

SEMI M73-1108

TEST METHODS FOR EXTRACTING RELEVANT CHARACTERISTICS FROM MEASURED WAFER EDGE PROFILES

This standard was technically approved by the global Silicon Wafer Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on August 29, 2008. It was available at www.semi.org in October 2008 and on CD-ROM in November 2008.

1 Purpose

1.1 SEMI M1 specifies the contour of the shaped edge of silicon wafers by using templates that allow a wide variation in wafer edge profiles manufactured by silicon suppliers to still meet the specification.

1.2 In many advanced wafer applications, a much tighter specification of the edge profile is required to control variations in subsequent circuit processing. These specifications frequently include values for certain characteristics that describe the segments of the edge profile contour.

1.3 A prerequisite for specifying tighter tolerances on edge profiles is an agreement about the names of the relevant characteristics used for describing edge profiles and a method for extracting these characteristics from a measured edge profile. Therefore in these test methods, terms used to describe the characteristics of the edge profile of silicon wafers are named and their meaning is illustrated by a schematic drawing.

1.4 This standard covers two test methods for deriving these characteristics from a measured edge profile.

2 Scope

2.1 These test methods are both in use within the industry. They are based on fitting the measured edge profile over certain segments with straight lines, circular arcs, or tangent lines to obtain values for profile segment parameters such as

- bevel angles,
- edge widths,
- apex lengths,
- apex angles, and
- shoulder radii.

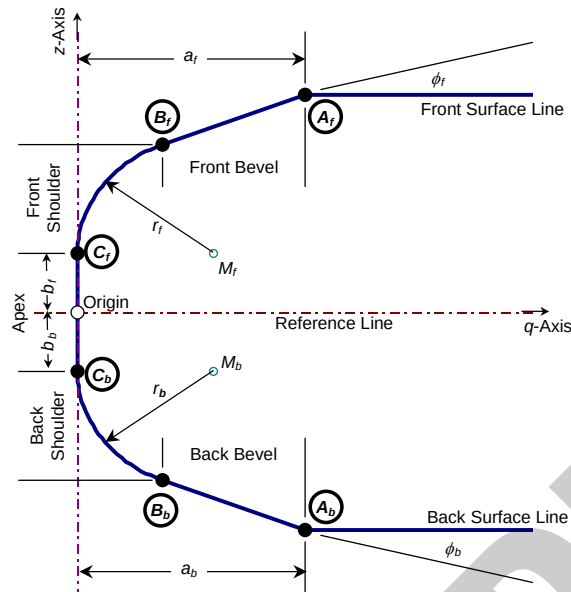
In addition, the locations of the reference points that separate the various segments of the edge profile are determined. These segment parameters are listed in order around the profile in Table 1 and are illustrated in Figure 1.

Table 1 Segment Parameters of an Edge Profile

Wafer thickness, t (μm) ^{#1}	Edge Width, a_f or a_b (μm) ^{#2}	Segment Parameters	Symbol	Unit	Explanation
		Front Bevel Angle	ϕ_f	°	Angle between front surface and front bevel, taken as positive into the wafer.
		Front Shoulder Radius	r_f	μm	Radius of the arc of the front shoulder.
		Front Apex Length	b_f	μm	Distance from origin to the beginning of the front shoulder arc.
		Front Apex Angle	β_f	°	Angle between z-axis and front apex, taken as positive in the + q direction.
		Back Apex Angle	β_b	°	Angle between z-axis and back apex, taken as positive in the + q direction.
		Back Apex Length	b_b	μm	Distance from origin to the beginning of the back shoulder arc.
		Back Shoulder Radius	r_b	μm	Radius of the arc of the back shoulder.
		Back Bevel Angle	ϕ_b	°	Angle of the back surface and back bevel, taken as positive into the wafer.

#1 The wafer thickness is in the z-direction.

#2 The edge width is in the q -direction. The edge width may be the same or different on the front and back surfaces of the wafer; if it is the same, the profile is symmetrical.



NOTE 1: In this figure and in the other figures in this standard, the edge of the wafer is depicted as a cross section of the wafer perpendicular to the wafer surface along the circular circumferential part of the wafer edge with the q -axis positive along a radius toward the center of the wafer and the z -axis positive toward the front surface of the wafer.

The apex angles β_f and β_b are assumed to be equal to zero for model profiles.

NOTE 2: In a real edge profile on a wafer, the sharp angles at the reference points A_f and A_b are smoothed so that the actual edge width is not so precisely identified. Consequently, the entire region of the wafer between the edge width and the outer limit of the fixed quality area cannot be expected to be flat.

Figure 1
Schematic Drawing of a Model Edge Profile Illustrating the Terms, Symbols and Reference Points Used to Describe the Profile

2.2 Because the fitting locations and procedures differ considerably between the two methods, the results obtained for specific segment parameters are not likely to be identical.

2.3 Both test methods covered by this standard are applicable to all types of measured edge profiles on silicon wafers.

2.3.1 In Test Method 1, the specified edge width is used to determine the regions of the measured edge profile to be fitted and the coordinates of the reference point locations are derived from fitted regions of the measured edge profile. Test Method 1 describes how to:

- extract the edge profile parameters directly from the measured edge profile at defined distances from the periphery of the wafer and compare them with the specified values,
- reconstruct the edge profile using the extracted characteristics, and
- assess the agreement between the measured, target, and reconstructed profiles, enabling the user to see how representative the extracted parameters are regarding the measured profile.

2.3.2 In Test Method 2, the specified bevel angle is used to determine both the regions of the measured edge profile to be fitted and the coordinates of the reference points A_f and B_f . Test Method 2 describes how to:

- extract the edge profile characteristic parameters by fitting lines or arcs to portions of the measured edge profile at defined distances from the periphery of the wafer and compare them with the specified values,
- compare the fitted lines and arcs with the appropriate portions of the measured profile enabling the user to see how well fit the extracted parameters are in each segment.

NOTE 1: For both test methods, measured results for three different edge profile types are given as examples in Related Information 1 at the end of this standard.

2.4 These test methods refer explicitly to silicon wafers, but they may also be applied to wafers of other materials.

2.5 These test methods do not cover requirements either for the equipment used to measure the edge profile or for the methodology of such measurement. They also do not describe how to assess the capability of either the equipment or the techniques for measuring edge profiles on wafers.

2.6 These test methods also do not cover evaluation of either surface finish or edge roll-off in the near-edge region.

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 The results of these test methods depend on the profile measurement quality.

3.2 The results of these test methods may be adversely impacted by particulate contamination on the wafer, defects of the wafer, misalignment of measurement system used, misalignment of wafer relative to measurement system, and severe wafer warp.

3.3 The values obtained for the extracted characteristics determined by these test methods are dependent on the values of the specified parameters, e.g., edge width or bevel angle, on which the test procedures are based.

4 Referenced Standards and Documents

4.1 SEMI Standards

SEMI M1 — Specification for Polished Monocrystalline Silicon Wafers

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI M59 — Terminology for Silicon Technology

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

5 Terminology

5.1 General terms, acronyms, abbreviations and symbols associated with silicon technology and used in this standard are listed and defined in SEMI M59. The definitions specifically related to edge profiles that are given in SEMI M59 include *back surface*, *edge profile*, *front surface*, and *thickness*.

5.2 Other Terminology Related to Edge Profile

5.2.1 *apex* — the blunt, but not necessarily linear, segment of an edge profile, oriented approximately perpendicular to the reference line and located between the front and back shoulders.

5.2.2 *apex angle* — the angle between the z-axis and the front or back apex; the sign of the apex angle is positive if the q-coordinate increases with increasing magnitude of |z|.

5.2.3 *apex length* — the distance along the z-axis between the front and back shoulders of the edge profile, usually divided into two distances from the reference line to the front and back shoulders.

5.2.4 *bevel* — the segment of the edge profile located between the surface line and the shoulder.

5.2.5 *bevel angle* — the angle between the median plane and the front or back bevel of the edge profile.

5.2.6 *center-referenced (adj.)* — property of a measurement, calculation, or coordinate system with the position established using the wafer center as the origin, such as in the wafer coordinate systems of SEMI M20.

5.2.7 *edge, of a silicon wafer* — the annular region of the wafer from the periphery inward that has been intentionally shaped chemically or mechanically to form the edge profile.

5.2.8 *edge-referenced (adj.)* — property of a measurement, calculation, or coordinate system with the position established using the periphery of the wafer as the origin.

5.2.9 *edge width* — the distance inwardly from the periphery of the wafer to the end of the edge profile. Because the inner boundary of the edge profile is not clearly delineated (see *profile transition*), the end of the edge profile is denoted by the reference point A_i .

5.2.10 *facet* — not preferred, use *edge*.

5.2.11 *facet length* — not preferred, use *edge width*.

5.2.12 *measured edge profile* — a finite array of q, z points representing the cross-sectional view of a wafer edge profile that is acquired by a measurement system.

5.2.13 *model edge profile* — a wafer edge profile with segments consisting only of straight lines (apex and bevel), and circular arcs (shoulder) in the cross-sectional view.

5.2.14 *near-edge region* — the annulus of the wafer between the inner boundary of the edge (inner end of the edge profile) and the outer region of the fixed quality area. The near-edge region may stop at the outer boundary of the FQA or extend a small distance into the FQA depending on the context.

5.2.15 *parameter, of an edge profile segment* — characteristic of the segment (length, angle, or radius).

5.2.16 *profile transition, of a silicon wafer* — the region of the wafer where the front or back surface meets the edge.

5.2.17 *q-axis* — the reference line in the cross-sectional view of the edge of the wafer with the origin at the intersection of the reference line and the wafer periphery and the positive direction toward the wafer center

5.2.18 *reconstructed edge profile* — a model edge profile constructed by using the parameters extracted from the measured edge profile.

5.2.19 *reference line* — the line, midway between the front and back surface lines, that represents the median plane in the cross-sectional view of the edge of the wafer; it is the q -axis of the q - z edge-referenced coordinate system of that cross-sectional view.

5.2.20 *segment, of an edge profile* — a defined region of an edge profile on a silicon wafer.

5.2.21 *shoulder* — the curved region of the edge profile between the bevel and the apex.

5.2.22 *shoulder radius* — the radius of a circle representing the shoulder.

5.2.23 *surface line* — a line in the cross-sectional view of the edge of the wafer representative of the front or back wafer surface beyond a specified point on the edge profile.

5.2.24 *target profile* — a model edge profile constructed by using specified or otherwise pre-selected edge profile parameters.

5.2.25 *z-axis* — the line perpendicular to the reference line passing through the periphery of the wafer in the cross-sectional view of the edge of the wafer with origin at the intersection of the periphery and the reference line and the positive direction toward the front surface of the wafer.

5.3 Symbols

5.3.1 For the convenience of users of this standard, the symbols used herein are summarized in Table 2 and Figure 1.

Table 2 Symbols Used in this Standard

Symbol	Meaning	Unit
$\beta^{1,2}$	apex angle	degrees
$\phi^{1,2,3}$	bevel angle	degrees
$a^{1,2,3}$	edge width (previously called <i>facet length</i>)	μm
$A_i^{1,2}$	reference point where the bevel meets the surface	$\mu\text{m}, \mu\text{m}$
$b^{1,2,4}$	apex length	μm
$B_i^{1,2}$	reference point between bevel and shoulder	$\mu\text{m}, \mu\text{m}$

Symbol	Meaning	Unit
$C_i^{#1, #2}$	reference point between shoulder and apex	μm , μm
$M^{#1, #2}$	center point of shoulder circle	μm , μm
O	origin of q - z edge-referenced coordinate system used in the cross-sectional view of the edge of the wafer	0 μm , 0 μm
q	radial coordinate of the q - z edge-referenced coordinate system used in the cross-sectional view of the edge of the wafer	μm
$r^{#1, #2}$	shoulder radius	μm
t	thickness	μm
z	vertical coordinate of the q - z edge-referenced coordinate system used in the cross-sectional view of the edge of the wafer	μm

#1 When used with the subscript i either or both front and back quantities are implied, as appropriate.

#2 When used with the subscript f the front surface quantity is implied. When used with the subscript b the back surface quantity is implied.

#3 When used with a prime (') the value of edge width or bevel angle that is specified by the customer, or otherwise assumed as a starting point in the test procedure, is implied.

#4 When used without a subscript the sum of b_f and b_b is implied.

6 Edge Profile Types

6.1 For convenience in discussing edge profiles, three sets of values of the parameters of three types of edge profiles are identified as follows (see Table 1):

- A — long edge width, small shoulder radius, and long apex length.
- B — short edge width, small shoulder radius, and long apex length.
- C — intermediate edge width, large shoulder radius, and short or almost no apex length.

6.2 The values of these various parameters are given in Table 3.

Table 3 Values of the Parameters of Different Edge Profile Types

Parameter	Symbol	Edge Profile Type		
		A	B	C
Edge Width	a_f or a_b	300 to 400 μm	200 to 270 μm	240 to 310 μm
Shoulder Radius	r_f or r_b	200 to 260 μm	200 to 260 μm	300 μm to $t/2$
Apex Length	b_f or b_b	100 to 175 μm	100 to 175 μm	0 to 100 μm

7 Test Method 1 — Edge-Width Method

7.1 Summary of Method

7.1.1 The measurement location is selected (at coordinates R , θ of the wafer coordinate system defined in SEMI M20) on the periphery of the wafer. If measurements are to be made at various places around the periphery of the wafer, a sampling plan for the measurement positions is selected.

7.1.2 A measured edge profile is acquired.

7.1.3 The cross-sectional view of the measured edge profile is aligned with the outermost edge position to the left and the inward radial extent to the right.

7.1.4 A coordinate system for the characterization of the edge profile is established.

7.1.5 Intervals of measurement points are defined over which lines or circular arcs are fitted to the surface lines, bevels, shoulders and apex.

7.1.5.1 Straight lines are fitted to the measurement points on the wafer bevels, surface lines and apex on wafer front and back surfaces.

7.1.5.2 Circles with radii r_i and center points M_i are fitted to the measurement points at the edge profile shoulder on wafer front and back surfaces (where here and subsequently the subscript i stands for f , front, or b , back).

7.1.6 The locations of the six reference points A_i , B_i , and C_i , which separate the seven regions of the edge profile, are determined by the intersections of the fitted lines and the tangent points of the circles.

7.1.7 The front and back edge widths a_i , bevel angles ϕ_i , shoulder radii r_i , apex lengths b_i , and apex angles β_i are calculated using above points, lines, and circles.

7.1.8 An edge profile is reconstructed using the extracted parameters and the root-mean square deviation of the reconstructed profile from the measured profile is calculated.

7.1.9 If several azimuth positions per wafer are used, the mean values, the standard deviations and their 95%-confidence intervals are calculated.

7.1.10 The extracted parameters, the coordinates of the points A_i , B_i , and C_i , the deviation between measured and reconstructed profile as well as their statistics are reported.

7.2 Procedure

NOTE 2: The following procedures are generally performed automatically within the measurement equipment. Information is provided here to indicate the nature of the procedures employed.

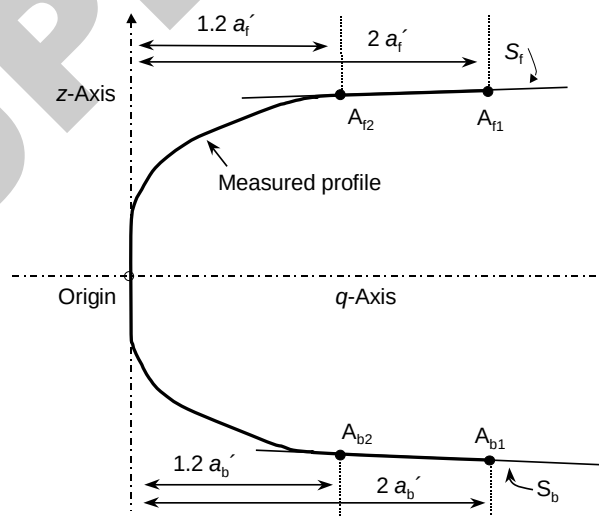
7.2.1 Select and record a sampling plan, if any, by agreement of the parties to the test.

7.2.2 Determine the azimuthal angular position of the profile measurement in degrees in accordance with the $R-\theta$ coordinate system of SEMI M20.

7.2.3 At an azimuth angle θ , acquire a wafer edge profile of the front and back regions of the wafer in the edge of the wafer from the apex to a distance greater than or equal to $2a'_i$, (where a'_i = the edge width in the front ($i = f$) and or back ($i = b$) region as specified by the customer) inward radially as a set of q - z -coordinates of measurement points by using appropriate equipment as agreed between the parties to the test.

7.2.4 Align the cross-sectional view of the measured edge profile with the outermost radial position of the edge profile to the left and the inward radial extent to the right (see Figure 1).

7.2.5 Establish a coordinate system by the following procedure (see Figure 2):



NOTE: The q -axis is bisecting the angle between lines S_f and S_b .

Figure 2
Illustration of the Set-up of a Coordinate System for the Edge Profile of a Wafer

7.2.5.1 Fit straight lines S_i ($i = f, b$), to the measurement points of the front and back surfaces with q -coordinates between $1.2 a_i'$ (point A_{i2}) and $2a_i'$ (point A_{i1}).

NOTE 3: All fits of straight lines and circular arcs to measured points required in this test method are performed by using a root-mean-square best fit procedure.

7.2.5.2 Calculate the reference line as the bisector of the lines S_i . Take the reference line as the q -axis of the coordinate system with the positive direction pointing towards the wafer center.

NOTE 4: In case the specified edge width is not known, either a default value (Table 4) or a recursive (iterative) calculation may be used (see Appendix 1).

NOTE 5: The inclination of the measured surface lines as compared to the “real” wafer surface is an artifact of currently widely used measurement systems. This difference is due to several effects like misalignment of the wafer with respect to the parallel light beam used for generating a shadow image of the edge profile, thickness variation of the wafer along the path of the light, and diffraction of light.

Table 4 Default Values for Specified Edge Widths a_f' and a_b'

Edge Profile Type	A	B	C
a_f' [μm]	350	235	275
a_b' [μm]	350	235	275

7.2.5.3 Take the origin of the coordinate system as the intersection of the q -axis with a straight line fitted through the five (5) measured points that are closest to the q -axis on each side of this axis.

7.2.5.4 Construct a line through the origin perpendicular to the q -axis and take this line as the z -axis of the coordinate system with the positive direction toward the wafer front surface.

NOTE 6: In SEMI M1, the z -axis as defined in ¶ 7.2.5.4 is called the y -axis and it has only positive values, going from its origin at the wafer surface (front or back) towards the wafer median plane.

7.2.6 Fit straight lines G_i to points of the measured edge profile in the bevel region with q -coordinates between $0.5a_i'$ (point B_{i1}) and $0.8a_i'$ (point A_{i3}) (see Figures 3 and 4).

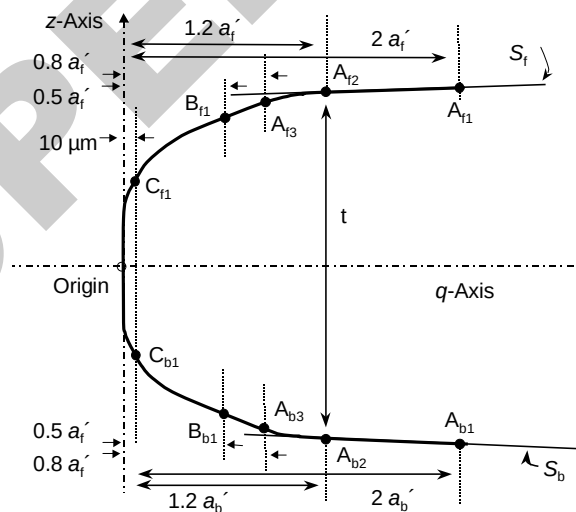


Figure 3
Determination of Points A_{i2} , B_{i1} , and C_{i1} , Ideal Surface Lines K_i , and Thickness t

7.2.6.1 Fit straight lines L_i to points of the measured edge profile in the apex region with q -coordinates between $0 \mu\text{m}$ (origin) and $10 \mu\text{m}$ (point C_{i1}) (see Figures 3 and 5).