance measurements respond to the local resistivity of the calibration specimens. Calibration specimens shall therefore have uniform resistivity such that the resistivity assigned to the specimen by use of the four-point probe method satisfactorily represents the resistivity value at the location where spreading resistance calibration measurements will be taken; otherwise systematic errors are incurred in calibration.

R3-3 *Choosing a Model for the Calibration Relation* — The empirical relation between spreading resistance and resistivity values of the calibration specimens are commonly approximated by a number of different relations: single-piece log-log least-squares fit, piecewise log-log fit, and polynomial fit. The best form or model to fit the calibration data has not been established. Any of the chosen models may have significant high-side or low-side systematic errors at various resistivity values compared to the unknown “true” relation.

R3-4 *Loss of Control of the Spreading-Resistance Probes* — Wear, contamination, or other degradation of the probes may cause sudden shifts in measurement response at some or all resistivity values. Such shifts may not be accompanied by recognizable loss of measurement precision and merely add an additional systematic error between calibration and test specimen measurement values.

R3-5 *Loss of Control of Specimen Preparation Process* — Contamination of specimen-polishing materials or post-polishing chemicals as well as excess polishing-induced damage or unrecognized differences in technique such as applied pressure, specimen area, or post-polishing storage environment may cause undetected systematic errors in test or calibration specimen values.

SEMI MF657-0705
TEST METHOD FOR MEASURING WARP AND TOTAL THICKNESS VARIATION ON SILICON WAFERS BY NONCONTACT SCANNING

This test method was technically approved by the global Silicon Wafer Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on April 6, 2005. It was available at www.semi.org in June 2005 and on CD-ROM in July 2005. Original edition published by ASTM International as ASTM F 657-80. Last previous edition SEMI MF657-92 (Reapproved 1999).

1 Purpose

1.1 Warp and thickness variation of silicon wafers can significantly affect the yield of semiconductor device processing.

1.2 Knowledge of these characteristics can help the supplier and customer determine if the dimensional characteristics of a particular wafer satisfy given geometrical requirements.

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

1.4 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.

2 Scope

2.1 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.

2.2 The test method is applicable to circular silicon wafers from 50 mm (or 2.0 in.) to 200 mm in diameter, and 100 μm (or 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.

2.3 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. 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.

2.4 This test method measures warp and TTV of a wafer with no mechanical force except gravity 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.

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

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 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.

3.2 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.

3.3 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.

3.4 Running probes off the test specimen during the scan sequence gives false readings.

3.5 Any change in the reference plane during scanning produces 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.

3.6 Non-parallelism of the reference plane to the granite base surface produces an error in the indicated measurement proportional to the non-parallelism.

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

3.8 Vibration of the test specimen relative to the probe-measuring axis introduces error.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M59 — Terminology for Silicon Technology

4.2 *ANSI Standard*

ANSI/ASME B46.1 — Surface Texture (Surface Roughness, Waviness, and Lay)[1]

4.3 *Federal Standard*

GGG-P 463 C Surface Plate, Granite[2]

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

5 Terminology

5.1 *Definitions*

5.1.1 *median surface (of a semiconductor wafer)* — the locus of points in the wafer equidistant from the front and back surfaces.

5.1.2 Other terms relating to silicon technology are defined in SEMI M59.

6 Summary of Test Method

6.1 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.

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

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

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

7 Apparatus

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

1 American National Standards Institute, New York Office: 25 West 43rd Street, New York, NY 10036, USA. Telephone: 212.642.4900, Fax: 212.398.0023, Website: www.ansi.org.

2 Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094.

7.1.1 *Reference Ring* — Consisting of a closed base and three hemispherical support pads (see Figure 1); a different size ring is required for use with each diameter of wafer to be measured (see Table 1). Each reference ring shall be fabricated of a metal whose thermal coefficient of expansion shall not exceed 11×10^{-6}/°C (or 6×10^{-6}/°F) at laboratory temperatures; be at least 19 mm (or 0.75 in.) thick, with the bottom surface lapped flat to within 250 nm (or 10 μin.); have an outside diameter approximately 50 mm (or 2 in.) larger than the nominal 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 ±130 μm (or ±0.005 in) on the circumference of a circle whose diameter is 6.35 mm (or 0.250 in.) less than the nominal diameter of the wafer as given in SEMI M1. The support pads shall be fabricated from tungsten carbide, or from a material of the same or greater hardness, have a nominal diameter of 3.18 mm (or 0.125 in.), and project 1.59 ± 0.13 mm (or 0.0625 ± 0.0050 in.) 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 250 nm (or 10 μin.) measured with 0.8 mm (or 0.31-in) cutoff in accordance with ANSI/ASME B 46.1.

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 M1. The guide pins shall be at least 380 μm (or 0.015 in.) higher than the support pads (see Figure 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 Figure 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 1.55 to 5.75 mm (or 0.062 to 0.225 in),

7.1.2.2 Displacement resolution of 250 nm (or 10 μin) 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 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 wafer than 6.78 mm (or 0.267 in) 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 1.0 mm (or 40 μin.).

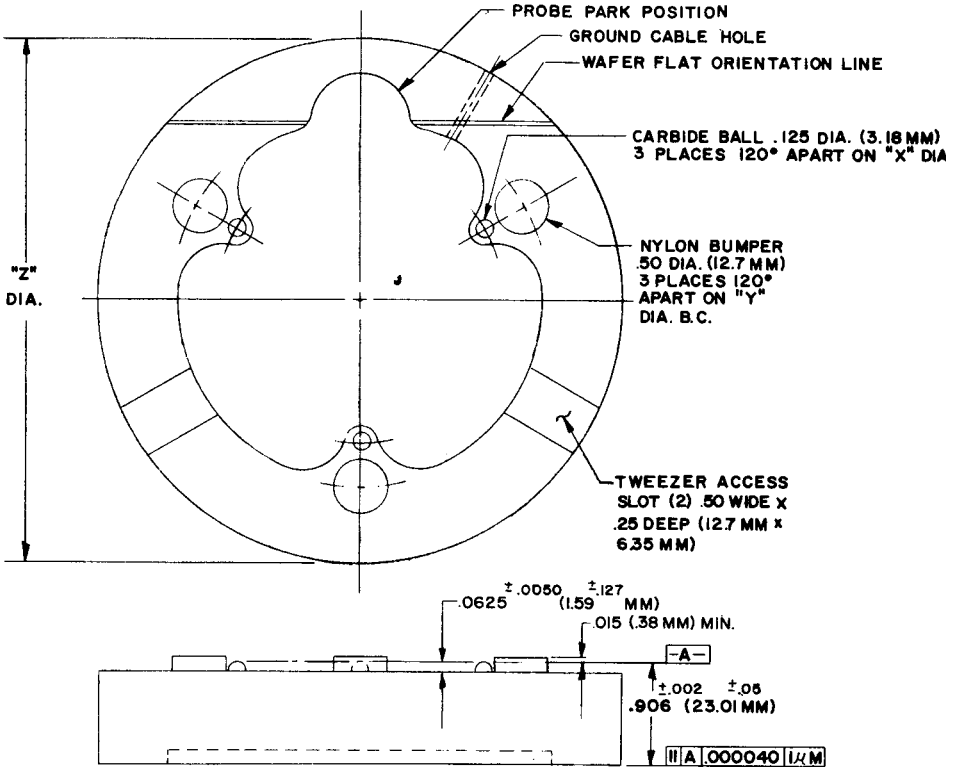


Figure 1
Reference Ring

Table 1 Dimensions of Reference Ring (see Figure 1)

Nominal Wafer Diameter	*X*		*Y*		*Z*	
	in.	*mm*	*in.*	*mm*	*in.*	*mm*
2 in.	1.750	44.45	2.515	63.88	≥4.00	≥101.6
3 in.	2.750	69.85	3.525	89.54	≥5.00	≥127.0
100 mm		93.65		113.20		≥150.0
125 mm		118.65		138.20		≥175.0
150 mm		143.65		163.20		≥200.0
200 mm		193.65		213.20		≥300.0

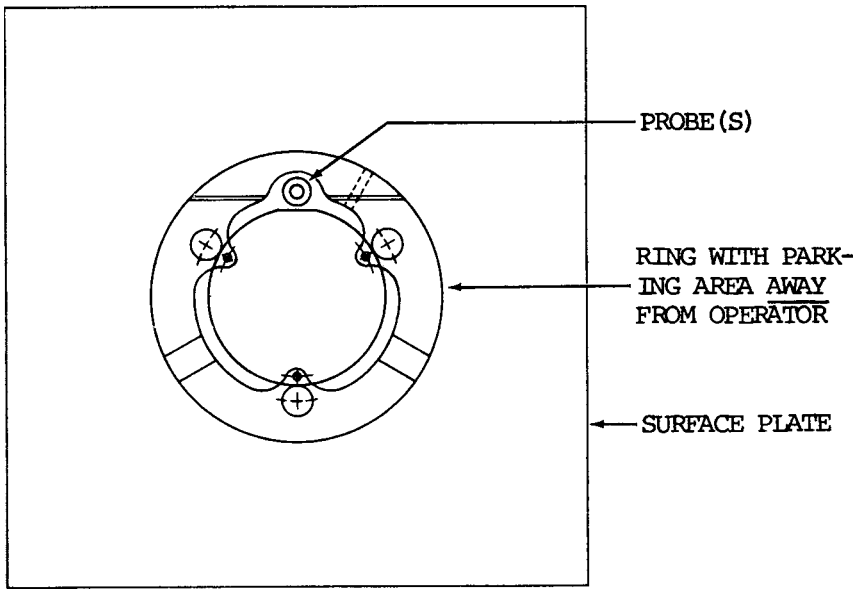


Figure 2
Orientation of Reference Ring

7.3 *Set-up Thickness Masters* — Covering a range equal to the nominal thickness of the wafer to be tested ±125 μm (or ±0.005 in.), in approximately 50 μm (or 0.002 in.) steps (a total of 6 masters). Each master shall have surfaces flat to within 250 nm (or 10 μin.) and a thickness variation no greater than 1.25 μm (or 50 μin.). The thickness of each master shall be known to within 1.25 μm (or 50 μin.). 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 0.2 μm (or 8 μin.) 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.

8.2 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 ¶7.3), 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 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 Figure 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 (§10 and Figure 4). 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 Figure 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 Figure 4. Remove the flat.

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

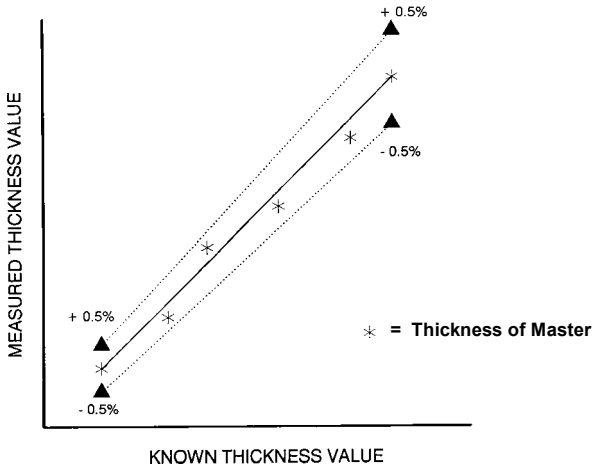


Figure 3
Thickness Gauge Linearity Check

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

NOTE 7: The value 1.5 μm (or 60 μin.) represents the total system transfer error of the reference ring together with the surface plate and is intentionally greater than the tolerance of 1.0 μm (or 40 μin.) 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 Figure 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 Figure 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.

10.7 For referee measurements only, repeat ¶¶10.4 through 10.7 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 Calculations

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 micrometers or inches according to the appropriate relation:

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

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

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 value(s) of warp or TTV or both.

11.3 For referee measurements:

11.3.1 Calculate each measured warp or TTV from Equation 1 or Equation 2, respectively.

11.3.2 Then calculate the mean value and standard deviation.

11.3.3 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 Location of test,

12.1.3 Identification of operator,

12.1.4 Identification of measuring instrument(s),

12.1.5 Lot identification, including nominal diameter and thickness,

12.1.6 Description of sampling plan, and

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

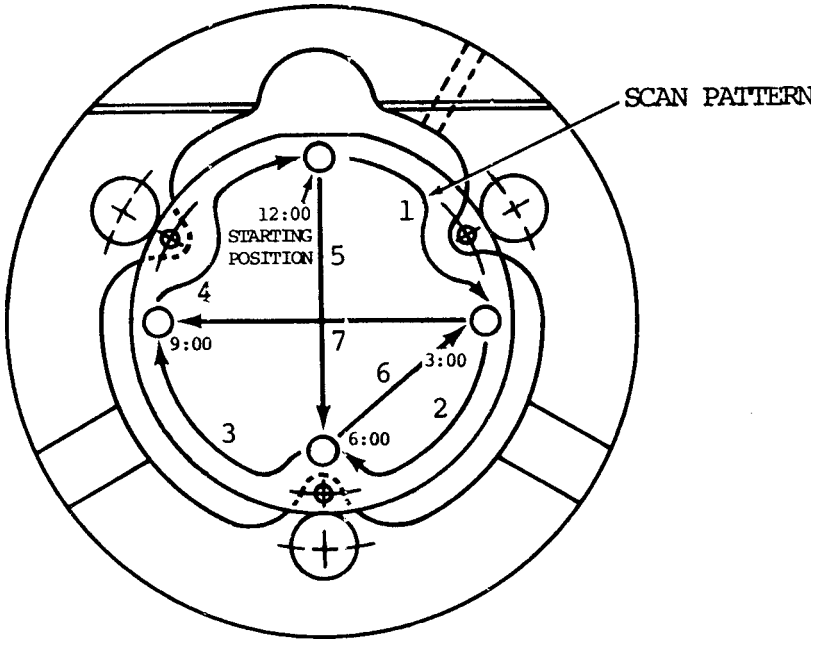


Figure 4
Measurement Scan Pattern

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

13 Precision and Bias

13.1 A round-robin experiment was conducted to estimate the precision of this test method.[3] 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 Figure 5).

13.4 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 Figure 6).

NOTE 8: In these figures, the numbers are identification numbers. The initial digit represents the approximate nominal diameter of the sample wafers in inches

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

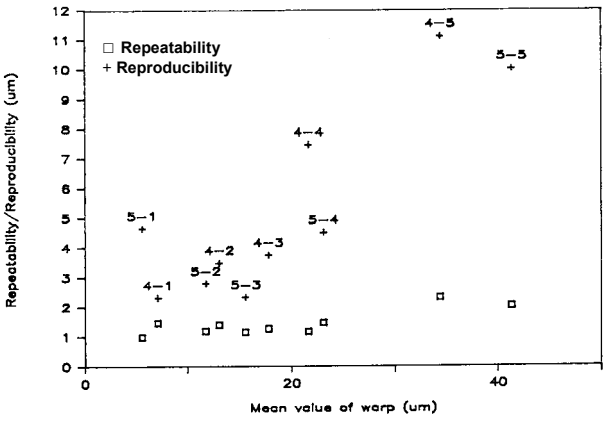


Figure 5
Repeatability and Reproducibility of Warp Values Determined by Interlaboratory Experiment

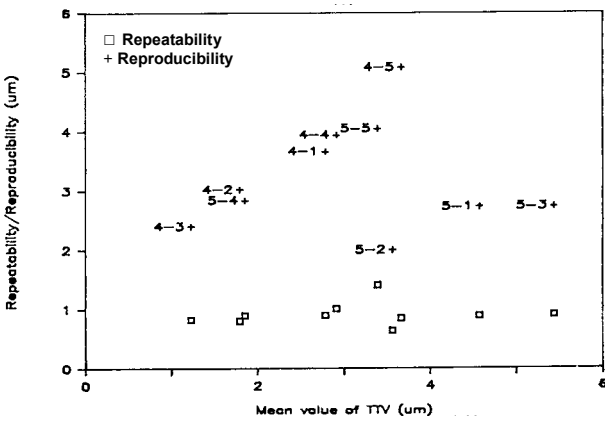


Figure 6
Repeatability and Reproducibility of TTV Values Determined by Interlaboratory Experiment

14 Keywords

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

3 Supporting data are available on request from SEMI Headquarters, 3081 Zanker Road, San Jose, CA, Telephone 408-943-7021, Fax: 408-943-7015, e-mail: standards@semi.org. Request International Standards Research Report 1005.

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SEMI MF671-0705
TEST METHOD FOR MEASURING FLAT LENGTH ON WAFERS OF SILICON AND OTHER ELECTRONIC MATERIALS

This test method was technically approved by the global Silicon Wafer Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on April 7, 2005. It was available at www.semi.org in June 2005 and on CD-ROM in July 2005. Original edition published by ASTM International as ASTM F 671-80. Last previous edition SEMI MF671-99.

1 Purpose

1.1 The length of fiducial flats is an important materials characteristic for determining the suitability of material for use in semiconductor processing.

1.2 Automatic wafer handling equipment widely used in semiconductor device manufacturing processes relies on identification and orientation of the primary flat to obtain correct alignment.

1.3 This test method is suitable for use in research, development, process control, quality assurance, and materials acceptance applications.

2 Scope

2.1 This test method covers techniques for determination of the length of the flatted portion of a wafer periphery.

2.2 This test method is intended primarily for use on electronic materials in the form of nominally circular edge-contoured wafers with flat lengths up to 65 mm. The precision of this test method has been established directly only for silicon wafers, but it is not expected to be material dependent.

2.3 This test method is suitable for referee measurement purposes and may be used for routine acceptance measurements when specified limits require test precision greater than can be obtained with hand held scale and unaided eye.

2.4 This test method is independent of surface finish.

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

NOTE 1: DIN 50441, Part 4, is a similar, but not equivalent method for determining flat length. In this method the flat length is calculated from a measurement of flat depth. This method does not provide any correction for rounding at the ends of the flat.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health guides and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 Some operations performed after slicing, such as mechanical edge grinding and chemical etching, may reduce profile definition at the ends of the flatted area.

3.2 Backlash in the micrometer head assemblies may result in erroneous readings.

3.3 Failure to maintain sharp focus on the sample comparator screen image during measurement can introduce errors.

3.4 Comparator optics may sometimes incorporate image-reversal elements, which result in image conditions opposite to those described by this test method.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M59 — Terminology for Silicon Technology

4.2 *ANSI Standard*

ANSI/ASQC Z1.4 — Sampling Procedures and Tables for Inspection by Attributes[1]

4.3 *ASTM Standard*

E 122 — Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[2]

4.4 *DIN Standard*

DIN 50441, Part 4, — Measurement or the Geometric Dimensions of Semiconductor Wafers: Diameter and Flat Depth of Wafers[3]

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

5 Terminology

5.1 *Definitions*

5.1.1 *offset* (*of the end region of a flat on a silicon wafer*) — a perpendicular deviation at either end region of a flat from the horizontal reference line, used to define the flat boundaries.

5.1.2 Other terms relating to silicon technology are defined in SEMI M59.

6 Summary of Test Method

6.1 The specimen is aligned on an optical comparator. One end of the projected image of the flat is positioned on a reference point on the viewing screen. The micrometer reading is recorded, and the stage is manipulated to scan to the opposite end of the flat where the micrometer reading is again recorded. Flat length is the difference between the first and second readings.

7 Apparatus

7.1 *Shadowgraph Comparator* — Equipped as follows:

7.1.1 *20× Optical System*,

7.1.2 *Viewing Screen* — With minimum diameter of 254 mm (10 in.), and

7.1.3 *Sample Stage* — Capable of minimum micrometer travel of 50 mm or 2 in. in the *x* direction and goniometer rotation in the *x-y* plane.

7.1.3.1 Stage travel in the *x* direction shall move the projected image horizontally on the viewing screen. Travel in the *y* direction shall move the projected image vertically on the viewing screen.

7.1.3.2 The *x* micrometer shall have graduations of 25 μm (0.001 in.) or smaller.

7.1.3.3 The *y* direction stage travel must be enough to show the flatted regions of the largest wafer to be tested, or about three-fifths of the nominal diameter of the largest wafer to be tested.

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1 American National Standards Institute, American National Standards Institute, New York Office: 25 West 43rd Street, New York, NY 10036, USA. Telephone: 212.642.4900, Fax: 212.398.0023, Website: www.ansi.org.

2 *Annual Book of ASTM Standards*, Vol 14.02, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Telephone: 610-832-9500, Fax: 610-832-9555, Website: www.astm.org.

3 Deutches Institut für Normung e.V., standards are available in both English and German editions from Beuth Verlag GmbH, Burggrafenstrasse 6, 10787 Berlin, Germany, Telephone: 49.30.2601-0, Fax: 49.30.2601.1263, Website: www.beuth.de.

7.1.4 An overlay, with reference lines perpendicular to each other intersecting at the center, and ten calibrated divisions on the vertical reference line above and below center, corresponding to 50 μm (0.002 in.) per division *at the sample location.* See Figure 1.

NOTE 2: For a 20× overlay, the calibration divisions on the overlay itself are 1 mm apart.

7.2 *Microscope Stage Micrometer* — On clear glass or plastic, the scale to be at least 1.3 mm (0.05 in.) long with 25 μm (0.001 in.) divisions.

7.3 *Machinists' Steel Scale* — 150 mm (or 6 in.) minimum length, graduated in 0.50 mm (0.02 in.) or 0.25 mm (0.01 in.).

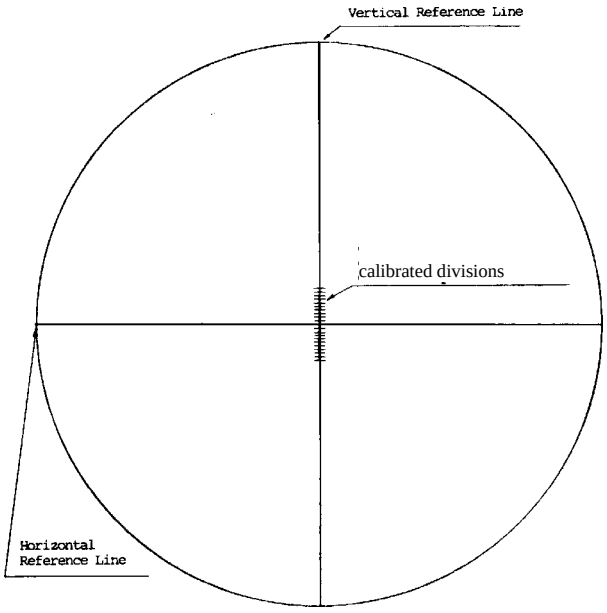


Figure 1
Overlay

8 Sampling

8.1 Unless otherwise specified, ASTM Practice E 122 shall be used. When so specified, appropriate sample sizes shall be selected from each lot in accordance with ANSI/ASQC Z1.4–1993. Inspection levels shall be agreed upon between the supplier and purchaser.

9 Calibration

9.1 *Comparator Optical Magnification*

9.1.1 Place the microscope stage micrometer on the comparator sample stage so that its projected image is at the center of the viewing screen.

9.1.2 With a steel scale on the viewing screen, count the number of 25 μm (0.001 in.) lines projected over a 25 mm (or 1 in.) distance. Divide the number into 1000 to obtain the actual magnification.

9.1.3 Magnification must be between 19.8 and 20.2 to be usable for this method.

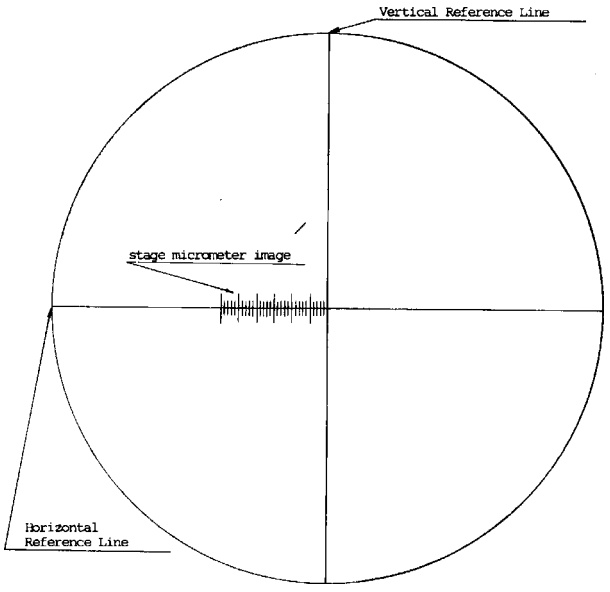


Figure 2
Calibration of the Horizontal Travel Comparator Stage

9.2 *Comparator Micrometer Travel — x Direction*

9.2.1 Set the *x*-travel micrometer to zero.

9.2.2 Align the projected image of the microscope stage micrometer such that the array of scale division lines is horizontal and the right most lines are all to one side of the vertical reference line on the viewing screen as in Figure 2.

9.2.3 Using the *x*-travel micrometer, scan the image of the microscope stage micrometer until the array has been transposed to the opposite side of the vertical reference line in an analogous manner.

9.2.4 Read the *x*-travel micrometer scale. This value should agree with the full-range value of the microscope stage micrometer scale within 25 μm (0.001). If the value does not agree, adjust or repair the micrometer.

10 Procedure

10.1 Mount the overlay (see Figure 1) on the viewing screen. Position the horizontal reference line approximately parallel to the floor.

10.2 Identify near the horizontal reference line the projected image of a point on the sample stage. A defect or a particle of dust will serve this purpose. This projected image should be no larger than one-half division on the overlay scale.

10.3 Align the horizontal reference line to the *x*-axis travel by repeatedly scanning the point identified in ¶10.2 and manipulating the overlay and the *x*-*y* movement of the sample stage. Alignment is achieved when this point is centered on the horizontal reference line when scanned from one edge of the viewing screen to the other.

10.4 Place the wafer on the stage so that the central portion of the projected image of the flat is centered on the viewing screen and is coincident with the horizontal reference line.

10.5 Visually fit the projected image of the flat to the horizontal reference line.

10.5.1 Scan from one end of the flat to the other using the *x*-axis micrometer.

10.5.2 If the apparent shape of the flat is convex, adjust the goniometer and micrometers, while repeating ¶10.5.1 such that the high point is contacting the reference line and the low points are equidistant from the reference line. See Figure 3.

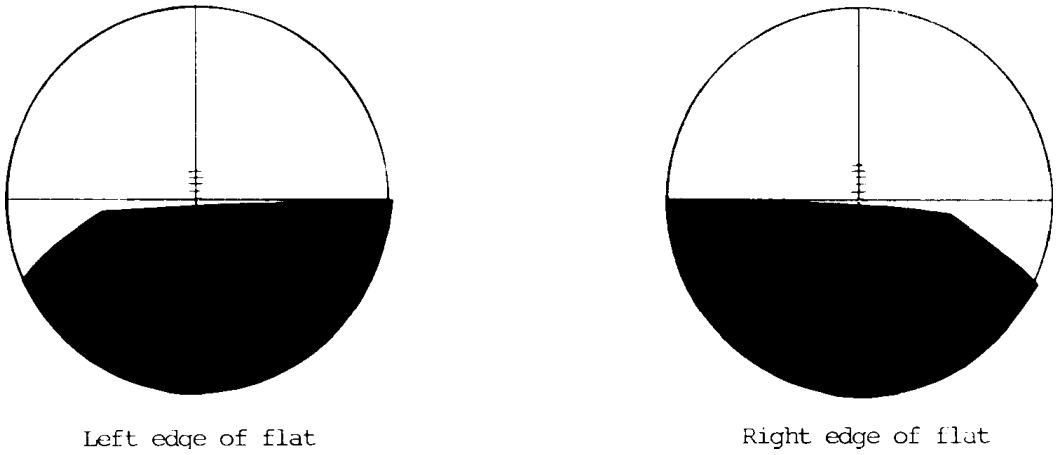


Figure 3
Aligning a Convex Shaped Flat

10.5.3 If the apparent shape of the flat is concave, adjust the goniometer and micrometers, while repeating ¶10.5.1 such that the high points are contacting the reference line. See Figure 4.

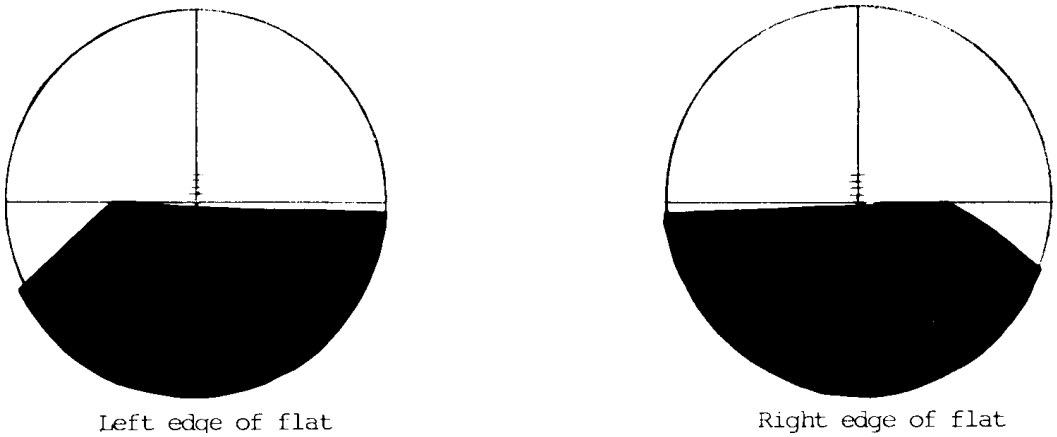


Figure 4
Aligning a Concave Shaped Flat

10.6 Adjust the projected image of the flat using the *x*-axis micrometer so that the left end is coincident with the intersection of the vertical and horizontal reference lines.

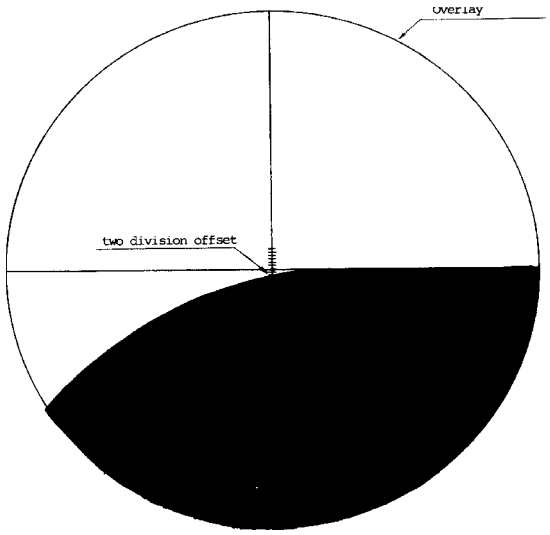
10.7 To determine the location of the end of the flatted region, use the point at which the wafer image on the comparator screen is one division away from the horizontal reference line. This corresponds to an offset of 50 μm (0.002 in.) on the wafer. (See Figure 5.)

10.8 Record the micrometer reading to the nearest 25 μm or 0.001 in. as E_l (left) on the data sheet (see example in Figure 6).

10.9 Scan the projected image of the flat using the *x*-axis micrometer so that the right end is coincident with the intersection of the vertical and horizontal reference lines.

10.10 Determine the location of the right end of the flatted region using the offset procedure described in ¶10.7.

10.11 Record the micrometer reading to the nearest 25 μm or 0.001 in. as E_r (right) on the data sheet.



NOTE: This figure illustrates the use of offset with a two division offset, but the procedure of the text method requires use of a one division offset

Figure 5
Illustration of the Use of Offset

11 Calculation

11.1 Compute flat length, *l*, for each sample as follows:

$$l = E_l - E_r \quad (1)$$

11.2 Record the values obtained on the data sheet.

12 Report

12.1 Report the following information:

12.1.1 Date of test,

12.1.2 Operator and laboratory identification,

12.1.3 Comparator make and model, together with nominal viewing screen diameter,

12.1.4 Wafer identification,

12.1.5 Wafer nominal diameter, and

12.1.6 Measured flat length.

13 Precision[4]

13.1 An interlaboratory evaluation of this test method was conducted in which seven laboratories made measurements on 18 silicon wafers, 10 of which were edge rounded by mechanical grinding. Wafers with nominal diameters of 2 in., 3 in., 100 mm, and 125 mm were included. Each wafer contained a secondary flat in one of the secondary flat configurations specified in SEMI M1. The nominal flat lengths ranged from 6 mm (0.2 in.) to 40 mm (1.6 in.).

13.2 Each participating laboratory was requested to report three replicate sets of data. However, only 17 data sets were reported. Therefore, the within-laboratory repeatability could not be reliably estimated.

13.3 The offset requirement of ¶10.7 which was specified as 100 μm (0.004 in.) at the time of the test was not applied consistently; its efficacy cannot be verified from the reported results.

13.4 Because of the foregoing limitations, all the reported data were pooled to estimate the between-laboratory reproducibility. The variabilities of measured flat length were independent of both the nominal length and whether

4 Supporting data are available on request from SEMI Headquarters, 3081 Zanker Road, San Jose, CA, Telephone 408-943-7021, Fax: 408-943-7015, e-mail: standards@semi.org. Request International Standards Research Report 1002.

or not the wafer was edge rounded. For this situation, the sample standard deviation is a valid measure of the measurement variability.

13.4.1 The two-sigma standard deviation for all wafers was ±1.5 mm (0.060 in.) or less.

13.4.2 For 90% of all wafers, the two-sigma standard deviation was ±1.2 mm 0.046 in.) or less.

FLAT LENGTH DETERMINATION

Laboratory _____

Test Operator _____

Comparator Make and Model _____

Viewing Screen Diameter _____

Date of Test	*Wafer Identi-fication*	*Nominal Wafer Diameter*	E_l	E_r	*Flat Length* $(E_l - E_r)$

Figure 6
Suggested Data Sheet Format

14 Keywords

14.1 flat; optical comparator; primary flat; secondary flat; semiconductor; silicon; wafer

SEMI MF674-0705
PRACTICES FOR PREPARING SILICON FOR SPREADING RESISTANCE MEASUREMENTS

These practices were technically approved by the global Silicon Wafer Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on April 7, 2005. It was available at www.semi.org in June 2005 and on CD-ROM in July 2005. Original edition published by ASTM International as ASTM F 674-80. Last previous edition SEMI MF674-92 (Reapproved 1999).

1 Purpose

1.1 Resistivity is probably the single most important parameter for the characterization of silicon starting material for semiconductor device fabrication. Spreading resistance measurements are used to measure resistivity variations in raw silicon crystals and completed semiconductor devices. The reproducibility of spreading resistance measurements on silicon specimens is known to depend on the manner of specimen preparation. The interpretation of spreading resistance measurements depends in turn on the reproducibility of test specimen measurements and on the reproducibility of calibration specimen measurements.

1.2 The procedures given are intended to confer a high degree of reproducibility to spreading resistance measurements, and offer improvement over other preparation techniques.[1]

2 Scope

2.1 These practices cover the surface preparation of silicon samples using diamond polishing prior to measurement of resistivity variations by the spreading resistance technique.

NOTE 1: Benefits derived from diamond polishing are (1) stability and reproducibility of spreading resistance values on large area or beveled specimens, and (2) acuity of beveled surface geometry. The benefits of stability and reproducibility are likely to apply to both conductivity types and all resistivity values; however, they have been demonstrated extensively only for (111) *n*-type above 1 Ω·cm. Enhanced bevel acuity is independent of conductivity-type or resistivity value.

2.2 Separate practices are given for preparation of large-area specimens for measurement of lateral resistivity variations and for preparation of bevel-sectioned specimens (usually small chips) for measurement of vertical variations of resistivity (depth profiling).

2.3 The two practices are covered as follows:

- Front-Surface Diamond Polishing §7 through §9
- Diamond Bevel Polishing §10 through §12

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health guides and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 Polishing of silicon with diamond causes light but controllable and uniform scratch damage to the silicon surface. Nevertheless, such uniform damage is compatible with spreading resistance measurement data having very low scatter. Contamination of the polishing medium with hard foreign particles can cause random heavy scratch damage to a specimen. If encountered by the spreading resistance probes, heavily scratch-damaged regions may yield erratic measurement results.

3.2 Contamination of the specimen with water subsequent to polishing may adversely affect the reproducibility of spreading resistance measurements.

1 Ehrstein, J. R., Ricks, D. R. and Robinson, L. A., "Spreading Resistance Measurements, Measurement Techniques for High Power Semiconductor Materials and Devices," Annual Report, Oct. 1, 1977 to Sept. 30, 1978, NBSIR 79-1756, F.F. Oettinger, ed.

4 Referenced Standards and Documents

4.1 *SEMI Standard*

SEMI M59 — Terminology for Silicon Technology

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

5 Terminology

5.1 *Definitions*

5.1.1 Terms relating to silicon technology are defined in SEMI M59.

6 Summary of Practices

6.1 Silicon specimens are polished using fine-grain diamond compound in a non-aqueous fluid. Polishing of silicon wafers or other large-area specimens is done against a nonwoven polishing cloth; bevel polishing of small specimens is done against a frosted lapped glass surface. When polishing is complete, residual polishing compound is removed by an organic solvent.

FRONT-SURFACE DIAMOND POLISHING

7 Apparatus

7.1 *Polishing Machine* — Oscillating-tub polisher or other similar small laboratory-scale polishing machine capable of providing randomized motion of the silicon specimen over the polishing pad.

7.2 *Mounting Block and Fixture* — To support and apply vertical load to the silicon specimen during polishing.

7.3 *Polishing Pad* — Nonwoven cloth pad of a texture specified as being compatible with the grain size of diamond used during polishing. The polishing pad should be adhesive-backed for attaching to a support plate.

NOTE 2: The preferred material is of a type identified as a "chemotextile."

7.4 *Support Plate* — Of glass or other similar hard material compatible with the chosen polishing machine and capable of providing a flat support for the polishing pad during polishing.

7.5 *Microscope* — Optical microscope having a total magnification of at least 30× and provision for oblique illumination of the specimen.

7.6 *Hot Plate* — Capable of heating the sample mounting block and wax to 150°C.

8 Reagents and Materials

8.1 *Diamond Slurry* — Synthetic or natural diamond with grain size in the range 0.5 to 3 μm, inclusive, suspended in a nonaqueous liquid or paste carrier.

NOTE 3: The predominant causes of variation in the surface finish of the silicon specimen are expected to result from (1) the uniformity of particle size in the diamond grit, (2) the inclusion of a large fraction of needle-shaped grains (fines) in addition to the preferred symmetric grains (blocky diamond), and (3) in the case of diamond suspended in paste, the uniformity of the diamond distribution in the paste. For a fixed diamond grain size, whether the diamond is natural, single-crystal synthetic, or polycrystalline synthetic should make little difference in the resulting surface finish. However, the abrasive breakdown mechanisms differ somewhat for the different types of diamond. Consequently, the size and type of diamond should be chosen to give an acceptable cutting rate for the specimen and machine conditions that are used.

NOTE 4: For use with large-area specimens, the appropriate size diamond grain and, in part, the type of diamond to be used should be compatible with (1) the starting surface texture of the silicon, which may range from as-sawn to prepolished, and (2) the load that is applied during polishing.

8.2 *Solvent* — Suitable nonaqueous solvent for removing diamond slurry subsequent to polishing.

NOTE 5: The choice of solvent is governed in part by the composition of the carrier liquid or paste. The supplier of the diamond slurry should be consulted regarding the appropriate solvent. Acetone [$(CH_3)_2CO$] and methanol (CH_3OH) are known to work well for removing many commercial diamond compounds.

8.3 *Wax* — Glycol phthalate or other similar wax having a melting temperature of less than 150°C.

8.4 *Dry Air or Nitrogen* — Source of clean, dry air or nitrogen suitable for drying the specimen.

9 Procedure

9.1 If not previously done, attach the polishing pad to the rigid plate and place several drops of diamond polishing slurry at random locations on the polishing pad surface. Spread drops of slurry in a reasonably uniform manner over the pad so that the pad surface becomes damp and so that there are no freestanding layers of slurry. If the diamond is suspended in paste, be sparing in the amount of paste applied to the pad.

NOTE 6: Some polishing slurry adheres to the specimen and mounting fixture and is lost every time a specimen is removed and cleaned. Replenish the slurry on the pad regularly with a few drops of fresh slurry.

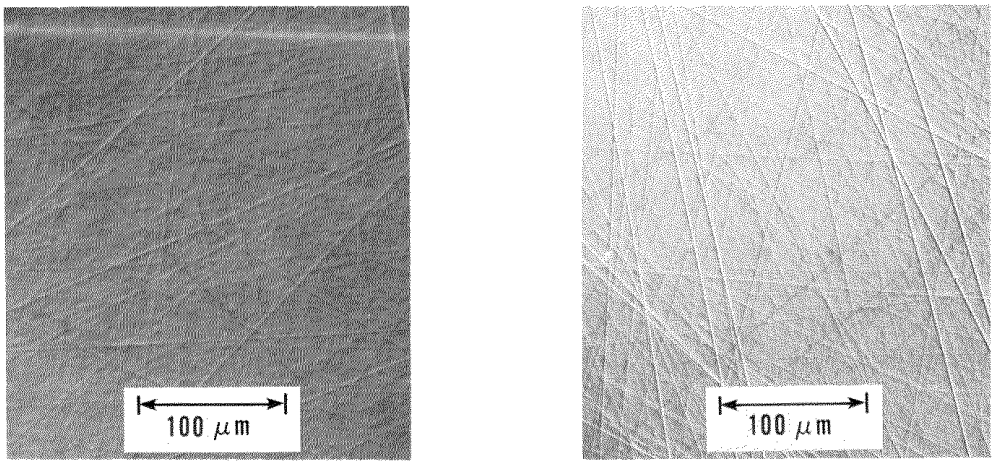
9.2 With the hot plate, heat the mounting block to the melting temperature of the wax. Mount the silicon specimen to the block with the wax. Allow the block to cool to room temperature.

9.3 Assemble the mounting block and attach specimen to the sample mounting fixture and place this assembly on the polishing pad in the polishing machine.

9.4 In accordance with the manufacturer's instructions for the polishing machine, polish until the specimen surface exhibits a uniform density of random-direction scratches comparable to the pattern shown in Figure 1. For this test, remove the polishing slurry from the specimen surface and examine that surface with the microscope.

NOTE 7: The time required to reach a uniform surface finish depends on specimen surface area, size of diamond grains, static load applied, rate of movement of the specimen surface over the polishing pad, and previous surface finish.

NOTE 8: The coarseness of the scratch damage on the specimen surface is related to the size of diamond grit used.



a. 0.5 μm Diamond **b. 3 μm Diamond**

Figure 1
Surface Texture of Large-Area Silicon Specimen Polished with Diamond Against Chemotextile Pad

9.5 When an acceptable surface finish has been reached, thoroughly swab or flush the specimen with the solvent to remove all diamond slurry residues. Use dry air or nitrogen to blow the specimen surface dry prior to carrying out any spreading resistance measurements.

DIAMOND BEVEL POLISHING

10 Apparatus

10.1 *Glass Plate* — Of suitable area for convenient use, which has been given a frosted surface by lapping with a water slurry of nominal 3 to 12 μm aluminum oxide, or similar abrasive, and thoroughly cleaned subsequent to lapping.

10.2 *Sample Mounting Block and Fixture* — For holding the silicon specimen at the desired beveling angle during the bevel-polishing process.

10.3 *Microscope* — Optical microscope having a total magnification of at least 30× and a system for illuminating the stage obliquely.

10.4 *Hot Plate*, capable of heating the mounting block and wax to 150°C.

11 Reagents and Materials

11.1 *Diamond Slurry* — Synthetic or natural diamond with a grain size in the range 0.05 to 0.25 μm, inclusive, suspended in a liquid or paste carrier.

11.2 *Solvent* — Suitable nonaqueous solvent for removing diamond slurry subsequent to polishing (see Note 5).

11.3 *Wax* — Glycol phthalate or other similar wax having a melting temperature of less than 150°C.

11.4 *Wipe, Lint-Free Paper, or Cloth* — Suitable for cleaning the glass plate.

11.5 *Oil Extender* — Compatible with the diamond slurry (see ¶11.1).

12 Procedure

12.1 Prior to beveling each specimen, clean the frosted surface of the glass plate by swabbing with the solvent using the lint-free wipe.

NOTE 9: Because of the rigidity of the glass surface, excessive damage to the beveled silicon surface can result from contamination of the polishing slurry with foreign material whose size is larger than that of the diamond grit.

12.2 Apply a small amount of diamond slurry (or paste) to the surface of the glass. Distribute the slurry (or paste) with a clean flexible metal or plastic spatula or other lint-free applicator so that a thin, uniform film results over an area whose dimensions are several times larger than the lateral dimension of the fixture used to support the beveling block. An oil extender may be used to prolong the life of the slurry. The oil extender generally slows the cutting somewhat and aids lubrication during beveling.

12.3 With the hot plate, heat the mounting block to the melting temperature of the wax. Mount the silicon specimen to the block with the wax. Allow the block to cool to room temperature.

12.4 Assemble the sample mounting block with specimen attached to the mounting fixture, and place this assembly on the glass plate. Lower the piston of the polishing fixture carefully and gently onto the glass plate to minimize the risk of chipping or otherwise damaging the silicon chip.

12.5 Polish the specimen by orbital, figure-eight, or reciprocating movement of the polishing fixture over the glass plate.

NOTE 10: Use of the above polishing procedure, wherein the specimen and its fixture are moved upon a stationary glass plate, risks the generation of random deep scratches on the beveled surface due to accumulated coarse debris on the polishing plate. It has been found that using a rotating glass plate while holding the specimen mounting fixture so that the leading edge of the beveled chip always faces into the direction of plate rotation reduces the risk. However, if each chip to be beveled is positioned at the same, or nearly the same, radial distance from the plate's center of rotation, uneven wear of the plate in the form of a channel, or wide groove, is likely to result. Such channeling of the polishing plate can be minimized or eliminated either by moving the specimen mounting fixture slowly along the plate radius while polishing, or by choosing a different radial position on the plate for each chip to be beveled.

12.6 Clean and inspect the specimen periodically to determine whether an adequate amount of specimen surface has been exposed by beveling (see Note 5).

12.7 Repeat ¶12.5 and ¶12.6 as necessary until an adequate extent of beveled surface is obtained.

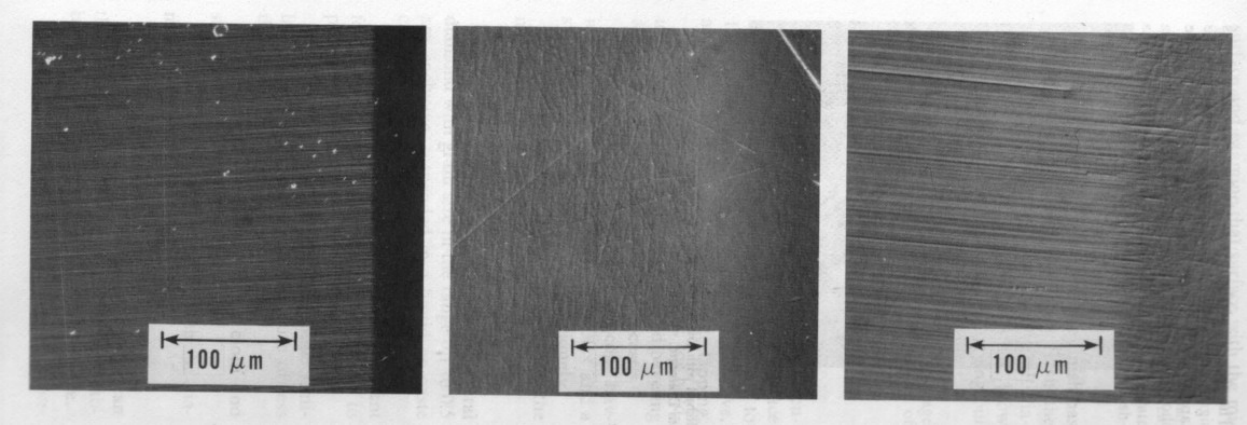
NOTE 11: At the beginning of the beveling process an extremely small area of silicon supports the static load of the polishing assembly, and pressures on the silicon are extremely high. To minimize the possibility of fracture of the edge of the silicon chip, it has been found advisable to begin bevel polishing with a relatively slow rate of motion of the polishing assembly.

12.8 When the desired amount of specimen surface has been exposed by beveling, thoroughly clean the specimen by flushing or swabbing with the appropriate organic solvent (see ¶11.2). Inspect the beveled surface for quality of

finish with the microscope. Compare the finish with the appropriate photograph of Figure 2, which shows results obtainable with different size diamond in the range specified for two types of motion during polishing. Repolish lightly if the finish appears to be significantly coarser than that shown in the appropriate photograph. Use dry air or nitrogen to blow the specimen surface dry prior to carrying out any spreading resistance measurements.

NOTE 12: Clean the polishing plate regularly to remove coarse polishing residue or air-borne contaminants. This cleaning can be done with a lint–free cloth or paper wipe and the same solvent used to clean polishing residue from the specimen. Inspect the plate when clean. If it shows signs of scratching, burnish marks, or areas where the lapped finish has been polished smooth, relap the plate then clean thoroughly to remove lapping debris and broken-in on scrap samples (see Note 13).

NOTE 13: A newly-frosted glass plate may not yield optimum results. Such a plate can be improved by preparing a number of samples of scrap silicon before beveling the test specimen of interest. The best indicator of frosted glass plate condition is the quality and uniformity of surface damage on the finished bevel.



a. 0.1 μm Diamond, Reciprocating Motion | **b. 0.1 μm Diamond, Figure-of-Eight Motion** | **c. 0.5 μm Diamond, Reciprocating Motion**

Figure 2
Surface Texture of Silicon Specimens Bevel-Sectioned with Diamond Against Ground-Glass Surface

13 Keywords

13.1 beveling; diamond polishing; resistivity; resistivity variations; sample preparation; semiconductor; silicon; spreading resistance; spreading resistance probe (SRP)

SEMI MF928-0305
TEST METHODS FOR EDGE CONTOUR OF CIRCULAR SEMICONDUCTOR WAFERS AND RIGID DISK SUBSTRATES

These test methods were technically approved by the Global Silicon Wafer Committee and are the direct responsibility of the North American Silicon Wafer Committee. Current edition approved for publication by the North American Regional Standards Committee on December 10, 2004 Initially available at www.semi.org January 2005; to be published March 2005. Original edition published by ASTM International as ASTM F 928-85. Last previous edition SEMI MF928-02.

1 Purpose

1.1 The edges of circular wafers of electronic materials are frequently required to be shaped after cutting the wafers from the ingot. Contouring the wafer edge reduces the incidence of chipping and minimizes epitaxial edge crown and photoresist edge bead during subsequent processing of the wafer. Similarly, edges of rigid disk substrates are frequently edge shaped.

1.2 The test methods described here provide means to determine that the wafer edge contour is appropriate to meet specifications, such as SEMI M1 or SEMI M9, which are intended to provide wafers avoiding the difficulties enumerated above.

2 Scope

2.1 These test methods provide means for examining the edge contour of circular wafers of silicon, gallium arsenide, and other electronic materials, and determining fit to limits of contour specified by a template that defines a permitted zone through which the contour must pass. Principal application of such a template is intended for, but not limited to, wafers that have been deliberately edge shaped.

NOTE 1: DIN 50441/2 is equivalent to Method B of this standard. It is the responsibility of DIN Committee NMP 221. DIN 50441/2, Measurement of the Geometric Dimensions of Semiconductor Slices; Testing of Edge Rounding, is available from Beuth Verlag GmbH, Burggrafenstrasse 6, 10787 Berlin, Germany, Telephone: 49.30.2601-0, Fax: 49.30.2601.1263, Website: www.beuth.de.

2.2 Two test methods are described.

2.2.1 Method A is destructive and is limited to inspection of discrete points on the periphery, including flats. The contour of deliberately edge-shaped wafers may not be uniform around the entire periphery, and thus the discrete location(s) may or may not be representative of the entire periphery.

2.2.2 Method A is recommended for examining the edge profile of flatted regions of the wafer.

2.2.3 Method A is best suited for referee purposes.

2.3 Method B is nondestructive and suitable for inspection of all points on the wafer periphery except flats.

2.3.1 Method B is appropriate for routine process monitoring such as alignment of wafer edge grinders, routine quality control and incoming/outgoing inspection purposes. In view of the uncertainty of precisely locating the intersection of the contour and the wafer surface when carrying out Method B, use of this method for commercial transactions is not recommended unless the parties to the test establish the degree of correlation that can be obtained.

2.3.2 Method B may also be applied to the examination of the edge contour of the outer periphery of substrates for rigid disks used for magnetic storage of data; metallic rigid disk substrates cannot conveniently be cleaved.

NOTE 2: Reference to wafers in the remainder of this standard shall be interpreted to include substrates for rigid disks unless the phrase “of electronic materials” is also included in the context.

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

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health guides and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 In Method B, the profile of the parallel surfaces of the wafer may not be sharply focused at distances exceeding approximately 0.5 mm (0.020 in.) from the extreme wafer edge toward the wafer center. This uncertainty in the wafer surface location may cause inaccuracy in positioning the wafer with respect to template lines. It may also make it difficult to determine whether the wafer edge profile lies within the permitted zone at point B of the template (see Figure 1). These difficulties can be overcome by aligning a straight edge to the wafer surface by direct contact, observing the shadow extension in the sharply focused region, and extrapolating the straight line edge of the template reference. In applying this technique, exercise care to avoid damaging or contaminating the wafer surface.

3.1.1 This limitation renders Method B unsuitable for determining the distance between the front and back wafer surfaces. The edge contours near the front and back surfaces of the wafer must be inspected separately.

3.2 In Method B, attempting to view the complete wafer periphery, except flats, through wafer rotation may necessitate frequent focus adjustment due to variations in wafer roundness and fixturing precision, including wafer centering.

3.3 By either test method, any foreign material such as large particles or high spots on the wafer surface in the light path will present a false edge contour by masking the true contour shape.

3.4 It is not always feasible to provide a uniform radius or bevel to the edges of wafers because silicon, gallium arsenide, and many other electronic materials as well as glass disk substrates are both hard and brittle. Wear of grinding tools, process variations, and the presence of flats on the circumference of wafers cause practical contours to have varying shapes. For this reason, templates are used that define an allowed range.

3.5 If a television system is used, the user is cautioned that distortions in the horizontal and vertical deflections may occur (see ¶9.2).

4 Referenced Standards

4.1 *SEMI Standards*

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M9 — Specifications for Polished Monocrystalline Gallium Arsenide Slices

4.2 *ANSI Standard*[1]

ANSI/ASQC Z1.4 — Sampling Procedures and Tables for Inspection by Attributes

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

5 Summary of Test Methods

5.1 Both test methods employ optical means to project a shadow of the edge contour at substantial magnification on a screen.

5.1.1 In applying Method A (destructive) the sample wafer is cleaved or broken along a diameter. A sharply focused image of the cross section of the wafer is obtained over a sufficiently large region near the edge with the aid of an optical comparator or projection microscope.

5.1.2 In Method B (nondestructive) the unbroken wafer is back lighted with collimated (parallel) light such that a sharply defined shadow of the wafer edge is projected on a screen. In this test method the wafer is not altered in any way.

5.2 By either test method, the contour of the wafer edge profile image is compared to a template that has been mounted or projected on the screen. The template defines a permitted zone through which the edge contour must pass.

1 American National Standards Institute, New York Office: 25 West 43rd Street, New York, NY 10036, USA. Telephone: 212.642.4900, Fax: 212.398.0023, Website: www.ansi.org.

6 Apparatus

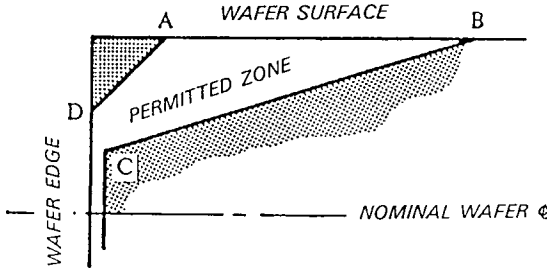
6.1 For Method A, an optical comparator or projection microscope capable of 100× magnification with viewing screen large enough to permit display of an area 1 mm by 1 mm (0.04 in. by 0.04 in.).

6.2 For Method B, a collimated light source (coherent or incoherent) and a television system, consisting of a camera, lenses to give 100× magnification and TV monitor capable of displaying a 1 by 1 mm (0.04 by 0.04 in.) area.

NOTE 3: An adjustable camera mount, slice holding fixture, or lens adjustment is desirable for sharp focusing.

6.3 *Fixture*, for holding the wafer to be tested. The fixture must provide means for positioning the wafer such that the plane of the surface of the wafer is parallel to the viewing direction. The fixture should be arranged in such a way that its position and orientation in a plane perpendicular to the viewing direction can be adjusted conveniently, or alternatively, the template can be moved. Optionally, for Method B, the fixture can provide means for rotation of the wafer about its axis of symmetry. The design of the fixture for Method B should be such that the wafer may be loaded, held in position, and unloaded with minimum risk of contamination or damage to the wafer.

6.4 *Template*, having transparent regions defining the area through which the contour of the edge of the wafer must pass and a semi-transparent region bounding the space. An example of a template is given in Figure 1. Instructions for constructing templates are given in §10.



NOTE: Only half is used to emphasize that these methods are not intended for measurement of thickness.

Figure 1
Template Showing One Half of Wafer Cross Section

6.5 *Gage Block or Precision Rod*, with dimensions approximately the same as the thickness of the wafer to be tested and accurately known for use in establishing the magnification of the apparatus.

6.6 *Rule*, 150 mm (6 in.) long with scale gradations of 0.5 mm (0.02 in.) or less.

7 Sampling

7.1 Unless otherwise specified, ANSI/ASQC Z1.4 shall be used. Inspection levels shall be agreed upon between the supplier and purchaser.

7.2 The number and location of the test points on the periphery of each wafer shall be agreed upon between the supplier and purchaser.

8 Specimen Preparation

8.1 For Method A, cleave or fracture the wafer along a diameter.

NOTE 4: This may be conveniently accomplished by positioning the wafer over a small diameter rod and pressing downward on both sides. Alignment by eye is sufficient. If required by the sampling plan, cleave additional pieces along the edge of the wafer.

9 Determination of Magnification Factor

9.1 For Method A, adjust the comparator or microscope to the magnification to be used for the test. Using a gage block or precision rod of accurately known dimensions, follow the comparator or microscope manufacturer's instructions to establish object-to-image magnification to three significant figures.

9.2 For Method B, position a gage block on the fixture (see ¶6.3) such that the known dimension can be measured in the vertical direction on the screen using an appropriate rule. Measure the image vertical dimension to the nearest 0.02 in. (0.5 mm) and adjust magnification until the desired magnification for the test is obtained. Reposition the gage block such that the screen image of the known dimension can be measured in the horizontal direction. Adjust magnification to give the same value as the vertical.

NOTE 5: Television systems may have distortions in either vertical or horizontal deflection circuits caused by improper settings of vertical or horizontal size or linearity. If magnification in both horizontal and vertical directions is not equal to the desired resolution, recalibration of the television system may be required.

10 Preparation of Template

10.1 Multiply each of the chosen or specified template coordinates by the magnification factor.

10.2 Prepare on transparent material a full-scale template having the dimensions calculated in ¶10.1 with a projected image accuracy of ± 0.5 mm (± 0.020 in.).

10.2.1 Mount the template on the screen such that the images of the wafer surfaces are parallel with the corresponding template lines. Alternatively, the template can be electronically generated or projected by the optical system.

11 Procedure

11.1 *Method A*

11.1.1 Mount the test specimen in the fixture with the cleaved or broken surface of the wafer facing the objective lens and approximately perpendicular to the viewing direction.

11.1.2 Adjust the comparator focus such that a sharp image of the wafer is seen on the screen.

11.1.3 Position the wafer by appropriate motion of the fixture so that the contour profile image is tangent to the overlay template at both the edge and front surface.

11.1.4 Determine whether or not the contour of the edge of the wafer between the points of tangency lies entirely within the permitted zone of the template. If the specification has other requirements, such as those relating to the specific shape of the profile, inspect the profile image for adherence to such conditions.

11.1.5 Repeat ¶11.1.3 and ¶11.1.4 with the opposite side of the contour profile image tangent to the overlay template at both the edge and the back surface.

11.1.6 If the test specimen includes the full diameter, reverse the fixture on the comparator table to permit the edge contour at the opposite end of the wafer diameter to be seen on the screen and repeat ¶11.1.2 through ¶11.1.5.

11.1.7 If additional parts of the wafer were prepared as test specimens, repeat ¶11.1.1 through ¶11.1.5 for each.

11.1.8 Record as “passed” those wafers for which all observed edge contours lie entirely within the permitted zone and which meet all other specification requirements.

11.2 *Method B*

11.2.1 Mount a whole wafer in the fixture.

11.2.2 Adjust the focus of the apparatus to give the sharpest image of the extreme edge of the wafer as seen on the screen.

11.2.3 Position the wafer by appropriate motion of the fixture so that the contour profile image is tangent to the overlay template at both edge and front surface (see ¶3.1).

11.2.4 Determine whether or not the contour of the edge of the wafer between the points of tangency lies entirely within the permitted zone of the template. If the specification has other requirements, such as those relating to the specific shape of the profile, inspect the profile image for adherence to such conditions.

11.2.5 Rotate the wafer in the fixture while continuously observing the contour. Due to diameter and roundness tolerances, the specimen contour profile image may move with respect to the overlay template while rotating the

specimen. Adjust wafer or template position and focus as required to assure proper judgment of template fit. Repeat ¶11.2.3 and ¶11.2.4 at specified points in accordance with the sampling plan.

NOTE 6: Flatted regions of the wafer periphery cannot be evaluated by this test method.

11.2.6 Repeat ¶11.2.3 through ¶11.2.5 with the opposite side of the contour profile image tangent to the overlay template at both the edge and the back surface.

11.2.7 Record as "passed" those wafers for which all edge contours examined lie entirely within the permitted zone and which meet all other specification requirements.

12 Report

12.1 Report as a minimum the following information:

12.1.1 Date of test,

12.1.2 Name of person conducting the test,

12.1.3 The lot number of other identification of the material,

12.1.4 Method used, A or B,

12.1.5 Position(s) on the wafer periphery that were examined,

12.1.6 The number of wafers in the lot,

12.1.7 The number of test wafers, and

12.1.8 The number of accepted wafers.

13 Precision and Bias

13.1 Although these test methods do not return a test result, an interlaboratory test was conducted to determine the reliability of the nondestructive Method B when applied to silicon wafers. In this test, a lot of 25, 125 mm diameter, edge profiled, silicon wafers was tested in accordance with Method B against the edge contour template and other requirements of SEMI M1. The wafers were measured by nine different organizations using several types of commercially available edge contour measuring instruments, all of which had similar optical systems. In one case the magnification used was 60× instead of 100× as specified in ¶6.2.

13.1.1 In no case was a wafer judged to be within the specification requirements by all participants. Only three wafers were judged by all participants to fail, but different participants reported different reasons for failure; the other 22 wafers were judged to pass by some and to fail by others, but again the same failure mode was not always reported. Most of the difficulty centered around determination of whether or not the edge profile extended further into the wafer than 0.508 mm (the specified location of point B in the SEMI template). Some participants reported failure on the front of the wafer, some on the back, and some reported that failure occurred because the contour passed inside point C. These results confirm the difficulties with locating the wafer surface indicated in ¶3.1. No participant reported use of the straight-edge technique suggested in ¶3.1, so the efficacy of that procedure was not evaluated in the test.

13.1.2 The results also confirmed the difficulties with interference from particulate contaminants. Several observers reported protrusions or sharp points on the wafer periphery, but these were not generally reported. Examination of the wafers under conditions in which the edge of the wafer could be accessed during the test showed that such apparent protrusions could be removed by blowing or wiping with lens cleaning tissue.

13.1.3 For more details, refer to the Research Report.[2]

13.2 At the recommended magnification, 100×, a dimension of 25 μm (0.001 in.) at the object plane produces a screen image of 2.5 mm (0.1 in.). The smallest size details of edge contours to be inspected by these test methods are of comparable dimensions.

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2 Available on request from SEMI Headquarters, 3081 Zanker Road, San Jose, CA, Telephone 408-943-7021, Fax: 408-943-7015, e-mail: standards@semi.org. Request International Standards Research Report MF0928.

14 Keywords

Contour; edge contour; gallium arsenide; optical comparator; projection microscope; rigid disk; semiconductor; silicon; wafer

SEMI MF847-0705
TEST METHODS FOR MEASURING CRYSTALLOGRAPHIC ORIENTATION OF FLATS ON SINGLE CRYSTAL SILICON WAFERS BY X-RAY TECHNIQUES

These test methods were technically approved by the global Silicon Wafer Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on April 7, 2005. It was available at www.semi.org in June 2005 and on CD-ROM in July 2005. Original edition published by ASTM International as ASTM F 847-83. Last previous edition SEMI MF847-02.

1 Purpose

1.1 The orientation of flats on silicon wafers is an important materials acceptance requirement. The flats are used in semiconductor device processing to provide consistent alignment of device geometries with respect to crystallographic planes and directions.

1.2 The orientation of a wafer flat is the orientation of the surface of the flat (on the edge of the wafer). Flats are usually specified with respect to a low-index plane, such as a (110) plane. In such cases the orientation of the flat may be described in terms of its angular deviation from the low-index plane.

1.3 This standard covers two test methods for determining flat orientation.

1.4 Either one of these test methods is appropriate for process development and quality assurance applications. Until the interlaboratory precision of these test methods has been determined, it is not recommended that they be used between supplier and customer unless correlation studies are completed satisfactorily.

2 Scope

2.1 These test methods cover the determination of α, the angular deviation between the crystallographic orientation of the direction perpendicular to the plane of a fiducial flat on a circular silicon wafer, and the specified orientation of the flat in the plane of the wafer surface.

2.2 These test methods are applicable for wafers with flat length values in the range of those specified for silicon wafers in SEMI M1. They are suitable for use only on wafers with angular deviations in the range from –5° to +5°.

2.3 The orientation accuracy achieved by these test methods depends directly on the accuracy with which the flat surface can be aligned with a reference fence and the accuracy of the orientation of the reference fence with respect to the X-ray beam.

2.4 Two test methods are covered as follows:

- Test Method A — X-Ray Edge Diffraction Method §8 through §13
- Test Method B — Laue Back Reflection X-Ray Method §14 through §18

2.4.1 Test Method A is nondestructive and is similar to Test Method A of SEMI MF26, except that it uses special wafer holding fixtures to orient the wafer uniquely with respect to the X-ray goniometer. The technique is capable of measuring the crystallographic direction of flats to a greater precision than the Laue back reflection method.

2.4.2 Test Method B is also nondestructive, and is similar to ASTM Test Method E 82, and to DIN 50 433, Part 3, except that it uses “instant” film and special fixturing to orient the flat with respect to the X-ray beam. Although it is simpler and more rapid, it does not have the precision of Test Method A because it uses less precise and less expensive fixturing and equipment. It produces a permanent film record of the test.

NOTE 1: The Laue photograph may be interpreted to provide information regarding the crystallographic directions of wafer misorientation; however, this is beyond the scope of the present test method. Users desiring to carry out such interpretation should refer to ASTM Test Method E 82, to DIN 50 433, Part 3, or to a standard X-ray textbook.[1,2] With different wafer holding fixturing, Test Method B is also applicable to determination of the orientation of a wafer surface.

1 Wood, E. A., *Crystal Orientation Manual,* (Columbia University Press, New York, NY, 1963).

2 Barret, C. S., and Massalski, T. B., *The Structure of Metals,* 3rd edition (McGraw-Hill, New York, NY, 1966).

2.5 The values stated in SI units are to be regarded as the standard. The inch-pound values given in parentheses are for information only.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health guides and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 The alignment of the flat against the reference fence may be affected by the straightness of the flat. In the unlikely event that the flat profile is convex, the flat orientation may not be unique. More often the flat surface will touch the reference fence along two lines perpendicular to the wafer surface at two points. In this case, the orientation determined is that of the plane through the two lines on the plane perpendicular to the wafer surface that passes through the two points. In the latter cases, the orientation determined is that which is obtained in subsequent processing of the wafer when the alignment is between the flat and a reference fence.

3.2 Misalignment of the various fixtures degrades both the interlaboratory reproducibility and the absolute accuracy of both test methods. The single-instrument repeatability is not degraded provided the fixturing is rigid.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M59 — Terminology for Silicon Technology

SEMI MF26 — Test Methods for Determining the Orientation of a Semiconductive Single Crystal

4.2 *ASTM Standards*

E 82 — Test Method for Determining the Orientation of a Metal Crystal[3]

E 122 — Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[4]

4.3 *DIN Standard*

50433, Part 3 — Determination of the Orientation of Single Crystals by Means of Laue Back Scattering[5]

4.4 *ANSI Standard*

ANSI/ASQC Z1.4 — Sampling Procedures and Tables for Inspection by Attributes[6]

4.5 *Other Standard*

Code of Federal Regulations, Title 10, Part 20, Standards for Protection Against Radiation[7]

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

5 Terminology

5.1 *Definitions*

5.1.1 Terms relating to silicon technology are defined in SEMI M59.

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3 *Annual Book of ASTM Standards*, Vol 03.01, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Telephone: 610-832-9500, Fax: 610-832-9555, Website: www.astm.org.

4 *Annual Book of ASTM Standards*, Vol 14.02.

5 Deutches Institut für Normung standards are available in both English and German editions from Beuth Verlag GmbH, Burggrafenstrasse 6, 10787 Berlin, Germany, Telephone: 49.30.2601-0, Fax: 49.30.2601.1263, Website: www.beuth.de.

6 American National Standards Institute, American National Standards Institute, New York Office: 25 West 43rd Street, New York, NY 10036, USA. Telephone: 212.642.4900, Fax: 212.398.0023, Website: www.ansi.org.

7 Published in Federal Register, Nov. 16, 1960. Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

6 Hazards

6.1 These test methods use X radiation; it is absolutely necessary to avoid personal exposure to X rays.

6.1.1 It is especially important to keep hands or fingers out of the path of the X rays and to protect the eyes from scattered secondary radiation.

6.1.2 The use of commercial film badge or dosimeter service is recommended, together with periodic checks of the radiation level at the hand and body positions with a Geiger-Muller counter calibrated with a standard nuclear source.

NOTE 2: The present maximum permissible dose for total body exposure of an individual to external X-radiation of quantum energy less than 3 MeV over an indefinite period is 1.25 R (3.22×10^{-4} C/kg) per calendar quarter (equivalent to 0.6 mR/h (1.5×10^{-7} C/kg·h)) as established in the *Code of Federal Regulations*, Title 10, Part 20. The present maximum permissible dose of hand and forearm exposure under the same conditions is 18.75 R (4.85×10^{-3} C/kg) per calendar quarter (equivalent to 9.3 mR/h (2.4×10^{-6} C/kg·h)). Besides the above stated regulations, various other government and regulatory organizations have their own safety requirements.

6.1.3 It is the responsibility of the user to make sure that the equipment and the conditions under which it is used meet applicable regulations.

7 Sampling

7.1 Unless otherwise specified, ASTM Practice E 122 shall be used.

7.2 When so specified, appropriate sample sizes shall be selected from each lot according to ANSI/ASQC Z1.4.

7.3 Inspection levels shall be agreed upon between the parties to the test.

TEST METHOD A — X-RAY EDGE DIFFRACTION METHOD

8 Summary of Test Method

8.1 In this test method a holding fixture that uniquely orients the wafer being tested with respect to its geometric features is used to position the wafers with respect to the X-ray goniometer.

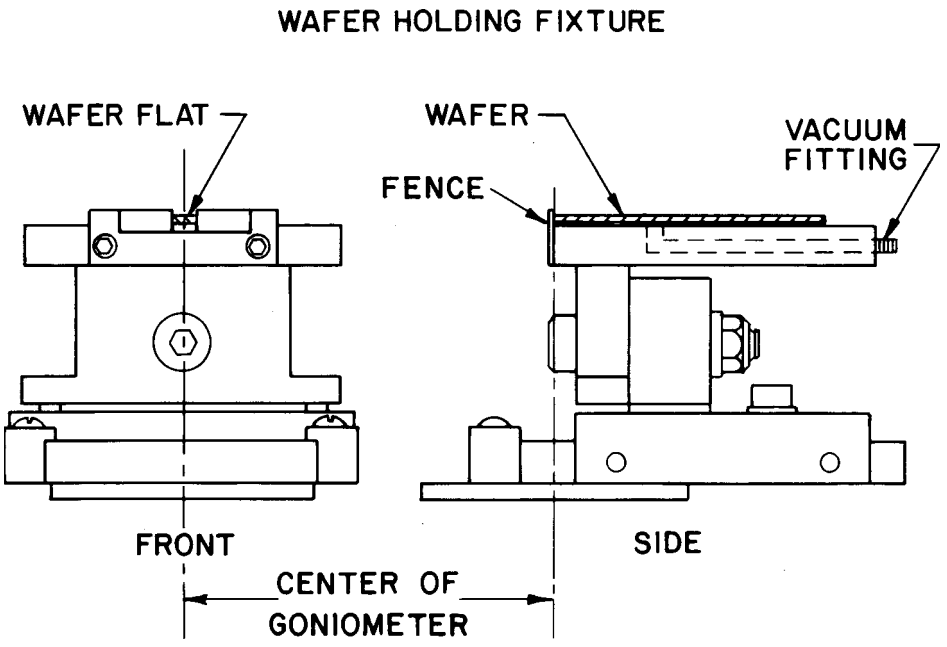
8.2 The goniometer is rotated to determine the Bragg angle with respect to the geometric features by X-ray diffraction from the crystallographic planes of the wafer edge, first with the wafer front surface up and then with front surface down.

8.3 The average angular deviation is calculated from the goniometer readings.

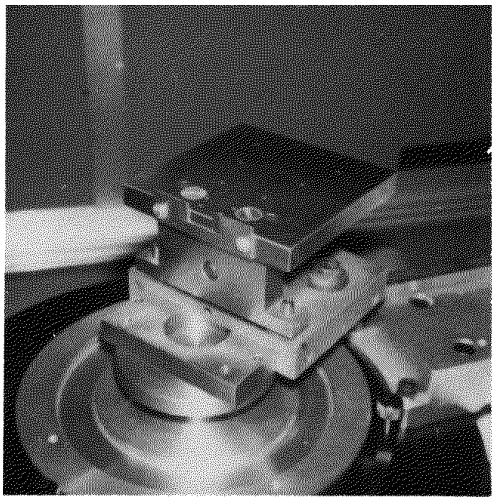
9 Apparatus

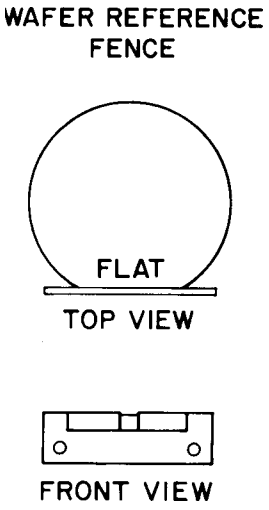
9.1 *X-ray and Goniometer Apparatus* — In accordance with ¶5.1 of SEMI MF26, except that the X-ray beam shall be collimated using a vertical slit.

9.2 *Wafer-Holding Fixture*, to orient the sample wafer uniquely with respect to the X-ray goniometer (see Figure 1). The fixture must include a vacuum hold-down with a flat horizontal surface and a reference fence perpendicular to this surface. These components establish an *x-y* axis that is fixed with respect to the goniometer and the X-ray beam. The exact dimensions of the fixture depend on the layout of the X-ray apparatus. The critical features are:



a. Front and Side Views





b. Photograph of Mounted Fixture **c. Detail of Wafer and Reference Fence**

Figure 1
Wafer Holding Fixture for X-Ray Edge Diffraction Method

9.2.1 The horizontal surface must be parallel to the plane of the X-ray beam so that the diffracted beam impinges on the detector (see Figure 2).

9.2.2 Both the side of the reference fence against which the wafer flat is located, and the fixture surface to which the reference fence mates, must be flat to within one part in 10,000.

10 Procedure

10.1 Position the detector so that the angle between the extension of the incident X-ray beam and the line joining the detector and the axis of rotation of the specimen is equal (to the nearest minute) to twice the Bragg angle (see Figure 2).

NOTE 3: This angle (twice the Bragg angle) is listed in Table 1 for CuKα radiation for the recommended reflecting planes corresponding to common silicon wafer flat locations.

10.2 Place the wafer to be tested on the fixture, front surface up. Take care to ensure that the flat is securely located against the reference fence and activate the vacuum holddown.

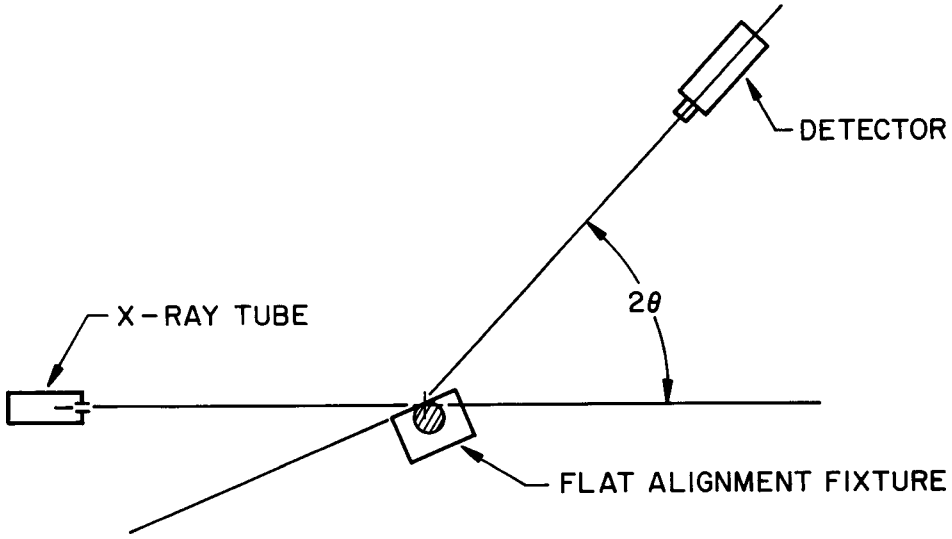


Figure 2
Schematic of the Diffraction Geometry for the X-Ray Edge Diffraction Method

Table 1 Bragg Angles, θ, for X-Ray Diffraction of Cu-Kα Radiation in Silicon Crystal[#1]

Flat Location			*Recommended Reflecting Plane*			*Detector Location (2 times Bragg Angle)*
h	*k*	*l*	*h*	*k*	*l*	
1	1	0	2	2	0	47°20′
2	1	1	4	2	2	88°08′
1	0	0	4	0	0	69°12′

[#1] Wavelength λ = 1.5417 Å.

10.3 With the goniometer movement mechanism, adjust the fixture about the axis of rotation perpendicular to the incident and reflected beams until the diffracted intensity is at a maximum.

10.4 Record to the nearest 1 min, as ψ_1, the angle that is indicated on the goniometer.

10.5 Remove the wafer from the fixture, turn it over so that the front surface is now down. Again, take care to ensure that the flat is securely located against the reference fence and activate the vacuum holddown.

10.6 With the goniometer movement mechanism, adjust the fixture about the axis of rotation perpendicular to the incident and reflected beams until the diffracted intensity is at a maximum.

10.7 Record to the nearest 1 min, as ψ_3, the angle that is indicated on the goniometer.

11 Calculation

11.1 Calculate and record the average angular deviation as follows:

$$\alpha = \frac{\psi_1 - \psi_3}{2} \quad (1)$$

where:

α = average angular deviation,

ψ_1 = first angle reading taken on goniometer, and

ψ_3 = second angle reading taken on goniometer.

12 Report

12.1 Report the following information:

12.1.1 Identity of samples tested including supplier and supplier lot identity,

12.1.2 Date of test and identity of operator making the measurements,

12.1.3 Specified flat and surface orientations, and

12.1.4 Measured values of ψ_1 and ψ_3 and the calculated value of α for each wafer.

13 Precision and Bias

13.1 The single-instrument, single-operator repeatability of this measurement was estimated by measuring one wafer 50 times (25 times each side). This test yielded a distribution of calculated values of α with a 1-σ value of 1.94 min.

TEST METHOD B — LAUE BACK REFLECTION X-RAY METHOD

14 Summary of Test Method

14.1 In this test method the wafer is mounted in a Laue back-reflection X-ray camera and a collimated beam of "white" (continuous or Bremsstrahlung) radiation is directed at the wafer flat.

14.2 A spot is produced on the film for each set of crystal planes that satisfies the Bragg equation for any wavelength component of the impinging radiation.

14.3 The pattern on the film is read with an engineering drafting head.

14.4 When the flat surface is within 5° of the specified low-index plane, the angle between the nearest zone of Laue spots that goes through the center of the pattern and the zero reference line is a direct measure of the angular deviation.

15 Apparatus

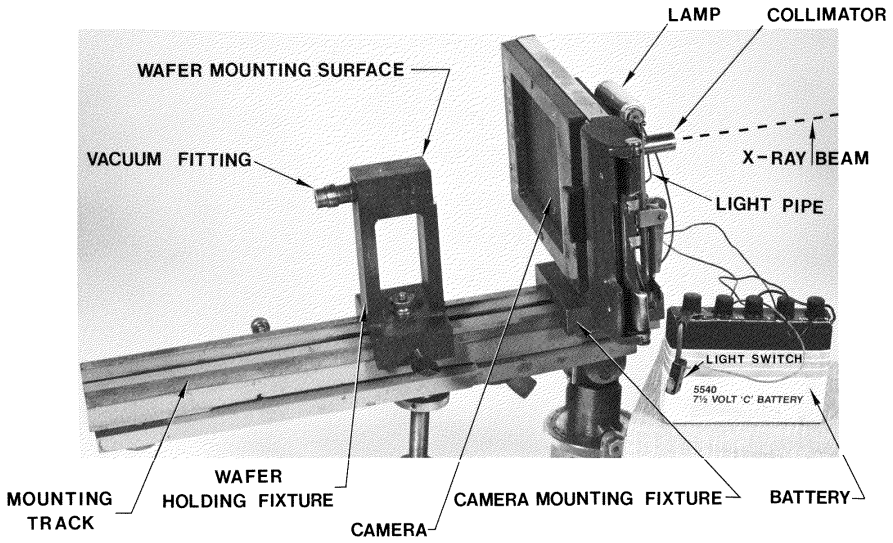
15.1 *Commercially Available X-Ray Diffraction Apparatus* — Utilizing a silver or tungsten tube as the X-ray source and including a shutter to control the X-ray exposure.

15.2 *Laue Back-Reflection X-ray Camera* — With the following features (see Figure 3):

15.2.1 *Mounting Track* — With the upper surface and one side round precision flat perpendicular to each other, aligned with the X-ray beam from the source.

15.2.2 *Wafer Holding Fixture* — On which two plane surfaces are ground so that when it is clamped to the mounting track one surface is perpendicular and the other is parallel with the horizontal (upper) surface of the mounting track to 1 min of arc (29 μm in 100 mm) (see Figure 4). The vertical surface contains holes connected to a vacuum line through a fitting on the back of the fixture. In use, the flat is aligned to the horizontal reference surface and the vacuum holds the wafer against the vertical surface.

15.2.3 *Camera* — having a film holder with provision for establishing precisely a horizontal reference line. This is conveniently done by installing a light source with two light pipes and 75 μm (0.003 in.) diameter light collimators at the midpoint of the shorter dimension of the film, as near to the edges of the sensitive area of the film as possible (see Figure 5). A tube for collimating the X-ray beam is required at the center of the film holder (see Figure 3).



NOTE: Use of high-speed "instant" film together with a fluorescent screen results in shorter test times than with wet-processed films.[8] A holder of this type is commercially available. This holder has built into it four reference spots which define two orthogonal lines which pass through the center of the film when the X-ray beam collimator is located (these reference spots are not utilized in the present test method). If this type of holder is used, the collimator tube must not protrude above the surface of the fluorescent screen because of film and clip interference problems during loading and processing of the film.

Figure 3
Photograph of Assembled View of Laue Camera and Wafer Holder

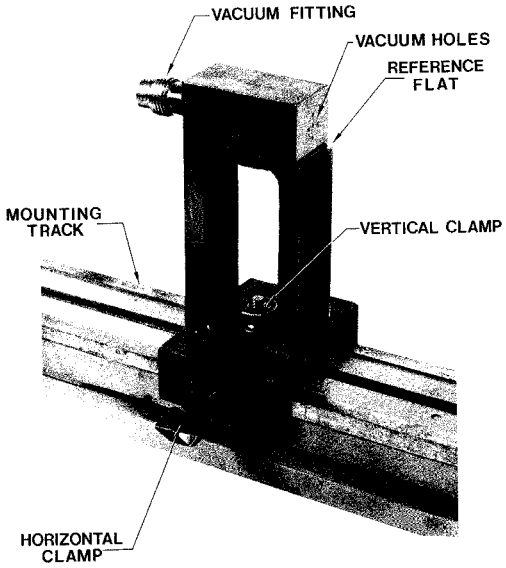


Figure 4
Photograph of Wafer Holding Fixture and Mounting Track

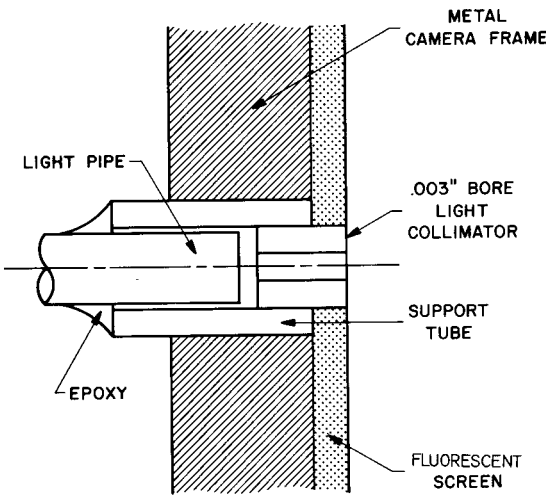
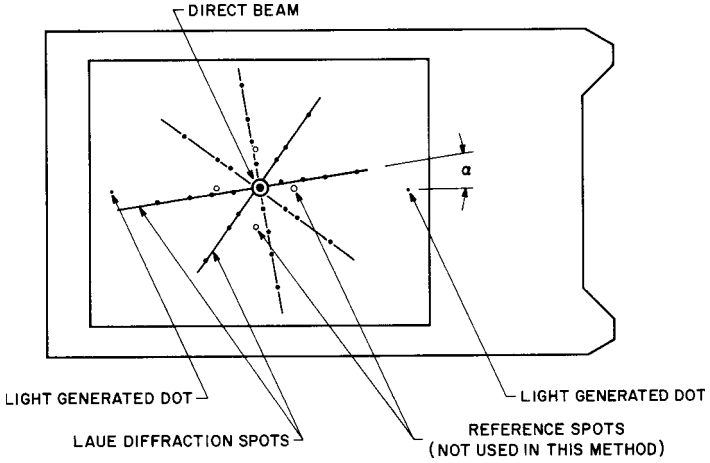


Figure 5
Section of Laue Camera Platen Showing Light Pipe and Collimating Tube

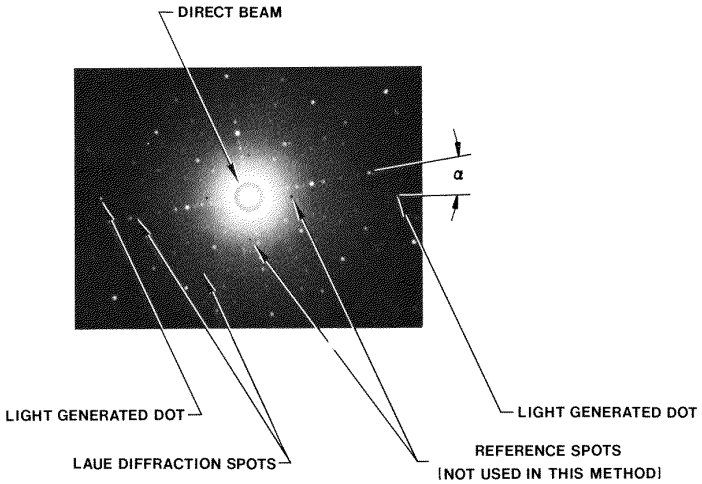
8 Schmidt, P. H., and Spencer, E. G., "X-Ray Diffraction Camera Using Polaroid Film," *Rev. Sci. Instrum.* **35**, 957–958 (1964).

15.2.4 *Camera Mounting Fixture* — For clamping the camera to the mounting track so that the collimator is aligned with the X-ray beam and the horizontal reference line established by the light-generated dots is parallel with the upper surface of the mounting track to 1 min of arc (29 μm in 100 mm).

15.3 *Drafting Head Protractor* — With a clear plastic blade and finest vernier divisions of six min of arc or less for reading the Laue photograph. A straight line, approximately 125 mm (or 5 in.) long, and in line with the centerpoint of the protractor, is inscribed on the bottom of the plastic blade.



a. Schematic Representation



b. Actual Photograph

Figure 6
Laue Pattern

16 Procedure

16.1 Place the wafer to be tested on the wafer holding fixture so that the flat is resting securely against the reference flat on the fixture. Turn on the vacuum to hold the wafer securely against the fixture.

16.2 Turn on the X-ray source, adjust the voltage and current (Note 4), and load the film into the camera. Open the X-ray shutter and expose the film for an appropriate time (Note 5). During exposure, pulse the light to generate the dots which define the horizontal reference line, and develop the film.

NOTE 4: For a tungsten X-ray tube typical voltage and current are 50 to 60 kV and 20 to 30 mA, respectively.

NOTE 5: Use of high-speed, instant film (ASA 300) and a fluorescent screen results in typical exposure times of 1 to 2 min.

16.3 Read the Laue pattern on the film.

16.3.1 Align the scribed line on the underside of the drafting head protractor with the two light-generated dots that define the horizontal reference line and set the protractor to 0°.

16.3.2 Rotate the protractor so that the scribed line is aligned with the zone of Laue spots that (1) passes through the center of the pattern and (2) is nearest to the horizontal reference line (see Figure 6).

16.3.3 Read to the nearest 0.1° (6 min) the angle on the protractor and record the value as the angular deviation, α.

17 Report

17.1 Report the following information:

17.1.1 Identity of samples tested including vendor and vendor lot identity,

17.1.2 Date of test and identity of operator making the measurements,

17.1.3 Specified flat and surface orientations,

17.1.4 The measured angular deviation α for each wafer, and

17.1.5 The photograph or a copy of the photograph of the Laue pattern for each wafer.

18 Precision and Bias

18.1 The single-instrument, multi-operator precision of this test method was estimated by extensive testing with three operators. This test yielded a distribution of readings with a 1-*s* value of 7 min of arc.

19 Keywords

19.1 crystallographic orientation; flats; Laue diffraction; silicon; single crystal

SEMI MF951-0305
TEST METHOD FOR DETERMINATION OF RADIAL INTERSTITIAL OXYGEN VARIATION IN SILICON WAFERS

These test methods were technically approved by the Global Silicon Wafer Committee and are the direct responsibility of the North American Silicon Wafer Committee. Current edition approved for publication by the North American Regional Standards Committee on December 10, 2004. Initially available at www.semi.org January 2005; to be published March 2005. Original edition published by ASTM International as ASTM F 951-85. Last previous edition SEMI MF951-02.

1 Purpose

1.1 The presence of oxygen can be beneficial to certain manufacturing operations by preventing the formation of process-induced defects. To the extent that this is true, it becomes important that the oxygen be uniformly distributed over the entire slice.

1.2 Multiple test plans are included to satisfy a variety of requirements. The characteristic shape and magnitude of oxygen concentration distributions in crystals are functions of the crystal growth process. Although the specified test plans are intended to cover oxygen concentration distributions which are typically found, other distributions may occur. In such cases, it may be necessary to use test positions other than those specified in order to adequately describe the distribution pattern.

1.3 This test method may be used for process control, research and development, and materials acceptance purposes. In the absence of an interlaboratory evaluation of the precision of this test method, its use for materials acceptance is not recommended unless the parties involved establish the degree of correlation which can be expected (see §12).

2 Scope

2.1 This test method covers test site selection and data reduction procedures for radial variation of the interstitial oxygen concentration in silicon slices typically used in the manufacture of microelectronic semiconductor devices.

2.2 This test method is intended as both a referee and production test through selection of an appropriate test position plan.

2.3 The interstitial oxygen content may be measured in accordance with SEMI MF1188, SEMI MF1619, DIN 50438/1, JEITA EM-3504, or any other procedure agreed upon by the parties to the test.

NOTE 1: SEMI MF1366 is not based on infrared absorption measurement and it measures total oxygen content, not interstitial oxygen content. It is also a destructive technique. However, it can be used to determine the radial variation of the oxygen content if suitable modifications of the test procedure are made.

2.4 Acceptable thickness and surface finish for the test specimens are specified in the applicable test methods. This test method is suitable for use on chemically etched, single-side polished and double-side polished silicon wafers or slices with no surface defects that could adversely change infrared radiation transmission through the test specimen (subsequently called slice), provided that appropriate test methods for oxygen content are selected.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health guides and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 Variations of optical thickness can be caused by thickness or surface finish variations, or both.

3.2 Beam size differences from instrument to instrument can cause errors when the beam area is smaller than the aperture used in this test method.

4 Referenced Standards

4.1 *SEMI Standards*

SEMI MF81 — Method for Measuring Radial Resistivity Variation on Silicon Wafers

SEMI MF533 — Test Method for Thickness and Thickness Variation of Silicon Wafers

SEMI MF1188 — Test Method for Interstitial Atomic Oxygen Content of Silicon by Infrared Absorption

SEMI MF1366 — Test Method for Measuring Oxygen Concentration in Heavily Doped Silicon Substrates by Secondary Ion Mass Spectrometry

SEMI MF1619 — Test Method for Measurement of Interstitial Oxygen Content of Silicon Wafers by Infrared Absorption Spectroscopy with *p*-Polarized Radiation Incident at the Brewster Angle

4.2 *JEITA* (*formerly JEIDA*) *Standard*[1]

EM-3504 (61) — Standard Test Method for Interstitial Atomic Oxygen Content of Silicon by Infrared Absorption

4.3 *DIN Standards*[2]

50435 — Determination of the Radial Resistivity Variation of Silicon or Germanium Slices by Means of a Four-Point-DC-Probe

50438/1 — Determination of Impurity Content in Silicon by Infrared Absorption: Oxygen

50441/1 — Determination of the Geometric Dimensions of Semiconductor Slices: Measurement of Thickness

4.4 *ANSI Standard*[3]

ANSI/ASQC Z1.4–1993 Sampling Procedures and Tables for Inspection by Attributes

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

5 Summary of Test Method

5.1 Instruments are selected and qualified according to the test procedure chosen.

5.2 Measurements are made at the specified test locations and a relative oxygen variation is calculated by one of four available plans.

6 Apparatus

6.1 *Infrared Spectrophotometer*, as required by the test method for interstitial oxygen measurement.

6.2 *Thickness Measurement Equipment*, as required by the test method.

6.3 *Fixturing*, capable of positioning test slices to the tolerances required in each plan, including a fixed 7.0 ± 0.5 mm circular aperture centered on the infrared beam.

7 Sampling

7.1 Sampling plans must be agreed upon by the participants.

7.2 For acceptance testing, ANSI/ASQC Z1.4-1993, normal level, must be used unless other agreements have been made.

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1 Japan Electronics and Information Technology Industries Association, 3rd floor, Mitsui Sumitomo Kaijo Bldg. Annex, 11, Kanda-Surugadai 3-chome, Chiyoda-ku, Tokyo 101-0062, Japan, Telephone: 81.3.3518.6434, Fax: 81.3.3295.8726, Website: www.jeita.or.jp.

2 Deutches Institut für Normung e.V., standards are available in both English and German editions from Beuth Verlag GmbH, Burggrafenstrasse 6, 10787 Berlin, Germany, Telephone: 49.30.2601-0, Fax: 49.30.2601.1263, Website: www.beuth.de.

3 American National Standards Institute, New York Office: 25 West 43rd Street, New York, NY 10036, USA. Telephone: 212.642.4900, Fax: 212.398.0023, Website: www.ansi.org.

8 Test Plans

8.1 *Test Plan A*

8.1.1 This test plan consists of measurements (1) at the center of the wafer, located within 3 mm of the intersection of any two diameters that are at least 45° apart, and (2) at one position 10.0 ± 1 mm from the sample periphery on one of the diameters parallel with or perpendicular to the major flat (or, for notched wafers, perpendicular to or parallel with the notch axis).

8.1.2 The positions of edge measurement sites are determined by the distance from the sample periphery to the center of the aperture.

8.1.3 The position A1 on the diameter perpendicular to the major flat (parallel with the notch axis) and at the side of the wafer opposite the major flat (or notch) is preferred (see Figure 1). Positions A2 and A3 on the diameter parallel with the major flat (perpendicular to the notch axis) may be selected to replace position A1 if agreed to by both customer and supplier. Specify Test Plan A1, Test Plan A2, or Test Plan A3 depending on the position selected.

8.1.4 When an interfering minor flat is present, locate the edge position as though the minor flat were not present.

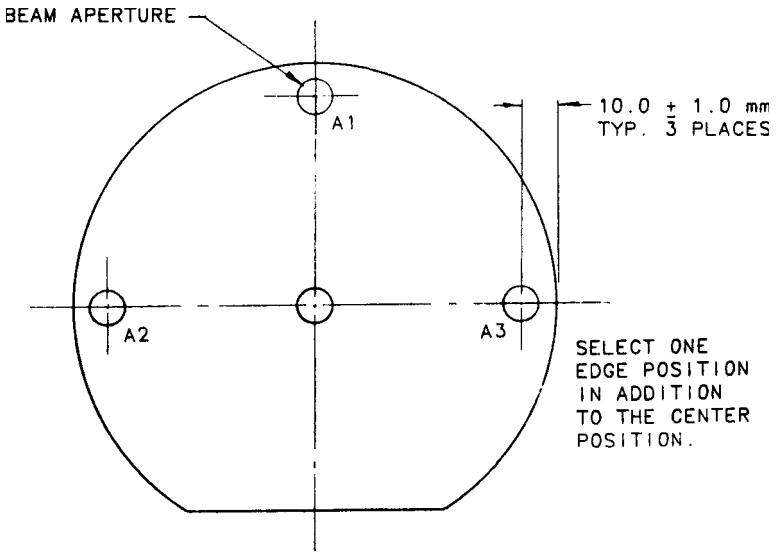

Figure 1
Test Plan A

8.2 *Test Plan B*

8.2.1 This test plan consists of measurements at the center of the wafer, located within 3 mm of the intersection of any two diameters that are at least 45° apart, and at two positions 10.0 ± 1 mm from the sample periphery on each end of the diameter parallel with the major flat (or, for notched wafers, perpendicular to the notch axis) (see Figure 2).

8.2.2 In addition, two optional measurements may be made at the half radius [(R/2) ± 1 mm] positions on the same diameter of the wafer. If made, these optional measurements must be in addition to measurements at the center and two edge positions. Customer and supplier must agree on the use of measurements at R/2 positions. Specify Test Plan B1 when using all five positions.

8.2.3 When an interfering minor flat is present, locate the edge position as though the minor flat were not present.

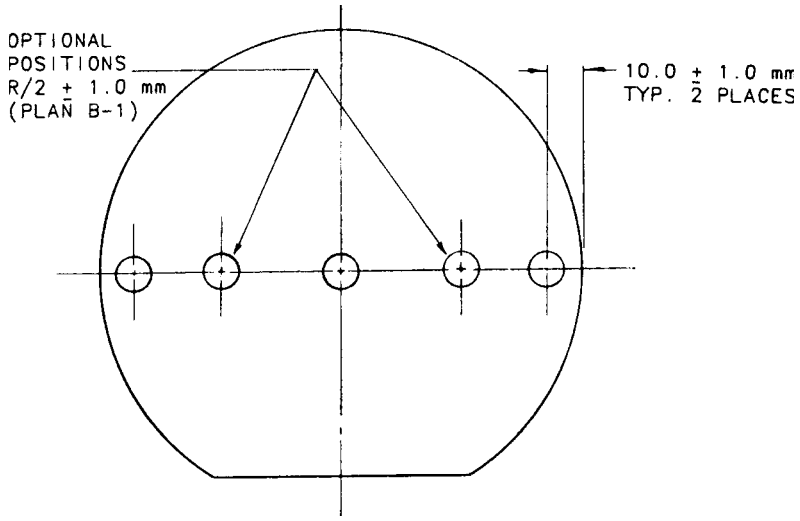

Figure 2
Test Plan B

8.3 *Test Plan C*

8.3.1 This test plan consists of measurements at each of the five measurement positions defined in Plan B of both SEMI MF81 and DIN 50435 and in both SEMI MF533 and DIN 50441/1.

8.3.2 Edge position tolerances are ±1 mm; center position shall be within 3 mm of the intersection of any two diameters which are at least 45° apart (see Figure 3).

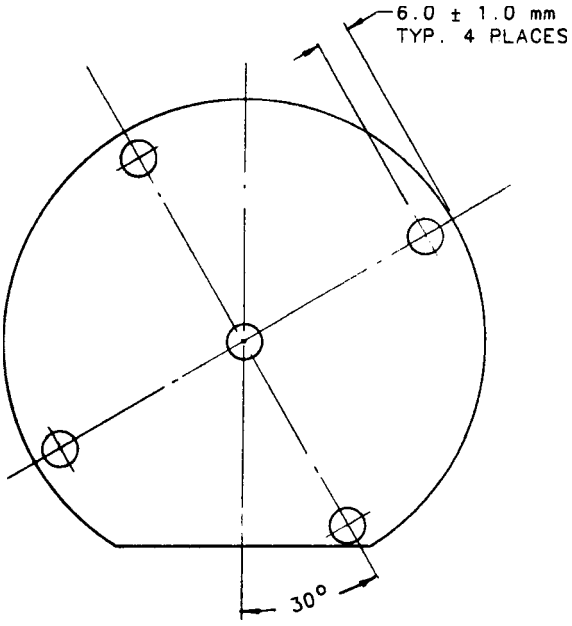

Figure 3
Test Plan C

8.4 *Test Plan D*

8.4.1 This test plan consists of measurements at a series of points between the edge and center of the wafer along the diameter parallel with the major flat (or perpendicular to the notch axis) (see Figure 4).

8.4.2 The first position, nearest sample periphery, shall be located in the same manner as Position A2 of Plan A (see Figure 1).

8.4.3 Position spacing shall be in 10 cm steps, center-to-center, continuing to within 5 mm of the sample center.

8.4.4 Position numbering begins at the edge (1) and is sequenced toward the center position.

8.4.5 If a minor flat is located near Position 1, begin sequencing at the opposite edge.

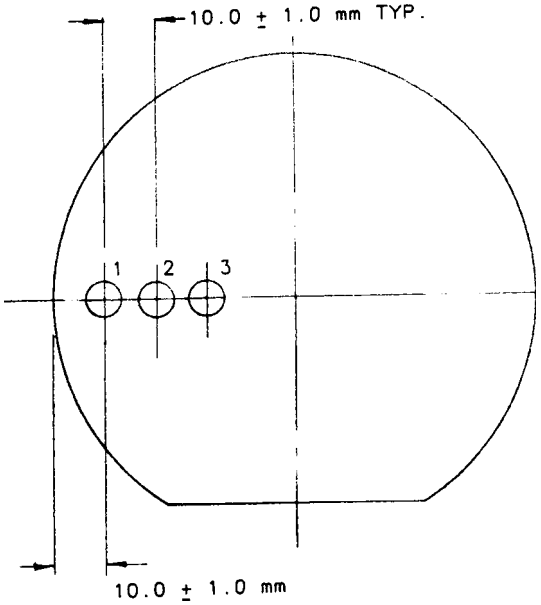

Figure 4
Test Plan D

9 Procedure

9.1 Select one of the test plans defined in §8.

9.2 For referee tests, mark the side of the test slice facing the spectrophotometer infrared source in a noninterfering manner.

9.3 Place test slice in the fixture apparatus and position in accordance with the selected test plan.

9.4 If the slice thickness is not known for each test site of the selected test plan to ± 0.5% of the nominal slice thickness, measure the slice thickness at each test site in accordance with SEMI MF533 or DIN 504441/1. Record the measured or known thicknesses.

9.5 Direct the spectrophotometer infrared beam through the 7 mm aperture located adjacent to the test slice. Move the test slice, relative to the stationary beam and aperture, to the first test site of the selected plan. Measure and record the oxygen content at this test site.

9.6 After making the first measurement, move the test slice, relative to the stationary beam and aperture, to the remaining test sites of the selected plan. Measure and record oxygen content at each test site.

9.6.1 Keep all controllable instrument parameters constant during a test sequence (number of scans, temperature, reference slice, resolution, etc.).

9.7 For referee tests, repeat the test plan sequence four additional times.

10 Calculations

10.1 Calculate the radial oxygen variation (*ROV*), in percent, for the sample plan selected:

10.1.1 *Test Plan A — Two Positions* (Figure 1):

$$ROV = \frac{\text{Edge Value} - \text{Center Value}}{\text{Center Value}} \times 100 \quad (1)$$

10.1.2 *Test Plan B — Three Positions* (Center and Two Edges, Figure 2):

$$ROV = \frac{(\text{Avg of Edge Values}) - \text{Center Value}}{\text{Center Value}} \times 100 \quad (2)$$

10.1.3 *Test Plan B1 — Five Positions* (Figure 2):

10.1.3.1 *ROV* is the larger of the values found from Equation 2 and from the following:

$$ROV = \frac{(\text{Avg of R/2 Values}) - \text{Center Value}}{\text{Center Value}} \times 100 \quad (3)$$

10.1.4 *Test Plan C — Five Positions* (Figure 3):

$$ROV = \frac{(\text{Avg of Edge Values}) - \text{Center Value}}{\text{Center Value}} \times 100 \quad (4)$$

10.1.5 *Test Plan D — Multiple Positions* (Figure A1-4):

$$ROV = \frac{\text{Individual High Value}) - \text{Individual Low Value}}{\text{Center Value}} \times 100 \quad (5)$$

NOTE 2: All edge positions are located from the center of the IR beam to the slice edge. All other non-center positions are located such that the center of the IR beam is located as given by the dimensions in Figures 1–4.

10.2 For referee tests, calculate the *ROV* for each of the five determinations and calculate the average *ROV* as follows:

$$ROV = \frac{ROV_1 + ROV_2 + ROV_3 + ROV_4 + ROV_5}{5} \quad (6)$$

where ROV_i is the *ROV* calculated from the i^{th} measurement.

11 Report

11.1 Report the following information:

11.1.1 Date, operator, and affiliation,

11.1.2 Description of test method used,

11.1.3 Number of slices and their identification,

11.1.4 Sample descriptions including nominal resistivity, thickness, diameter, and surface finishes,

11.1.5 Sample plan used,

11.1.6 Instrument factors,

11.1.6.1 Manufacturer/model,

11.1.6.2 Resolution,

11.1.6.3 Apertured beam size,

11.1.6.4 Differential or air reference method,

11.1.6.5 Measurement wavelength region,

11.1.7 *ROV* results, and

11.1.8 Any unusual relevant conditions.

12 Precision

12.1 The test method precision is directly dependent on the precision of the individual oxygen measurements. If the only sources of precision errors are the individual measurements, the radial oxygen variation precision can be computed for each sampling plan.

13 Bias

13.1 No reference standards are available for oxygen variation, so it is impossible to determine bias except for that of the individual measurements. Bias of the individual measurements should be determined in accordance with the procedures of the test methods utilized.

14 Keywords

infrared transmission; interstitial oxygen; oxygen; radial variation; silicon; uniformity; variation

SEMI MF1049-0304
PRACTICE FOR SHALLOW ETCH PIT DETECTION ON SILICON WAFERS

This practice was technically approved by the Global Silicon Wafer Committee and is the direct responsibility of the North American Silicon Wafer Committee. Current edition approved for publication by the North American Regional Standards Committee on December 4, 2003. Initially available at www.semi.org February 2004; to be published March 2004. Originally published by ASTM International as ASTM F 1049-87. Last previous edition SEMI MF1049-02.

1 Purpose

1.1 High levels of etch pits are reported[1] to indicate metallic contamination that is detrimental to wafer processing. This can be deduced from the density of etch pits on the surface of the wafer.

1.2 This practice is used to detect shallow etch pits that may be related to the level of metallic impurities near the surface of silicon epitaxial or polished wafers.

2 Scope

2.1 This practice covers detection of high densities of shallow etch pits on silicon wafers doped either *p*- or *n*-type and with resistivities as low as 0.005 Ω·cm. This practice is applicable for silicon wafers cut from crystals grown in either a (111) or (100) crystal orientation.

2.2 This practice is not recommended for use in defect density evaluations, but as a subjective means of estimating defect densities and distributions on the surface of a polished or epitaxial wafer.

NOTE 1: For determination of shallow and other defect densities in wafer production environments, use of the sequence of procedures in SEMI MF 1726, SEMI MF1727, SEMI MF1809, and SEMI MF1810 is recommended.

2.3 This practice utilizes a thermal oxidation process followed by a chemical preferential etchant to create and then delineate shallow etch pits.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health guides and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 Etch artifacts are the primary cause of difficulty in identifying shallow etch pits. Etch artifacts are generated in various ways such as gas bubble formation during etching, improperly cleaned surface prior to etching, or insufficient etch solution volume.

3.2 Excessive silicon staining (very dark color) during the preferential etching may obscure or prevent the development of shallow etch pits on heavily doped *p*-type silicon material (<0.2 Ω·cm).[2]

NOTE 2: Light staining will not affect subsequent defect etch results. However, heavy stains are undesirable.

4 Referenced Standards

4.1 *SEMI Standards*

SEMI C54 — Specifications and Guidelines for Oxygen

SEMI C59 — Specifications and Guidelines for Nitrogen

SEMI C28 — Specifications and Guidelines for Hydrofluoric Acid

SEMI M17 —Guide for a Universal Wafer Grid

SEMI MF154 — Guide for Identification of Structures and Contaminants Seen on Specular Silicon Surfaces

SEMI MF1726 — Practice for Analysis of Crystallographic Perfection of Silicon Wafers

SEMI MF1727 — Practice for Detection of Oxidation Induced Defects in Polished Silicon Wafers[3]

SEMI MF1809 — Guide for Selection and Use of Etching Solutions to Delineate Structural Defects in Silicon

SEMI MF1810 — Test Method for Counting Preferentially Etched or Decorated Surface Defects in Silicon Wafers

4.2 *ASTM Standard*

D 5127 — Guide for Ultra Pure Water Used in the Electronics and Semiconductor Industry[3]

1 Pearce, C. W., and McMahon, R. G., "Role of Metallic Contamination in the Formation of 'Saucer' Pit Defects in Epitaxial Silicon," *J. Vac. Sci. Tech.*, **14**, 40 (1977).

2 Schimmel, D. G., and Elkind, M. J., "An Examination of the Chemical Staining of Silicon," *J. Electrochem. Soc.*, **125**, 152 (1978).

3 *Annual Book of ASTM Standards*, Vol 11.01, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Telephone: 610-832-9500, Fax: 610-832-9555, Website: www.astm.org

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

5 Terminology

5.1 *Definitions*

5.1.1 *haze* — on a semiconductor wafer, non-localized light scattering resulting from surface topography (microroughness) or from dense concentrations of surface or near-surface imperfections.

5.1.1.1 *Discussion* — Haze due to the existence of a collection of imperfections of the type that result in haze cannot be readily distinguished by the eye or other optical detection system without magnification. In a scanning surface inspection system, haze and laser-light scattering events comprise the laser surface scanner signal due to light scattering from a wafer surface.

5.1.2 *shallow etch pits* — etch pits that are small and shallow in depth under high magnification, >200×. Also known as *saucer pits*.

6 Summary of Practice

6.1 Silicon wafers, either epitaxial or polished, are thermally oxidized and preferential etched to reveal small etch pits, shallow in depth, when observed through an interference contrast microscope.

6.2 The distribution of the etch pits on the surface of the wafer is determined and recorded on a diagram.

7 Apparatus

7.1 *High-Intensity, Narrow-Beam Light Source* — Tungsten filament with a concentrated beam intensity greater than 16 klx (1500 fc) and a beam diameter of 20 to 40 mm (0.8 to 1.6 in.) at a position 100 mm (4 in.) from the light-source housing. The light beam shall not be collimated and shall be capable of forming an image of the bulb filament at the lamp focus length.

NOTE 3: Some standard microscope illuminators meet these requirements.

7.2 *Hydrofluoric Acid-Proof Chemical Laboratory Apparatus* — Fluorocarbon, polyethylene, or polypropylene beakers, graduates, tweezers, eye protection, apron, gloves, and protective sleeves.

7.3 *Wafer Holders* — HF acid-proof wafer carriers which hold wafers. These are required if more than one wafer is to be etched at a time.

7.4 *Optical Microscope* — Equipped with interference contrast attachment. The eyepiece and objective lens in combination shall give 200× to 1000× magnification.

NOTE 4: Nomarski differential interference contrast is an example of interference contrast.

7.4.1 *Stage Micrometer* — With divisions of 0.002 mm or finer, if an estimate of the shallow etch pit density is to be made.

7.5 *Acid Sink* — A fume hood and facilities for disposing of acids and their vapors.

7.6 *Spin Dryer* — Used to dry the wafers. Although this item is not required, it is useful to provide a surface free of residue artifacts.

8 Reagents and Materials

8.1 *Purity of Reagents* — Reagents for which SEMI specifications have not been developed shall conform to the specifications of the Committee of Analytical Reagents of the American Chemical Society[4]. Other grades may be used provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8.1.1 *Hydrofluoric Acid* (HF) — concentrated, in accordance with Grade 1 of SEMI C28.

8.1.2 *Nitrogen* (N_2) — 99.998% purity, in accordance with Grade 4.8 of SEMI C59.

8.1.3 *Oxygen* (O_2) — 99.98% purity, in accordance with SEMI C54.

8.2 *Purity of Water* — Reference to water shall be understood to mean Type E-3 or better water as described in ASTM Guide D 5127.

8.3 *Schimmel Etch for* (*100*) *and* (*111*) *Surfaces*[5]

8.3.1 *Chromic Acid Solution* — Make a 0.75 M solution by placing 75 g of chromium trioxide (CrO_3) in a 1-L glass volumetric flask and then add sufficient water to make a solution volume of 1 L, or 1000 mL. The solution may be stored up to 6 months in clean glass, TFE-fluorocarbon, polyethylene, or polypropylene bottles.

8.3.2 *For Test Specimens with Resistivity Greater Than 0.2 Ω·cm n- or p-Type* — Immediately before using, add 2 parts hydrofluoric acid (HF) to 1 part chromic acid solution by volume. Prepare and mix in HF-proof beakers.

8.3.3 *For Test Specimens with Resistivity Less Than 0.2 Ω·cm n- or p-Type* — Immediately before using,

4 Reagent Chemicals, *American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

5 Schimmel, D. G., "Defect Etch for ⟨100⟩ Silicon Evaluation," *J. Electrochem. Soc.*, **126**, 479–483 (1979).

add 2 parts hydrofluoric acid (HF) to 1 part chromic acid solution and 1.5 parts water by volume. Prepare and mix in HF-proof beakers.

8.3.4 The specified chemicals shall have the following nominal assay:

- Chromium trioxide >98.0%
- Hydrofluoric acid, concentrated 49 ± 0.25%

8.3.5 The chemicals used in this evaluation procedure are potentially harmful and must be handled in an acid exhaust fume hood, with utmost care at all times.

9 Sampling

9.1 Select wafers to represent the lot to be tested as specified in producer-consumer agreements.

10 Specimen Preparation

10.1 In most instances this practice may be used for polished or epitaxial wafers as they are received, but if cleaning is required, the parties using this practice must establish a mutually acceptable cleaning procedure prior to etching.

11 Procedure

11.1 Handle wafers only with a clean, nonmetallic pickup tool or automated transfer unit to avoid scratching or contaminating the surface.

11.2 Oxidize the wafers by the thermal sequence listed in Table 1.

NOTE 5: Large diameter furnaces may have difficulty in duplication of this process. Rapid thermal processing is an acceptable alternative.

11.2.1 Preheat the furnace to the push temperature.

11.2.2 Load the specimen wafers into the wafer boat, being careful to avoid binding, scratching, or contamination.

Table 1 Shallow Pit Oxidation Procedure

Step	*Function*	*Conditions*
Push (Load)	Ambient	1% O_2, 99% N_2
	Temperature	950° C
	Push Rate	60 cm/min.
Oxidation	Ambient	1% O_2, 99% N_2
	Temperature	950° C
	Time	7 min
Pull (Unload)	Ambient	1% O_2, 99% N_2
	Temperature	950° C
	Pull Rate	60 cm/min.

11.2.3 Insert the boat into the hot zone at the rate called for in Table 1. The wafer boat shall be centered in the uniform hot zone.

11.2.4 Follow the oxidation and pull procedures as specified in Table 1.

11.2.5 Because silicon wafers and quartz accessories are extremely hot when they are removed from the oxidation furnace, allow the materials adequate time to cool before handling.

11.3 Transfer the room temperature wafers from the quartz boat to a wafer holder using the pickup tool or automated transfer unit.

11.4 Remove the thermal oxide layer using hydrofluoric acid for 2 min followed by water rinse and dry, using the spin dryer, if available.

11.4.1 *Caution* — Hydrofluoric acid solutions, used here and for etching, are particularly hazardous and specific preventive measures must be strictly observed. Safety or protective gear should be worn while handling acid solutions. Safety requirements vary, but the essentials are: acid sink and personnel covering including plastic gloves, safety glasses, face shield, acid gown, and shoe covers. Hydrofluoric acid solutions should not be used by anyone who is not familiar with the specific preventive measures and first aid treatments given in the appropriate Material Safety Data Sheet.

11.5 Etch the wafers for 2 minutes in an adequate amount of Schimmel etch appropriate for the wafer resistivity (see Sections 8.3.2 and 8.3.3). If the defect etch pits are too small to distinguish, increase the etch time up to 5 min.

11.5.1 **Warning:** Chromic acid, contained in the defect etch solutions, should not be released into drains that lead directly to domestic sewers. Chromates are an extreme eco-hazard and must be first treated by reduction to the trivalent form. Chromic acid is a strong oxidizing agent and should not be allowed to contact organic solvents or other easily oxidized materials.

11.6 Quickly transfer the loaded wafer holder into a water bath to rinse the wafers.

11.7 Dry the wafers, using the spin dryer, if available.

12 Evaluation

12.1 View the wafers at 1× magnification under the high-intensity, narrow-beam light source in a dark hood. If haze is observed, further examine the etched wafer under a minimum of 200× magnification to establish if the haze is due to shallow etch pits. If no shallow etch pits are seen, record the wafer as being free of shallow etch pits.

NOTE 6: The percentage of the wafer covered may be determined with the use of the universal wafer grid specified in SEMI M17 that divides the wafer into 1000-area elements. If the universal wafer grid is used, record the size of the edge exclusion or the fixed quality area used. A1.6-mm peripheral ring on a 125-mm diameter wafer represents 5% of the wafer area.

12.2 Determine the level of haze present on the surface from Table 2.

Table 2 Haze Level Classification

Level	*% of Wafer Area*
A	0–5
B	5–25
C	25–75
D	75–100

12.3 *Optional Estimation of Shallow Etch Pit Density* — If it is desired to estimate the shallow etch pit density, use the procedure in Related Information 1.

13 Report

13.1 Report the following information:

13.1.1 Date of test, laboratory and operator identification,

13.1.2 Identification of wafer lot,

13.1.3 Identification of the test wafer(s) (including conductivity type, orientation, diameter, growth method, and back surface condition),

13.1.4 Level of haze for each wafer tested, and

13.1.5 A diagram showing the location and distribution of areas of high shallow etch-pit density, and, if estimates of shallow etch-pit density are made, locations of the count positions.

13.2 If the shallow etch-pit density was estimated on one or more wafers, also report the following information of each wafer tested:

13.2.1 Magnification used in the test,

13.2.2 Average estimated shallow etch-pit density, and

13.2.3 Maximum and minimum measured shallow etch-pit density, if more than one count position was employed.

14 Keywords

14.1 epitaxial; oxidation; preferential etch; saucer pit; shallow etch pit; silicon