Background Statement for SEMI Draft Document 4280
New Standard: TEST METHODS FOR EXTRACTING RELEVANT CHARACTERISTICS FROM MEASURED WAFER EDGE PROFILES

Note: This background statement is not part of the balloted item. It is provided solely to assist the recipient in reaching an informed decision based on the rationale of the activity that preceded the creation of this document.

Note: Recipients of this document are invited to submit, with their comments, notification of any relevant patented technology or copyrighted items of which they are aware and to provide supporting documentation. In this context, “patented technology” is defined as technology for which a patent has issued or has been applied for. In the latter case, only publicly available information on the contents of the patent application is to be provided.

In advanced wafer technologies, the edge profile templates in SEMI M1 are too wide to use for a specification. This standard is intended to provide test methods for determining certain edge profile characteristics on silicon wafers from profiles measured in a way not covered by this standard. Both test methods included in this standard are used in various parts of the industry, but because they use very different procedures for extracting the values of the parameters, the results obtained by the two methods are expected to differ significantly.

The two test methods were balloted independently in cycle 5 as Documents 4426A and 4435A. These ballots were formally adjudicated by the Silicon Wafer Committee during its meeting in conjunction with SEMICON Japan 2007 in Makuhari the week of December 2nd, 2007. The significant number of comments and reasons for rejection of each of these documents had caused the working group to prepare a combined standard including both test methods and responding to many of the comments on the ballot for balloting in 2008. Because a final draft of this document was not approved at SEMICON Japan, it was decided to defer the balloting to Cycle 2.

All the necessary edge profile terminology is included in this draft. Although there has not been full agreement of this selection of terms, there is wide consensus on the ones included. All the points that John Valley made on the ballot except one have been addressed. The term cusp that he proposed for reference points A_f and A_b turns out to be inappropriate because the specification for edge profiles in SEMI M1 requires that “6.6.2.4 No sharp points or protrusions are permitted anywhere on the wafer edge profile.” This aspect of the edge profile specification is not likely to be changed as a result of the current activity. However, because of the nature of the profile where it meets the wafer surface, a definition for the term profile transition has been added.

The term profile extension (previously called facet) was eliminated along with the term edge face because there is no need for terms covering two regions of the edge profile. We had previously eliminated the term delta that also covers two regions.

The word periphery is used in a number of SEMI silicon related standards to indicate the outermost boundary of the wafer. This is consistent with the English language definition of this word: “the perimeter of a circle or other closed curve.”¹ Note also that the definition of perimeter is “the boundary of a closed plane figure.”² Consequently, it is not necessary to include this term in the SEMI terminology list.

It should also be noted that SEMI M59 contains four terms related to edge profiles, which are reproduced here for reference during the development of the document. However, if anyone feels that these definitions need modification to refer to edge profile technology as it is being developed, a comment should be placed on your ballot and the working group will take up the issue(s) as new business in cooperation with the International Terminology task force.

- back surface — the exposed surface opposite to that upon which active semiconductor devices have been or will be fabricated.
- edge profile — on edge contoured wafers (whose edges have been shaped chemically or mechanically), a description of the contour of the boundary of the wafer that joins the front and back surfaces.

² ibid., p 861.
• **front surface** — the exposed surface upon which active semiconductor devices have been or will be fabricated.

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

In addition, a guide to specifying the edge profile independently of metric algorithms, doc. 4428A, New Standard “Guide to Specifying Edge Profile of Silicon Wafers,” based on the use of a restricted template constructed from a target profile, is under development in the SEMI International Edge Profile WG (EPWG). This document is also balloted concurrently in cycle 3, 2008.

The Document 4280 ballot results will be reviewed by the EPWG and the International AWG TF and adjudicated by Silicon Wafer Committee during their meetings in conjunction with SEMICON West in San Francisco the week of July 13, 2008.
SEMIDraft Document 4280
New Standard: TEST METHODS FOR EXTRACTING RELEVANT
CHARACTERISTICS FROM MEASURED WAFER EDGE PROFILES

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>
<thead>
<tr>
<th>Segment Parameters</th>
<th>Symbol</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Bevel Angle</td>
<td>( \phi_f )</td>
<td>°</td>
<td>Angle between front surface and front bevel, taken as positive into the wafer.</td>
</tr>
<tr>
<td>Front Shoulder Radius</td>
<td>( r_f )</td>
<td>( \mu m )</td>
<td>Radius of the arc of the front shoulder.</td>
</tr>
<tr>
<td>Front Apex Length</td>
<td>( b_f )</td>
<td>( \mu m )</td>
<td>Distance from origin to the beginning of the front shoulder arc.</td>
</tr>
<tr>
<td>Front Apex Angle</td>
<td>( \beta_f )</td>
<td>°</td>
<td>Angle between z-axis and front apex, taken as positive in the +q direction.</td>
</tr>
<tr>
<td>Back Apex Angle</td>
<td>( \beta_b )</td>
<td>°</td>
<td>Angle between z-axis and back apex, taken as positive in the +q direction.</td>
</tr>
<tr>
<td>Back Apex Length</td>
<td>( b_b )</td>
<td>( \mu m )</td>
<td>Distance from origin to the beginning of the back shoulder arc.</td>
</tr>
<tr>
<td>Back Shoulder Radius</td>
<td>( r_b )</td>
<td>( \mu m )</td>
<td>Radius of the arc of the back shoulder.</td>
</tr>
<tr>
<td>Back Bevel Angle</td>
<td>( \phi_b )</td>
<td>°</td>
<td>Angle of the back surface and back bevel, taken as positive into the wafer.</td>
</tr>
</tbody>
</table>

#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.

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.

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

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.

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 Ai.

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>β¹,²</td>
<td>apex angle</td>
<td>degrees</td>
</tr>
<tr>
<td>φ¹,²,³</td>
<td>bevel angle</td>
<td>degrees</td>
</tr>
<tr>
<td>a¹,²,³</td>
<td>edge width (previously called facet length)</td>
<td>μm</td>
</tr>
<tr>
<td>A¹,²</td>
<td>reference point where the bevel meets the surface</td>
<td>μm, μm</td>
</tr>
<tr>
<td>p¹,²,⁴</td>
<td>apex length</td>
<td>μm</td>
</tr>
<tr>
<td>B¹,²</td>
<td>reference point between bevel and shoulder</td>
<td>μm, μm</td>
</tr>
<tr>
<td>C¹,²</td>
<td>reference point between shoulder and apex</td>
<td>μm, μm</td>
</tr>
<tr>
<td>M¹,²</td>
<td>center point of shoulder circle</td>
<td>μm, μm</td>
</tr>
<tr>
<td>O</td>
<td>origin of q-z edge-referenced coordinate system used in the cross-sectional view of the edge of the wafer</td>
<td>0 μm, 0 μm</td>
</tr>
<tr>
<td>q</td>
<td>radial coordinate of the q-z edge-referenced coordinate system used in the cross-sectional view of the edge of the wafer</td>
<td>μm</td>
</tr>
<tr>
<td>r¹,²</td>
<td>shoulder radius</td>
<td>μm</td>
</tr>
<tr>
<td>t</td>
<td>thickness</td>
<td>μm</td>
</tr>
<tr>
<td>z</td>
<td>vertical coordinate of the q-z edge-referenced coordinate system used in the cross-sectional view of the edge of the wafer</td>
<td>μm</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Edge Profile Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Edge Width</td>
<td>( a_f ) or ( a_b )</td>
<td>300 to 400 ( \mu )m</td>
</tr>
<tr>
<td>Shoulder Radius</td>
<td>( r_f ) or ( r_b )</td>
<td>200 to 260 ( \mu )m</td>
</tr>
<tr>
<td>Apex Length</td>
<td>( b_f ) or ( b_b )</td>
<td>100 to 175 ( \mu )m</td>
</tr>
</tbody>
</table>

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 \( \beta_f \) and \( \beta_b \) 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.

### 7 Test Method 1 — Edge-Width Method

#### 7.1 Summary of Method

7.1.1 The measurement location is selected (at coordinates \( R, \theta \) 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 \( A_i, B_i, C_i \), 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 \( \phi_i \), shoulder radii \( r_i \), apex lengths \( b_i \), and apex angles \( \beta_i \) 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 $\theta$, 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):

[Diagram of a coordinate system with labels for points $A_{i2}$, $A_{i1}$, $S_i$, $1.2a_i'$, $2a_i'$, $q$-axis, and $z$-axis.]

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

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 $1.2a_i'$ (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 $a_b'$

<table>
<thead>
<tr>
<th>Edge Profile Type</th>
<th>$A$</th>
<th>$B$</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_f'$ [µm]</td>
<td>350</td>
<td>235</td>
<td>275</td>
</tr>
<tr>
<td>$a_b'$ [µm]</td>
<td>350</td>
<td>235</td>
<td>275</td>
</tr>
</tbody>
</table>

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 0.5$a_f'$ (point $B_{i1}$) and 0.8$a_f'$ (point $A_{i3}$) (see Figures 3 and 4).

![Figure 3](image)

**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 $\phi_i$, apex angles $\beta_i$, and thickness $t$, as follows:

7.2.7.1 Take the locations of the reference points $A_i$ as the intersection of the line $G_i$ and the line $S_j$ (see Figure 4) or of the line $G_j$ and the line $S_k$.

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 $\phi_i$ 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 $\beta_i$ 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 $A_j$ and $A_h$ 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 \( B_i \) (see Figure 5).

7.2.8.2 Fit circular arcs to the edge shoulder regions with \( q \)-coordinates \( \geq 10 \) µm (point \( C_i \)) 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 7: The \( z \)-coordinate of \( B_i \) is larger than the \( z \)-coordinate of \( C_i \), unless the shoulder radius is very small. The same procedure for fitting the circle can be applied in case that the \( z \)-coordinate of \( B_i \) is smaller than the \( z \)-coordinate of \( C_i \). The shoulder radius can be calculated by \( r_i = 10 \) µm/(1 – \cos((90-\phi_i-\beta_i)/2)) in case that the locations of points \( B_i \) and \( C_i \) are identical or almost identical, so that only one or no measurement point is left between them.

NOTE: This diagram is for the front portion of the edge profile only. Similar constructions are made on the back portion to determine the location of the reference point \( A_b \) and the magnitudes of the bevel angle \( \phi_b \) and the edge width \( a_b \).

Figure 4
Enlargement of a Section of Figure 3 Showing Determination of the Location of Reference Point \( A_f \) and the Magnitudes of the Bevel Angle \( \phi_f \) and the Edge width \( a_f \)

NOTE: This diagram is for the front portion of the edge profile only; similar constructions are made on the back portion to determine the magnitude of the apex angle \( \beta_f \).

Figure 5
Enlargement of a Section of Figure 3 Showing Determination of the Magnitude of the Apex Angle \( \beta_f \) and the Location of Point \( C_f \), which delimits the fit interval and is 10 µm away from the \( z \)-axis

7.2.8.3 Take the shoulder radii \( r_i \) as the radii of these circles and label their center points \( M_i \) (see Figure 6).

7.2.8.4 Take the locations of the reference points \( B_i \) as the points where the circles become tangent with lines \( G_i \).
7.2.8.5 Take the locations of the reference points \( C_i \) as the points where the circles become tangent with lines \( L_i \).

7.2.8.6 Take the magnitude of the apex lengths \( b_i \) as the \( z \)-coordinates of reference points \( C_i \).

7.2.9 Repeat the procedures of \( \text{¶¶7.2.3 through 7.2.8.3} \) at any azimuth angle required.

7.3 Calculations

NOTE 8: The following calculations are generally performed automatically within the measurement equipment. Information is provided here to indicate the nature of the calculations employed.

7.3.1 Construct a cross-sectional view of an apex-length adjusted target profile in accordance with Appendix A2.

7.3.2 Generate a reconstructed profile by using the reference points \( A_i, B_i, C_i \), the center points \( M_i \), shoulder radii \( r_i \) of circles \( R_i \), and the apex angles \( \beta_i \):

![Diagram of apex-length adjusted target profile]

NOTE: This diagram is for the front portion of the edge profile only; similar constructions are made on the back portion to determine the magnitudes of the apex length \( b_f \) and shoulder radius \( r_f \) and the locations of the reference points \( B_f \) and \( C_f \).

Figure 6

Enlargement of a Section of Figure 3 Showing Determination of the Magnitudes of the Apex Length \( b_f \) and Shoulder Radius \( r_f \) and the Locations of Reference Points \( B_f \) and \( C_f \)

7.3.2.1 Connect the reference points \( A_i \) and \( B_i \) by a straight line that is at an angle \( \phi_i \) with the wafer surface.

7.3.2.2 Connect the reference points \( B_i \) and \( C_i \) by a circular arc with radius \( r_i \) and center point \( M_i \); this arc is tangent to the lines on either side at the two reference points.

7.3.2.3 Draw a straight line through the reference point \( C_i \) that has an angle of \( \beta_i \) with respect to the \( z \)-axis, starting at reference point \( C_i \) and ending at the \( q \)-axis.

7.3.3 Optional, to be decided between customer and supplier:

7.3.3.1 Calculate the root-mean-square deviation \( \sigma_{RM} \) between the measured and reconstructed profiles by taking all distances between the reconstructed profile and measurement points perpendicular to the reconstructed profile. The deviation \( \sigma_{RM} \) is calculated for all points between or at points \( A_{i3} \) and \( A_{i2} \) or optionally between or at points \( A_{i2} \) and \( A_{i1} \).

NOTE 9: It is recommended to calculate \( \sigma_{RM} \) between or at points \( A_{i3} \) and \( A_{i2} \) because the measured profile is not approximated by the reconstructed profile between points \( A_{i2} \) and \( A_{i3} \) by definition.

7.3.3.2 Calculate the root-mean-square deviation \( \sigma_{TM} \) between the measured and target profiles by taking all distances between the target profile and measurement points perpendicular to the target profile.

7.3.3.3 Calculate the root-mean-square deviation \( \sigma_{RT} \) between the target and reconstructed profiles by taking all distances between the reconstructed profile and the target profile perpendicular to the reconstructed profile.

NOTE 10: It is recommended to calculate \( \sigma_{RT} \) between or at points \( A_{i3} \) and \( A_{i2} \) because the target profile is not approximated by the measured profile between points \( A_{i2} \) and \( A_{i3} \).
7.3.4 If measurements are made at multiple azimuth angles, calculate mean, standard deviation or other statistical quantities of each of the parameters determined as well as of the root mean square deviations of the differences between the measured and reconstructed profiles and the target and reconstructed profiles as agreed by the parties to the test.

8 Test Method 2 — Slope-Change Method

8.1 Summary of Method

8.1.1 The measurement location is selected (at coordinates $R, \theta$ 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 edge of the wafer, a sampling plan for the measurement locations is selected.

8.1.2 A wafer edge profile is acquired.

8.1.3 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.

8.1.4 An edge-referenced coordinate system for the characterization of the edge profile is established.

8.1.5 The aligned measured profile is decomposed into seven regions by determining three points each on the front and back of the profile. The seven regions are apex, front and back shoulder, front and back bevel and front and back surface.

8.1.6 The reference points $A_i$ and $B_i$ (where here and subsequently the subscript $i$ stands for $f$, front, or $b$, back) are located using the specified value of bevel angle.

8.1.7 A system of supplementary reference points is set up using agreed upon values on edge side of the edge profile to complete the establishment of the regions of the measured profile that are to be fitted with straight lines.

8.1.8 Appropriate straight lines and curves are fitted to the measurement points between defined points.

8.1.9 The front and back edge widths, $a_i$, bevel angles, $\phi_i$, shoulder radii, $r_i$, apex lengths, $b_i$, and apex angles, $\beta_i$ are calculated using above points, lines, and circles.

8.1.10 If measurements are made at several azimuth positions on the wafer, the mean values, the standard deviations or the statistical quantities of the parameters are calculated.

8.1.11 The extracted parameters and the statistics are reported.

8.2 Procedure

NOTE 11: The following procedures are generally performed automatically within the measurement equipment. Information is provided here to indicate the nature of the procedures employed.

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

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

8.2.3 At the azimuthal angle $\theta$, acquire a wafer edge profile of the front and back regions of the wafer in the edge of the wafer from the apex to distance $2L = 1.2$ mm inward radially as a set of $q$-$z$ coordinates of measurement points $(q, z)$ by using appropriate equipment as agreed between the parties to the test.

NOTE 12: For this test method, it is assumed that accurate profile data have been acquired.

8.2.4 Align the cross-sectional view of the measured edge profile with the outermost edge position to the left and the inward radial extent to the right (see Figure 7).

8.2.5 Establish a coordinate system by the following procedure (see Figure 7):

8.2.5.1 Fit straight lines $S'_i$ ($i = 'f' \text{ or } 'b'$), to the measurement points of the front as well as the back surface using root-mean-square best fit using measurement points at a distance from the apex greater than $L = 600 \mu m$. 
8.2.5.2 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 toward wafer center.

8.2.5.3 Take the intersection of the $q$-axis with the edge profile as the origin of the coordinate system.

8.2.5.4 Construct the 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.

8.2.6 Find the slope-change points on both the front and back surfaces of the wafer edge profile (see Figure 8):

8.2.6.1 Draw a line tangent to the edge profile at the angle $\frac{1}{2}\phi'_i$ from the $q$-axis, where $\phi'_i$ is the specified bevel angle. Call the point of tangency $A_i$.

NOTE 13: If the specified bevel angle is not defined because the edge profile has no bevel region, skip ¶8.2.6.1 and take the specified bevel angle $\phi'_i$ equal to zero. In this case, the reference point $A_i$ coincides with the reference point $B_i$ defined in ¶8.2.6.2, and skip the steps in ¶¶8.2.7.1, 8.2.8.2 and 8.2.8.3.

NOTE 14: If the specified values of bevel angle are unknown, all the parameters can be calculated recursively in accordance with the procedure in Appendix 1 beginning with assumed bevel angles.

8.2.6.2 Draw a second line tangent to the edge profile at the angle $\phi'_i + \alpha$ from the $q$-axis, where $\alpha$ has a default value of $5^\circ$. Call the point of tangency $B_i$.

NOTE: This diagram is for the front region of the edge profile; similar constructions are made on the back region to determine the points $A_b$, $B_b$, and $C_b$.
8.2.6.3 Draw a third line tangent to the edge profile at the angle $90^\circ - \alpha$ from the $q$-axis. Call the point of tangency the reference point $C_i$.

8.2.7 Establish a system of auxiliary lines as follows:

8.2.7.1 Draw two lines parallel to the $q$-axis at distances $d_{Li}$ and $d_{Li}$ from the point $A_i$ toward the $q$-axis, where $d_{Li}$ has a default value of $0.2L_{ABi}$ and $d_{Li}$ has a default value of $0.8L_{ABi}$, where $L_{ABi}$ is the distance form $A_i$ to $B_i$ in the $z$-direction. Call the points where these lines intersect the edge profile $P_i$ and $Q_i$, respectively (see Figure 9).

8.2.7.2 Construct a line $T$ parallel to the $z$-axis at $q = L$. Define the points where this line intersects the edge profile as $T_f$ and $T_b$ (see Figure 7).

8.2.8 Determine edge widths, $a_i$, bevel angles, $\phi_i$, shoulder radii, $r_i$, apex lengths, $b_i$, and apex angles, $\beta_i$ on both sides of the edge profile and the thickness $t$ by the following procedures (see Figure 10).

8.2.8.1 Determine the edge widths, $a_i$, as the $q$-coordinates of $A_i$.

8.2.8.2 Fit the lines, $G_i$, through the measured edge profile points between the points, $P_i$ and $Q_i$.

8.2.8.3 Determine the bevel angles, $\phi_i$, as the angles between the $q$-axis and the lines $G_i$ and calculate the standard error, $\sigma_{G_i}$, of the difference between $G_i$ and measured profile in the fitting region.

8.2.8.4 Fit the circles, $M_i$, through the measured edge profile points between the reference points $B_i$ and $C_i$. Take the shoulder radii, $r_i$, as the radii of the circles, $M_i$, and the calculate standard error, $\sigma_{M_i}$, of the difference between $M_i$ and measured profile in the fitting region.

8.2.8.5 Fit the lines, $K_i$, through the measured edge profile points between the points, the origin and the reference point $C_i$.

8.2.8.6 Determine the apex length, $b_i$, as the absolute magnitude of the $z$-coordinates of $C_i$.

8.2.8.7 Determine the apex angle, $\beta_i$, as the angles between the $z$-axis and the lines $K_i$ and calculate the standard error, $\sigma_{K_i}$, of the difference between $K_i$ and measured profile in the fitting region.

8.2.8.8 Repeat the procedures of ¶8.2.3 through 8.2.8.7 at any azimuth angle required.

8.2.8.9 Determine the thickness as the distance in the $z$-direction between $T_f$ and $T_b$.

8.2.9 If measurements are made at multiple azimuth angles, calculate mean, standard deviation or the statistical quantities of the parameters determined as agreed by the parties to the test.
9 Report

9.1 Report the following basic information:

9.1.1 Date, time of test,
9.1.2 Identification of operator,
9.1.3 Location (laboratory) of test,
9.1.4 Identification of measuring instruments, including measuring equipment and calculation equipment (identification of make, model, software version, etc.),
9.1.5 Method used (Test Method 1, Edge-Width Method or Test Method 2, Slope-Change Method),
9.1.6 Profile acquisition spatial resolution and data point spacing,
9.1.7 Lot identification, wafer identification,
9.1.8 Description of sampling plans, if any, and,
9.1.9 Specified or recursively calculated edge widths $a'_f$ and $a'_b$ (Test Method 1) or specified or recursively calculated bevel angles $\phi'_f$ and $\phi'_b$ (Test Method 2). Indicate whether specified or calculated values were used.

9.2 Report the following results for each measurement location around the wafer circumference (See Tables 5 and 6 for examples):

9.2.1 The azimuthal angle $\theta$ of the measurement location,
9.2.2 Extracted edge widths, $a_f$ and $a_b$,
9.2.3 Extracted bevel angles, $\phi_f$ and $\phi_b$,
9.2.4 Extracted shoulder radii, $r_f$ and $r_b$,
9.2.5 Extracted total apex length, $b = b_f + b_b$,
9.2.6 Extracted apex angles $\beta_f$ and $\beta_b$. 

NOTE 1: These diagrams are for the front region of the edge profile; similar constructions are made on the back region to determine the back edge width $a_b$, bevel angle $\phi_b$, shoulder radius $r_b$, apex angle $\beta_b$, and apex length $b_b$.

NOTE 2: The right-hand inset is a detailed drawing showing determination of the apex angle $\beta_f$. 

Figure 10

Determination of Front Edge Width $a_f$, Bevel Angle $\phi_f$, Shoulder Radius $r_f$, Apex Length $b_f$ and Apex Angle $\beta_f$. 

LETTER (YELLOW) BALLOT
9.2.7 Extracted wafer thickness, \( t \),

9.2.8 The coordinates of the points \( A_i, B_i, \) and \( C_i \),

9.3 Report the goodness of fit parameters as follows:

9.3.1 For Test Method 1, only, optionally, to be decided between customer and supplier, the root mean square deviation \( \sigma_{RM} \) of the measured profile from the reconstructed profile, the root mean square deviation \( \sigma_{MT} \) of the measured profile from the target profile, and/or the root mean square deviation \( \sigma_{RT} \) of the target profile from the reconstructed profile.

9.3.2 For Test Method 2, only, the standard errors of the fitting; \( \sigma_{G_i}, \sigma_{M_b}, \) and \( \sigma_{K_i} \).

9.4 In addition, if several azimuthal positions on the wafer were used, report mean values the corresponding standard deviation of the quantities in 9.2.2 through 9.3.2 together with any other statistical quantities agreed upon between supplier and customer.

Table 5 Example of a Reporting Table for Test Method 1, Edge-Width Method

<table>
<thead>
<tr>
<th>Segment Parameter</th>
<th>Symbol</th>
<th>Measured Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Position</td>
<td>( \theta )</td>
<td></td>
<td>degrees</td>
</tr>
<tr>
<td>Front Edge Width</td>
<td>( a_f )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td>Front Bevel Angle</td>
<td>( \phi_f )</td>
<td></td>
<td>degrees</td>
</tr>
<tr>
<td>Front Shoulder Radius</td>
<td>( r_f )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td>Front Apex Angle</td>
<td>( \beta_f )</td>
<td></td>
<td>degrees</td>
</tr>
<tr>
<td>Front Apex Length</td>
<td>( b_f )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td>Back Apex Length</td>
<td>( b_b )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td>Back Apex Angle</td>
<td>( \beta_b )</td>
<td></td>
<td>degrees</td>
</tr>
<tr>
<td>Back Shoulder Radius</td>
<td>( r_b )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td>Back Bevel Angle</td>
<td>( \phi_b )</td>
<td></td>
<td>degrees</td>
</tr>
<tr>
<td>Back Edge Width</td>
<td>( a_b )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td>Thickness</td>
<td>( t )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td>Coordinates of ( A_f )</td>
<td>–</td>
<td></td>
<td>( \mu m, \mu m )</td>
</tr>
<tr>
<td>Coordinates of ( B_f )</td>
<td>–</td>
<td></td>
<td>( \mu m, \mu m )</td>
</tr>
<tr>
<td>Coordinates of ( C_f )</td>
<td>–</td>
<td></td>
<td>( \mu m, \mu m )</td>
</tr>
<tr>
<td>Coordinates of ( C_b )</td>
<td>–</td>
<td></td>
<td>( \mu m, \mu m )</td>
</tr>
<tr>
<td>Coordinates of ( B_b )</td>
<td>–</td>
<td></td>
<td>( \mu m, \mu m )</td>
</tr>
<tr>
<td>Coordinates of ( C_b )</td>
<td>–</td>
<td></td>
<td>( \mu m, \mu m )</td>
</tr>
<tr>
<td>Goodness of Fit Parameters</td>
<td>( \sigma_{RM} )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td></td>
<td>( \sigma_{MT} )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td></td>
<td>( \sigma_{RT} )</td>
<td></td>
<td>( \mu m )</td>
</tr>
<tr>
<td>Segment Parameter</td>
<td>Symbol</td>
<td>Measured Value</td>
<td>Unit</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement Position</td>
<td>θ</td>
<td>degrees</td>
<td>–</td>
</tr>
<tr>
<td>Front Edge Width</td>
<td>(a_f)</td>
<td>µm</td>
<td>–</td>
</tr>
<tr>
<td>Front Bevel Angle</td>
<td>(φ_f)</td>
<td>degrees</td>
<td>(σ_{φ_f})</td>
</tr>
<tr>
<td>Front Shoulder Radius</td>
<td>(r_f)</td>
<td>µm</td>
<td>(σ_{r_f})</td>
</tr>
<tr>
<td>Front Apex Angle</td>
<td>(β_f)</td>
<td>degrees</td>
<td>(σ_{β_f})</td>
</tr>
<tr>
<td>Front Apex Length</td>
<td>(b_f)</td>
<td>µm</td>
<td>–</td>
</tr>
<tr>
<td>Back Apex Length</td>
<td>(b_b)</td>
<td>µm</td>
<td>–</td>
</tr>
<tr>
<td>Back Apex Angle</td>
<td>(β_b)</td>
<td>degrees</td>
<td>(σ_{β_b})</td>
</tr>
<tr>
<td>Back Shoulder Radius</td>
<td>(r_b)</td>
<td>µm</td>
<td>(σ_{r_b})</td>
</tr>
<tr>
<td>Back Bevel Angle</td>
<td>(φ_b)</td>
<td>degrees</td>
<td>(σ_{φ_b})</td>
</tr>
<tr>
<td>Back Edge Width</td>
<td>(a_b)</td>
<td>µm</td>
<td>–</td>
</tr>
<tr>
<td>Thickness</td>
<td>(t)</td>
<td>µm</td>
<td>–</td>
</tr>
<tr>
<td>Coordinates of (A_f)</td>
<td>–</td>
<td>µm, µm</td>
<td>–</td>
</tr>
<tr>
<td>Coordinates of (B_f)</td>
<td>–</td>
<td>µm, µm</td>
<td>–</td>
</tr>
<tr>
<td>Coordinates of (C_f)</td>
<td>–</td>
<td>µm, µm</td>
<td>–</td>
</tr>
<tr>
<td>Coordinates of (C_b)</td>
<td>–</td>
<td>µm, µm</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 6 Example of a Reporting Table for Test Method 2, Slope-Change Method
APPENDIX 1
RECURSIVE CALCULATION OF PARAMETERS

NOTICE: The material in this appendix is an official part of SEMI Mxx and was approved by full letter ballot procedures on date tbd.

A1-1 Test Method 1 — Edge-Width Method
A1-1.1 Introduction — The edge profile parameters can be calculated by a recursive procedure in case the specified edge width is not known. This is performed by assuming a specified edge width and repeating the procedures of Test Method A until the improvement $\Delta \sigma$ between iterations is smaller than an amount agreed upon by the parties to the test. Use a second index $n (n = 0, 1, 2, 3, ...)$ for identifying the number of repetitions.

A1-1.2 Procedure.
A1-1.2.1 Set $n = 0$.
A1-1.1.1 Start by assuming a specified edge width $a_i'$ of 350 $\mu$m and denote this by $a_{i0}$.
NOTE 1: Alternatively, if the edge profile type is known, the default edge width of Table A1-1 can be used to start the iteration.
A1-1.2.2 Set $n = n + 1$.
A1-1.2.3 Establish a coordinate system according to ¶¶7.2.5 through 7.2.5.4.
A1-1.2.4 Calculate points $A_i, B_i, C_i$ and the profile parameters according to ¶¶7.2.6 through 7.2.8.6.
A1-1.2.5 Denote the value of the extracted edge width by $a_{in}$.
A1-1.2.6 Generate a reconstructed profile according to ¶¶7.3.1 through 7.3.1.3.
A1-1.2.7 Calculate $\sigma_n$ according to ¶7.3.2.
A1-1.2.8 Calculate $\Delta \sigma_n = \sigma_n - \sigma_{n-1}$.
A1-1.2.9 Using $a_{in}$ as the specified edge width, repeat ¶¶A1-1.2.3 to A1-1.2.9 until $|\Delta \sigma_n|$ is less than or equal to 0.01$\sigma_n$ or the value agreed upon by the parties to the test.

Table A1-1 Starting Values for the Specified Edge Width $a_i'$

<table>
<thead>
<tr>
<th>Edge Width</th>
<th>$a_i'$ [µm]</th>
<th>$a_i''$ [µm]</th>
<th>Edge Profile Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>400</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>270</td>
<td>270</td>
<td>$t/2$</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>$t/2$</td>
</tr>
</tbody>
</table>

A1-2 Test Method 2 — Slope-Change Method
A1-2.1 Introduction — The edge profile parameters can be calculated by a recursive procedure in case the specified bevel angle is not known. This is performed by assuming a specified bevel angle and repeating the procedures of Test Method 2 until the improvement $\Delta \sigma$ between iterations is smaller than an amount agreed upon by the parties to the test. Use a second index $n (n = 0, 1, 2, 3, ...)$ for identifying the number of repetitions.

A1-2.2 Procedure
A1-2.2.1 Set $n = 0$.
A1-2.2.2 Start by assuming a specified bevel angle $\phi_i'$ of 22° and denote this by $\phi_{i0}$.
A1-2.2.3 Set $n = n + 1$.
A1-2.2.4 Establish a coordinate system according to ¶¶8.2.5 through 8.2.5.4.
A1-2.2.5 Calculate the profile parameters according to ¶¶8.2.6 to 8.2.8.7.
A1-2.2.6 Denote the value of the extracted bevel angle by $\phi_{(n+1)}$.

A1-2.2.7 Calculate $\Delta \phi_n = |\phi_{(n+1)} - \phi_n|$.

A1-2.2.8 Use $\phi_{(n+1)}$ as the specified bevel angle, repeat ¶¶A1-2.2.3 through A1-2.2.8 until $\Delta \phi_n$ is less than or equal to the value agreed upon by the parties to the test.
APPENDIX 2
TARGET PROFILE

NOTICE: The material in this appendix is an official part of SEMI Mxx and was approved by full letter ballot procedures on date tbd.

A2-1 Construction of an Apex-Length Adjusted Target Profile

A2-1.1 Use the following specified or otherwise pre-selected characteristics:

- front and back edge width \( a_f \) and \( a_b \),
- front and back bevel angle \( \phi_f \) and \( \phi_b \),
- front and back shoulder radius \( r_f \) and \( r_b \), and
- wafer thickness \( t \).

A2-1.2 Take the front and back wafer surfaces as parallel lines equidistant \((\frac{1}{2}t)\) from the reference line.

A2-1.3 Calculate the front and back apex length from the following equation:

\[
b_i = \frac{t}{2} - r_i \cos \phi_i - [a_i - r_i(1 - \sin \phi_i)] \tan \phi_i = \frac{1}{\cos \phi_i} \left[ \frac{t \cos \phi_i}{2} - a_i \sin \phi_i - r_i(1 - \sin \phi_i) \right] \quad \text{(A2-1)}
\]

where the symbols are defined in Figure 1 and Table 2.

A2-1.4 Draw the front apex as a straight line between the origin and the point \((0, b_f)\).

A2-1.5 Draw the front shoulder as an arc of radius \( r_f \) with its center, \( M_f \) at the point \((b_f, r_f)\). This arc extends to the point where the radius makes an angle \(-\phi_f\) with a line parallel with the \(z\)-axis through the point \(M_f\).

A2-1.6 Draw the front bevel as a straight line at an angle \(\phi_f\) with the front surface through the point \((\frac{1}{2}t, a_f)\).

A2-1.7 Draw the back apex as a straight line between the origin and the point \((0, -b_b)\).

A2-1.8 Draw the back shoulder as an arc of radius \( r_b \) with its center, \( M_b \) at the point \((-b_b, r_b)\). This arc extends to the point where the radius makes an angle \(-\phi_b\) with a line parallel with the \(z\)-axis through the point \(M_b\).

A2-1.9 Draw the back bevel as a straight line at an angle \(\phi_b\) with the back surface through the point \((\frac{1}{2}t, a_b)\).
RELATED INFORMATION 1
EXAMPLES OF MEASURED RESULTS

NOTICE: This related information is not an official part of SEMI Mxx and was derived from discussions of the working group that developed the standard during the initial course of development. This related information was approved for publication by full letter ballot procedures on date tbd.

R1-1 Examples from Test Method 1

R1-1.1 Examples are given that demonstrate the agreement between measured profiles and profiles reconstructed using the parameters extracted from measured profiles by the method described in Test Method 1.

R1-1.2 The method was applied to three different types of wafer edge profiles:

- Type A,
- Type B, and
- Type C.

R1-1.3 The parameters extracted from the measured profiles are summarized in Table R1-1, and the profiles are displayed in Figures R1-1, R1-2, and R1-3. The specified front and back edge widths \( a_f \) and \( a_b \) are taken to be equal in each of these examples.

NOTE 1: The reconstructed profiles presented here were generated by assuming the apex angles \( b_f,b_b \) to be equal to zero. Using the correct apex angles as given in Table R1-1 according to the procedure described in ¶7.3.1 through 7.3.3 will change the reconstructed profiles only slightly.

<table>
<thead>
<tr>
<th>Table R1-1 Parameters Extracted from Three Measured Profiles using Test Method 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Nominal edge width ( a_f ),( a_b ) (\mu m)</td>
</tr>
<tr>
<td>Front edge width ( a_f ),( a_b ) (\mu m)</td>
</tr>
<tr>
<td>Back edge width ( a_f ),( a_b ) (\mu m)</td>
</tr>
<tr>
<td>Front shoulder radius ( r_f ),( r_b ) (\mu m)</td>
</tr>
<tr>
<td>Back shoulder radius ( r_f ),( r_b ) (\mu m)</td>
</tr>
<tr>
<td>Front bevel angle ( \phi_f ),( \phi_b ) (deg)</td>
</tr>
<tr>
<td>Back bevel angle ( \phi_f ),( \phi_b ) (deg)</td>
</tr>
<tr>
<td>Front apex length ( b_f ),( b_b ) (\mu m)</td>
</tr>
<tr>
<td>Back apex length ( b_f ),( b_b ) (\mu m)</td>
</tr>
<tr>
<td>Front apex angle ( b_f ),( b_b ) (deg)</td>
</tr>
<tr>
<td>Back apex angle ( b_f ),( b_b ) (deg)</td>
</tr>
<tr>
<td>Thickness ( t ) (\mu m)</td>
</tr>
<tr>
<td>Root-mean-square deviation ( \sigma ),( \mu m)</td>
</tr>
</tbody>
</table>
NOTE: The red circles indicate the position of the characteristic points $A_i$, $B_i$, and $C_i$.

Figure R1-1
Measured (Magenta) and Reconstructed (Blue) Type A Edge Profiles

NOTE: The red circles indicate the position of the characteristic points $A_i$, $B_i$, and $C_i$.

Figure R1-2
Measured (Magenta) and Reconstructed (Blue) Type B Edge Profiles
NOTE: The red circles indicate the position of the characteristic points $A$, $B$, and $C$.

Figure R1-3
Measured (Magenta) and Reconstructed (Blue) Type C Edge Profiles
### R1-2 Examples from Test Method 2

R1-2.1 Examples of measured results by this method are shown. The selected types of edge profile for these examples are as follows:

- "Blunt" type (Type A) for which the specified bevel angle is taken as 22°,
- "Blunter" type (Type B) for which the specified bevel angle is taken as 22°, and
- "Round" type (Type C), which has no bevel segment.

**NOTE 2:** The bevel angle 22° is used as the general bevel angle because the specified bevel angle was unknown.

```
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a_F</td>
<td>362</td>
</tr>
<tr>
<td>a_B</td>
<td>370</td>
</tr>
<tr>
<td>b_F</td>
<td>100</td>
</tr>
<tr>
<td>b_B</td>
<td>109</td>
</tr>
<tr>
<td>φ_F</td>
<td>20.5°</td>
</tr>
<tr>
<td>φ_B</td>
<td>21.8°</td>
</tr>
<tr>
<td>r_F</td>
<td>211</td>
</tr>
<tr>
<td>r_B</td>
<td>193</td>
</tr>
<tr>
<td>β_F</td>
<td>1.8°</td>
</tr>
<tr>
<td>β_B</td>
<td>1.4°</td>
</tr>
<tr>
<td>t</td>
<td>777</td>
</tr>
<tr>
<td>A_F</td>
<td>(362μm, 387μm)</td>
</tr>
<tr>
<td>A_B</td>
<td>(370μm, 392μm)</td>
</tr>
<tr>
<td>B_F</td>
<td>(153μm, 311μm)</td>
</tr>
<tr>
<td>B_B</td>
<td>(137μm, 301μm)</td>
</tr>
<tr>
<td>C_F</td>
<td>(4μm, 100μm)</td>
</tr>
<tr>
<td>C_B</td>
<td>(3μm, -109μm)</td>
</tr>
<tr>
<td>σ_{AF, BF}</td>
<td>1.6μm, 1.8μm</td>
</tr>
<tr>
<td>σ_{AF, BF}</td>
<td>0.8μm, 0.9μm</td>
</tr>
<tr>
<td>σ_{CF, CB}</td>
<td>0.3μm, 0.4μm</td>
</tr>
</tbody>
</table>
```

**Figure R1-4**

Measured Profile (Magenta) and Fitted Lines (Blue) for a Type A Edge Profile
NOTE: The turquoise lines are the supplementary lines to define the bevel angles.

Figure R1-5
Measured Profile (Magenta) and Fitted Lines (Blue) for a Type B Edge Profile

- $a_F = 235\mu m$
- $a_B = 239\mu m$
- $b_F = 160\mu m$
- $b_B = 170\mu m$
- $\phi_F = 14.2^\circ$
- $\phi_B = 15.5^\circ$
- $r_F = 180\mu m$
- $r_B = 184\mu m$
- $\beta_F = 1.0^\circ$
- $\beta_B = 1.9^\circ$
- $T = 775\mu m$

$A_F$ (235$\mu m$, 385$\mu m$)
$A_B$ (239$\mu m$, -391$\mu m$)
$B_F$ (131$\mu m$, 353$\mu m$)
$B_B$ (129$\mu m$, -354$\mu m$)
$C_F$ (5$\mu m$, 160$\mu m$)
$C_B$ (5$\mu m$, -170$\mu m$)

$\sigma_{GF}, \sigma_{GB} = 1.8\mu m, 1.9\mu m$
$\sigma_{MF}, \sigma_{MB} = 1.1\mu m, 1.0\mu m$
$\sigma_{KF}, \sigma_{KB} = 0.5\mu m, 0.7\mu m$

Figure R1-6
Measured Profile (Magenta) and Fitted Lines (Blue) for a Type C Edge Profile

- $a_F = 345\mu m$
- $a_B = 335\mu m$
- $b_F = 71\mu m$
- $b_B = 78\mu m$
- $\phi_F = -$ 
- $\phi_B = -$ 
- $r_F = 320\mu m$
- $r_B = 309\mu m$
- $\beta_F = 2.1^\circ$
- $\beta_B = 2.3^\circ$
- $T = 777\mu m$

$A_F / B_F$ (345$\mu m$, 394$\mu m$)
$A_B / B_B$ (335$\mu m$, -394$\mu m$)

$C_F$ (3$\mu m$, 71$\mu m$)
$C_B$ (3$\mu m$, -78$\mu m$)

$\sigma_{GF}, \sigma_{GB} = -$ 
$\sigma_{MF}, \sigma_{MB} = 0.7\mu m, 1.0\mu m$
$\sigma_{KF}, \sigma_{KB} = 0.3\mu m, 0.3\mu m$
NOTICE: SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature, respecting any materials or equipment mentioned herein. These standards are subject to change without notice.

By publication of this standard, Semiconductor Equipment and Materials International (SEMI) takes no position respecting the validity of any patent rights or copyrights asserted in connection with any items mentioned in this standard. Users of this standard are expressly advised that determination of any such patent rights or copyrights, and the risk of infringement of such rights are entirely their own responsibility.