SEMI M73-1013[E] (Reapproved 1019)
TEST METHOD FOR EXTRACTING RELEVANT CHARACTERISTICS FROM MEASURED WAFER EDGE PROFILES

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NOTICE: This Document was reapproved with minor editorial changes.

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

		Segment Parameters	*Symbol*	*Unit*	*Explanation*
Wafer thickness, t (µm)[#1]	Edge Width, a_f or a_b (µm)[#2]	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.

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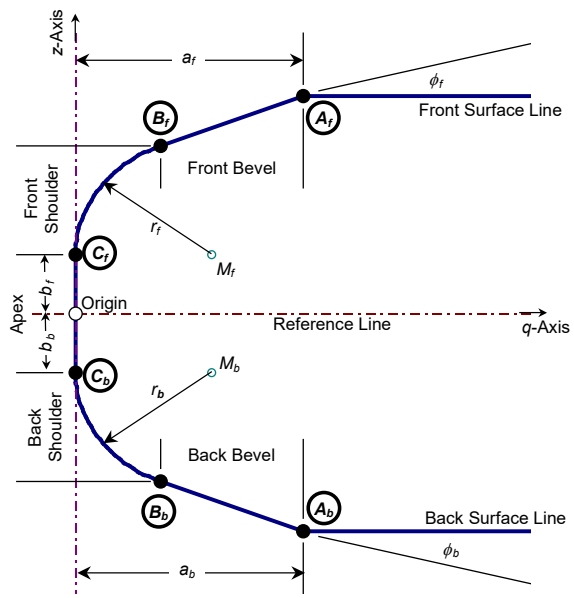
#2 The edge width is in the q-direction. If the edge width of the front and back surfaces of the wafer are the same, the profile is called symmetrical.



#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.

#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_i and B_i. 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.

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

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 and Safety Guidelines*

SEMI M1 — Specification for Polished Single Crystal Silicon Wafers

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI M59 — Terminology for Silicon Technology

SEMI M76 — Specification for Developmental 450 mm Diameter Polished Single Crystal Silicon Wafers

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 *Symbols*

5.2.1 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 *facet length*)	µm
$A_i^{\#1,\#2}$	reference point where the bevel meets the surface	µm, µm
$b^{\#1,\#2,\#4}$	apex length	µm
$B_i^{\#1,\#2}$	reference point between bevel and shoulder	µm, µm
$C_i^{\#1,\#2}$	reference point between shoulder and apex	µm, µm
$M^{\#1,\#2}$	center point of shoulder circle	µm, µm

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Symbol	*Meaning*	*Unit*
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 value ranges of the parameters of Table 1 are identified as follows for three types of edge profiles:

- 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 For 450 mm wafers only one set of values is reported in Table 3, according to the specifications for such wafers in SEMI M1.

6.3 The value ranges the various parameters may individually assume for the four edge profiles types are shown in Table 3.

Table 3 Value Ranges of the Parameters of Different Edge Profile Types for 300 and 450 mm Wafers

Parameter	*Symbol*	*300 mm Wafer 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
		450 mm Wafer Edge Profile		
Edge Width	a_f or a_b	300 to 400 µm		
Shoulder Radius	r_f or r_b	160 to 245 µm		
Apex Length	b_f or b_b	120 to 260 µm		

NOTE 2: The values in Table 3 do not represent specifications for the wafer edge profile. They only outline the range which the individual parameters may assume for the different edge profile types. For specifications of the wafer edge profile refer to SEMI M1 or SEMI M76.

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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 3: 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-θ 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):

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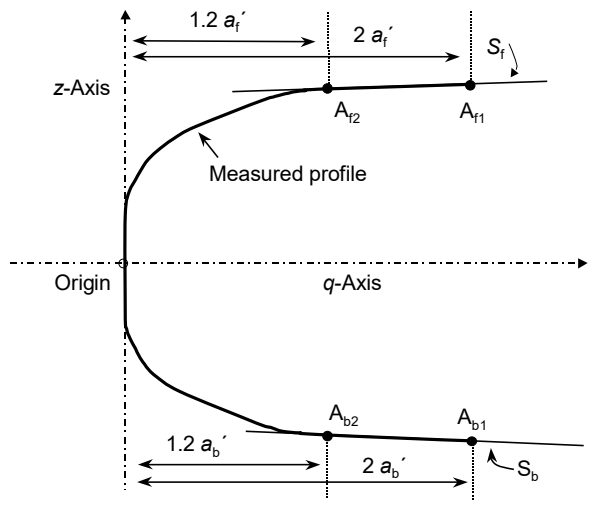

#1 The q-axis is bisecting the angle between lines S_f and S_b.

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 4: 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 5: 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 6: 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'

	300 mm Wafer Edge Profiles		
	A	*B*	*C*
a_f', a_b' [µm]	350	235	275
	450 mm Wafer Edge Profile		
a_f', a_b' [µm]	350		

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 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 7: 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.

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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).

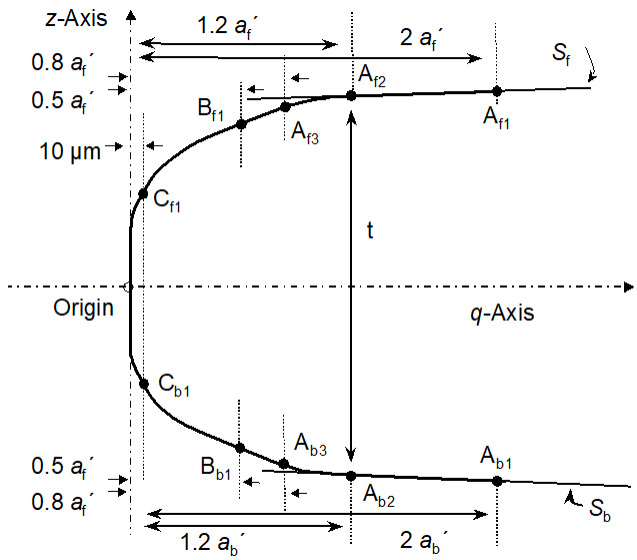

Figure 3
Determination of Points A_{i2}, B_{i1}, and C_{i1}, Ideal Surface Lines K_i, and Thickness t

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 µm (origin) and 10 µm (point C_{i1}) (see Figures 3 and 5).

7.2.7 Determine the locations of the reference points A_i and the magnitudes of the edge widths a_i, bevel angles ϕ_i, apex angles β_i, and thickness t, as follows:

7.2.7.1 Take the locations of the reference points A_i as the intersection of the line G_f and the line S_f (see Figure 4) or of the line G_b and the line S_b.

7.2.7.2 Take the magnitudes of the edge widths a_i as the q-coordinates of the reference points A_i (see Figure 4).

7.2.7.3 Take the magnitudes of the bevel angles ϕ_i as the angles between lines G_i and the q-axis (see Figure 4).

7.2.7.4 Take the magnitudes of the apex angles β_i as the angles between lines L_i and the z-axis (see Figure 5).

7.2.7.5 Take the magnitude of the thickness t as the distance between the points A_f and A_b in the z-direction (see Figures 3 and 4).

7.2.8 Determine the locations of the reference points B_i and C_i, the magnitude of the radii r_i of the edge profile shoulders and the apex lengths b_i, as follows:

7.2.8.1 Draw lines I_i parallel with lines G_i at a distance of 10 µm towards the q-axis. Note that the intersections of the lines I_i with the measured edge profile occur at points B_{i2} (see Figure 5).

7.2.8.2 Fit circular arcs to the edge shoulder regions with q-coordinates ≥10 µm (point C_{i1}) and with z-coordinates less than or equal to those of line I_f for the wafer front surface or greater than or equal to those of line I_b for the wafer back surface so that the resulting circle is tangent to the lines L_i on the ends nearest to the z-axis and to the lines G_i at the points furthest from the z-axis (see Figure 6).

NOTE 8: The z-coordinate of B_{i2} is larger than the z-coordinate of C_{i1}, unless the shoulder radius is very small. The same procedure for fitting the circle can be applied in case that the z-coordinate of B_{i2} is smaller than the z-coordinate of C_{i1}. The shoulder radius can be calculated by $r_i = 10\ \mu m/(1 - \cos((90-\phi_r-\beta_i)/2)$ in case that the locations of points B_{i2} and C_{i1} are identical or almost identical, so that only one or no measurement point is left between them.

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