

(numbers in parentheses are for 25-wafer FOSB, if different)

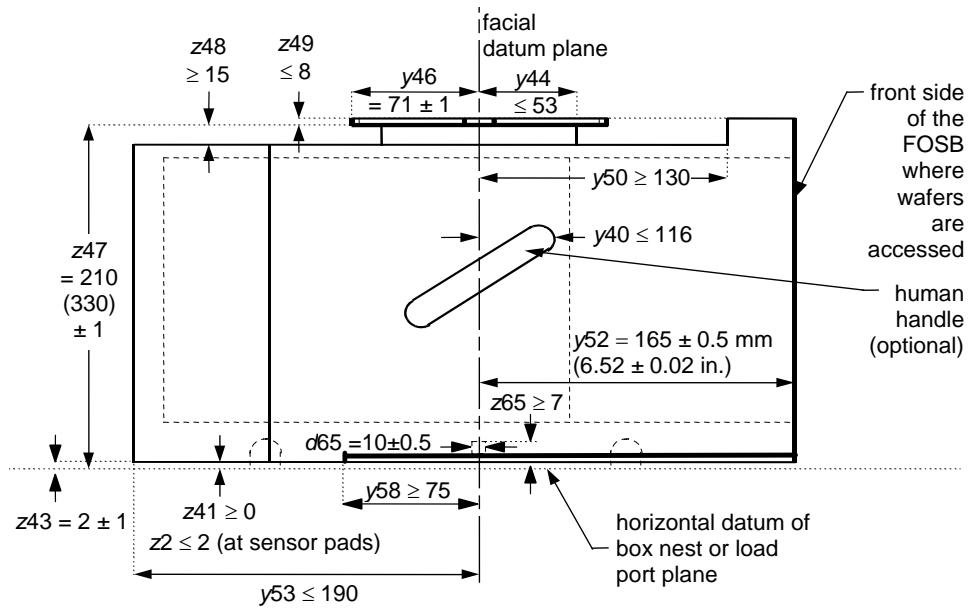


Figure 8
Side View of FOSB

(numbers in parentheses are for 25-wafer FOSB, if different)

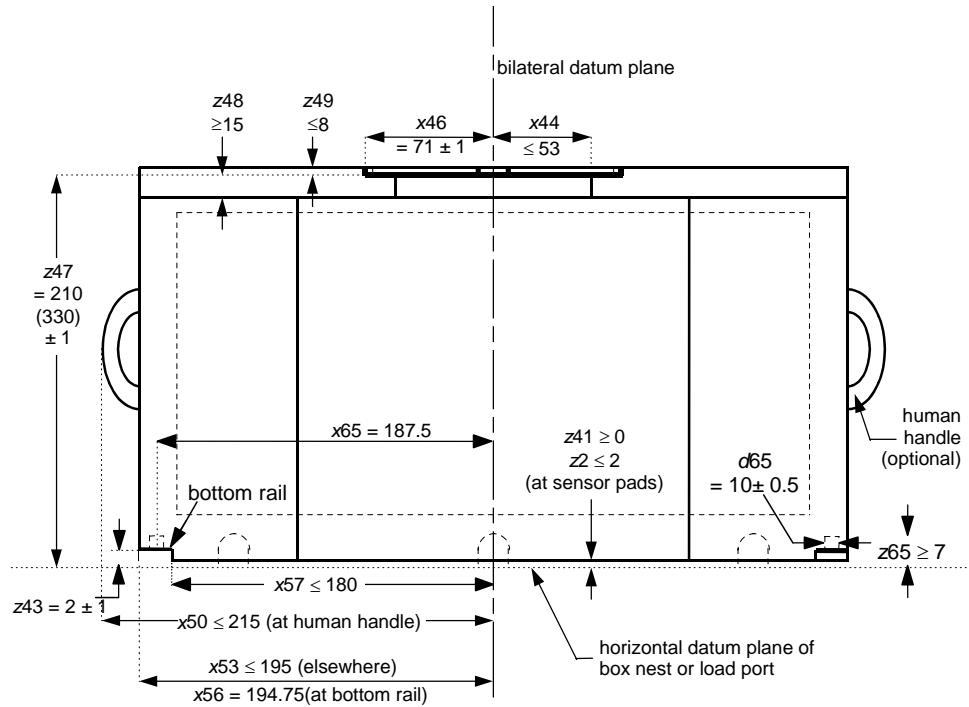


Figure 9
Rear View of FOSB

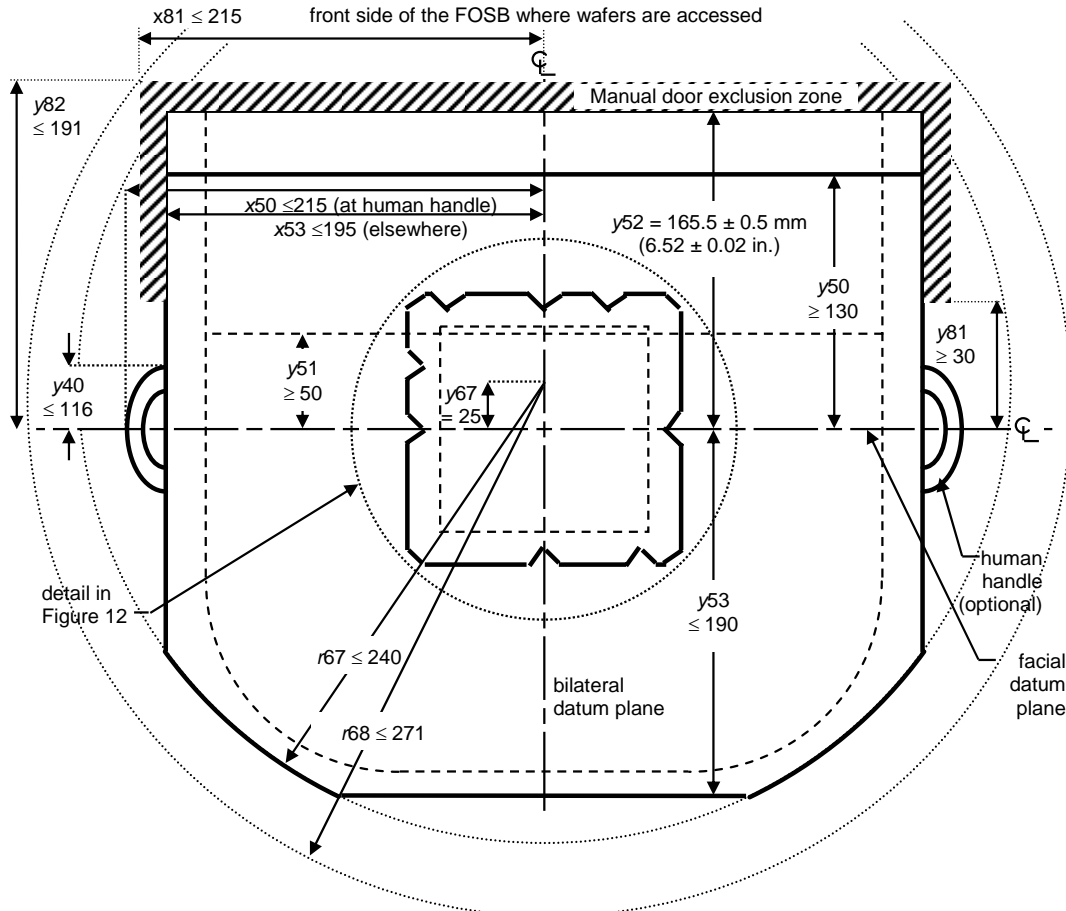


Figure 10
Top View of FOSB

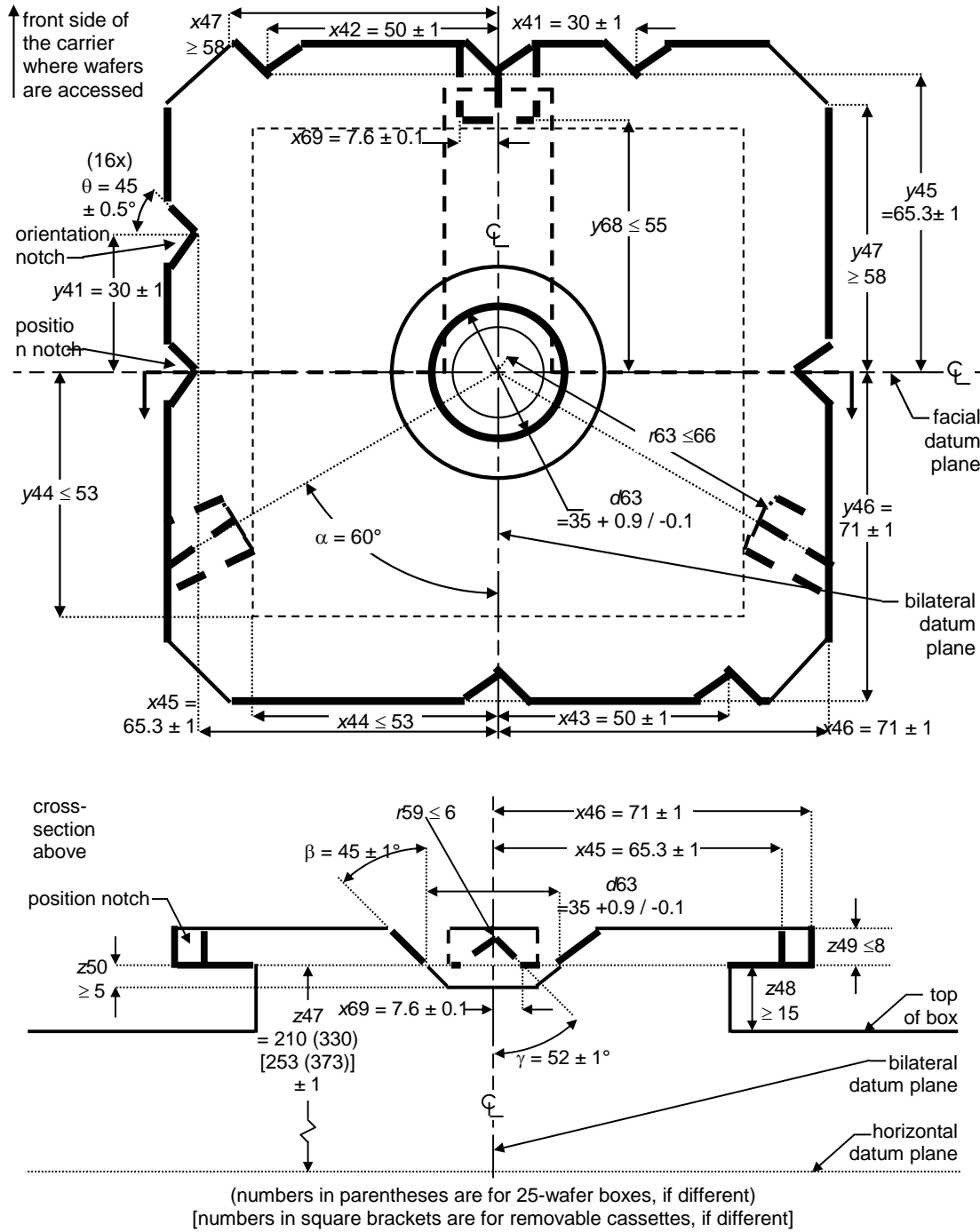
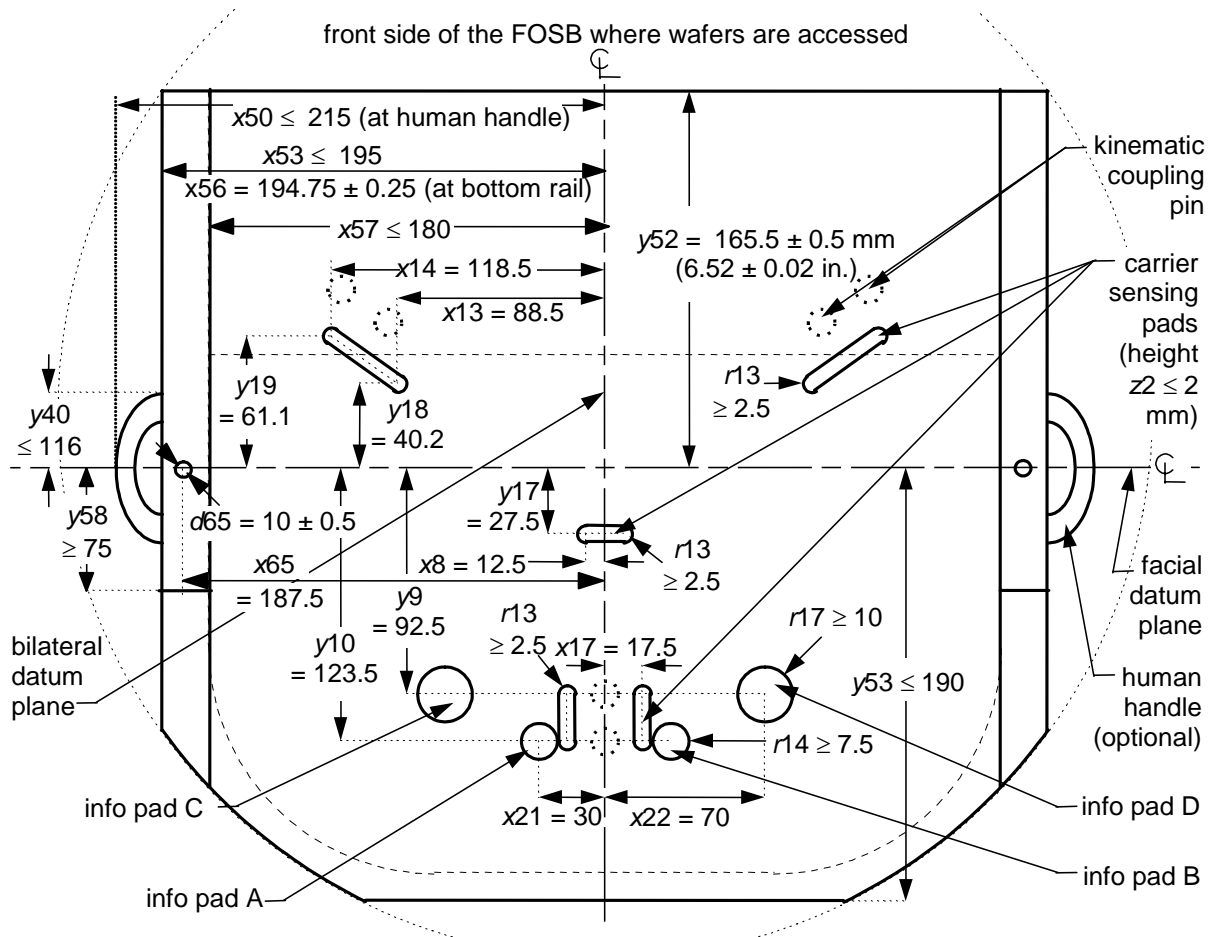


Figure 11
Top Robotic Handling Flange



NOTE: Info pad height (z_2, z_{26}) is described in table 3.

Figure 12
Bottom View of FOSB

5.14 *Retaining Features* — Figure 13 and 14 show two features on the bottom of the FOSB that may be used for retaining the FOSB onto the kinematic couplings. Retaining features are option for the FOSB with manual door, however those are required for the FOSB with automated-shippable door. This may be needed to prevent the FOSB from being knocked off the kinematic couplings by the action of pushing the FOSB against the front-opening interface. The front retaining feature contains a ramp that a wheel might roll up while the FOSB is being pushed toward the front-opening interface. The arm with the wheel (not specified here) then holds the FOSB down on the kinematic couplings. The center retaining feature consists of an oblong slot with a chamber above it. The FOSB can be clamped onto the kinematic couplings by inserting an oblong head on a shaft (not specified here) through the slot and rotating it 90° in either direction. Either retaining feature would only engage after the FOSB is fully seated on the kinematic coupling pins. Either retaining feature must be able to withstand a force in any direction of at least 60. It is recommended that SEMI E15.1 tool load ports be designed to accommodate the minimum hole dimensions of the retaining features to ensure carrier interchangeability. Projections on the tool load ports that mate with the retaining features should also not interfere with the misalignment correction function of the kinematic couplings.

5.15 Sensing Pads — As shown in Figure 12, when the FOSB is fully down on the kinematic coupling, the carrier sensing pads must be z2 above horizontal datum plane. It is recommended that the areas surrounding all of the carrier sensing pads be designed in conjunction with the features that mate with kinematic coupling pins so that a mechanical sensor pin cannot interfere with the lead-in function of the kinematic couplings. Other sensing pads (called info pads and given letter names) communicate information about the carrier. Note that since this is a bottom

view, the positions of sensors on a load port will be switched, with the sensor for info pad A on the right and the sensor for info pad B on the left as one faces the tool from the front. Table 3 defines all dimensions.

Table 3 External FOSB Dimensions and related forces applied to FOSB (Figures 8–14)

Symbol Used	Figure Number	Value Specified		Datum Measured from	Feature Measured to
		Manual Door	Auto-Door		
$\alpha^{#1}$	11	60°		bilateral datum plane	centerline of the right and left kinematic grooves in the top robotic handling flange
$\beta^{#1}$	11	45 ± 1°		nominal wafer centerline	surface of the center hole in the top robotic handling flange
$\gamma^{#1}$	11	52 ± 1°		bilateral datum plane or vertical plane rotated α away from it about nominal wafer centerline	angled surface of the kinematic grooves in the top robotic handling flange
$\theta^{#1}$	11	45 ± 0.5°		either vertical datum plane	sides of position and orientation notches
ϕ	14	30 ± 0.5°		horizontal line on bilateral datum plane	ramp of front retaining feature
$d63^{#1}$	11	35.0 + 0.9 / - 0.1 mm (1.378 + 0.035 / - 0.004 in.)		diameter centered on the nominal wafer centerline	sides the center hole in the top robotic handling flange at height z47
$d65$	8, 9, 12	10 ± 0.5 mm (0.39 ± 0.02 in.)		diameter centered on the intersection of x65 and the facial datum plane	surface of cylindrical fork-lift pin holes in left and right bottom conveyor rails
$f60$	None	175 N (39.3 lbf.) minimum		not applicable	force in any direction which both retaining features are able to withstand
$f61$	None	not applicable	40 N (8.99 lbf.) maximum	not applicable	force that a FOSB should be able to withstand when applied to one of the retaining features in any direction without negative impact to the intended function
$r13$	12	2.5 mm (0.10 in.) minimum		line segment along center of carrier sensing pad	edge of carrier sensing pad
$r14$	12	7.5 mm (0.30 in.) minimum		intersection of x21 and y10	edge of info pads A and B
$r17$	12	10 mm (0.39 in.) minimum		intersection of x22 and y9	edge of info pads C and D
$r59^{#1}$	11	6 mm (0.24 in.) maximum		not applicable	radius on peak of kinematic grooves in the top robotic handling flange
$r60$	13,14	16 ± 0.5 mm (0.63 ± 0.02 in.)		nominal wafer center line	ends of slot for center retaining feature
$r61$	13,14	16 mm (0.63 in.) minimum		nominal wafer center line	walls of chamber above slot in center retaining feature
$r63^{#1}$	11	66 mm (2.60 in.) maximum		nominal wafer centerline	near end of the right and left kinematic grooves in the top robotic handling flange
$r64$	13	9.5 mm (0.37 in.) maximum		not applicable	corners of front retaining feature
$r65$	None	1 mm (0.04 in.) maximum		not applicable	all concave features (radius)
$r66$	None	2 mm (0.08 in.) maximum		not applicable	all required convex features (radius)

Symbol Used	Figure Number	Value Specified		Datum Measured from	Feature Measured to
		Manual Door	Auto-Door		
r67	10	240 mm (9.45 in.) maximum		y67 in front of nominal wafer centerline	any part of FOSB
r68 ^{#2}	10	271 mm (10.67 in.) maximum	Not applicable	y67 in front of nominal wafer centerline	any part of FOSB manual door
r69	None	10 mm (0.4 in.) minimum (required) 15 mm (0.6 in.) (recommended for ergonomic reasons)		not applicable	correctable FOSB misalignment in any horizontal direction
x8	12	12.5 mm (0.49 in.)		bilateral datum plane	end of the line segment along center of center carrier sensing pad
x13	12	88.5 mm (3.48 in.)		bilateral datum plane	near end of the line segment along center of front carrier sensing pads
x14	12	118.5 mm (4.67 in.)		bilateral datum plane	far end of the line segment along center of front carrier sensing pads
x17	12	17.5 mm (0.69 in.)		bilateral datum plane	line segment along center of rear carrier sensing pads
x21	12	30 mm (1.18 in.)		bilateral datum plane	origin of radius r14 at center of info pads A and B
x22	12	70 mm (2.76 in.)		bilateral datum plane	origin of radius r17 at center of info pads C and D
x41 ^{#1}	11	30 ± 1 mm (1.18 ± 0.04 in.)		bilateral datum plane	front right orientation notch on robotic handling flange
x42 ^{#1}	11	50 ± 1 mm (1.97 ± 0.04 in.)		bilateral datum plane	front left orientation notch on robotic handling flange
x43 ^{#1}	11	50 ± 1 mm (1.97 ± 0.04 in.)		bilateral datum plane	rear orientation notch on robotic handling flange
x44 ^{#1}	9, 11	53 mm (2.09 in.) maximum		bilateral datum plane	encroachment of FOSB underneath robotic handling flange
x45 ^{#1}	11	65.3 ± 1 mm (2.57 ± 0.04 in.)		bilateral datum plane	nearest point of side position and orientation notches on robotic handling flange
x46 ^{#1}	9, 11	71 ± 1 mm (2.80 ± 0.04 in.)		bilateral datum plane	sides of robotic handling flange
x47 ^{#1}	11	58 mm (2.28 in.) minimum		bilateral datum plane	end of robotic handling flange front and rear
x50	9, 10, 12	215 mm (8.46 in.) maximum		bilateral datum plane	furthest reach of human handles
x53	9, 10, 12	195 mm (7.68 in.) maximum		bilateral datum plane	FOSB sides (apart from human handles)
x56	9, 12	194.75 ± 0.25 mm (7.667 ± 0.010 in.)		bilateral datum plane	outside edge of bottom conveyor rails
x57	9, 12	180 mm (7.09 in.) maximum		bilateral datum plane	FOSB sides underneath bottom conveyor rails
x60	13	8 ± 0.5 mm (0.31 ± 0.02 in.)		bilateral datum plane	sides of slot for center retaining feature
x64	13	35 mm (1.38 in.) minimum		bilateral datum plane	sides of front retaining feature

Symbol Used	Figure Number	Value Specified		Datum Measured from	Feature Measured to
		Manual Door	Auto-Door		
x65	9, 12	187.5 mm (7.38 in.)		bilateral datum plane	vertical axis of cylindrical fork-lift pin holes in left and right bottom conveyor rails
x68	13	25 mm (0.98 in.) minimum		bilateral datum plane	sides of volume above ramp on front retaining feature
x69 ^{#1}	11	7.6 ± 0.1 mm (0.299 ± 0.004 in.)		bilateral datum plane or vertical plane rotated α away from it about nominal wafer centerline	beginning of angled surface of the kinematic grooves in the top robotic handling flange
x81 ^{#2}	1	215 mm (8.46 in.) maximum	Not applicable	bilateral datum plane	outer edge of manual door
y9	12	92.5 mm (3.64 in.)		facial datum plane	front end of the line segment along center of rear carrier sensing pads and origin of radius $r17$ at center of info pads C and D
y10	12	123.5 mm (4.86 in.)		facial datum plane	rear end of the line segment along center of rear carrier sensing pads and origin of radius $r14$ at center of info pads A and B
y17	12	27.5 mm (1.08 in.)		facial datum plane	line segment along center of center carrier sensing pad
y18	12	40.2 mm (1.58 in.)		facial datum plane	near end of the line segment along center of front carrier sensing pads
y19	12	61.1 mm (2.41 in.)		facial datum plane	far end of the line segment along center of front carrier sensing pads
y40 ^{#1}	8, 10, 12	116 mm (4.57 in.) maximum		facial datum plane	furthest extent of human handles toward the front
y41 ^{#1}	11	30 ± 1 mm (1.18 ± 0.04 in.)		facial datum plane	left orientation notch on robotic handling flange
y42	None	± 0.5 mm (± 0.02 in.) flatness over each area		facial datum plane	surfaces that mate with the seal zones
y44 ^{#1}	8, 11	53 mm (2.09 in.) maximum		facial datum plane	encroachment of supports under the outer edge of the robotic handling flange
y45 ^{#1}	11	65.3 ± 1 mm (2.57 ± 0.04 in.)		facial datum plane	nearest point of front and rear position and orientation notches on robotic handling flange
y46 ^{#1}	8, 11	71 ± 1 mm (2.80 ± 0.04 in.)		facial datum plane	front and rear edge of robotic handling flange
y47 ^{#1}	11	58 mm (2.28 in.) minimum		facial datum plane	end of robotic handling flange sides
y49	None	134 mm (5.28 in.) maximum		facial datum plane	interior of FOSB sides between x51 and x52
y50	8, 10	130 mm (5.12 in.) minimum		facial datum plane	rear of upper door frame volume

Symbol Used	Figure Number	Value Specified		Datum Measured from	Feature Measured to
		Manual Door	Auto-Door		
y52	2, 8, 10, 12	165.5 \pm 0.5 mm (6.52 \pm 0.02 in.) at frame seal zones and 166 mm (6.54 in.) maximum elsewhere on box shell	165.5 \pm 0.5 mm (6.52 \pm 0.02 in.) at door and frame seal zones and at reserved spaces for vacuum application and 166 mm (6.54 in.) maximum elsewhere on door or box shell	facial datum plane	FOSB front
y53	8, 10, 12	190 mm (7.48 in.) maximum		facial datum plane	FOSB rear
y58	8, 12	75 mm (2.95 in.) minimum		facial datum plane	end of left and right conveyor rails
y62	13,14	28 mm (1.10 in.) maximum		facial datum plane	rear of front retaining feature
y63	13,14	37.3 \pm 0.5 mm (1.47 \pm 0.02 in.)		facial datum plane	rear of ramp on front retaining feature
y64	13,14	42.1 \pm 0.5 mm (1.66 \pm 0.02 in.)		facial datum plane	front of ramp on front retaining feature
y65	13,14	104 mm (4.09 in.) minimum		facial datum plane	front of front retaining feature
y67	10	25 mm (0.98 in.)		facial datum plane	origin of r67 on bilateral datum plane
y68 ^{#1}	11	55 mm (2.17 in.) maximum		facial datum plane	near end of the front kinematic groove in the top robotic handling flange
y81 ^{#2}	1	30 mm (1.18 in.) minimum	not applicable	facial datum plane	rear edge of manual door
y82 ^{#2}	1	191 mm (7.52 in.) maximum	not applicable	facial datum plane	front surface of manual door
z2	8, 9, 12	2 mm (0.08 in.) maximum		horizontal datum plane	bottom of carrier sensing pads and info pads (when down)
z26	12	9 mm (0.35 in.) minimum		horizontal datum plane	bottom of info pads (when up)
z30	none	106.5 \pm 0 mm (4.19 \pm 0 in.) for 13-wafer cassette and 166.5 \pm 0 mm (6.56 \pm 0 in.) for 25-wafer cassette		horizontal datum plane	vertical centerline of port
z41	8, 9	0 mm (0 in.) minimum		external horizontal datum plane	bottom of FOSB
z43	8, 9	2 \pm 1 mm (0.08 \pm 0.04 in.)		external horizontal datum plane	bottom conveyor rails

Symbol Used	Figure Number	Value Specified		Datum Measured from	Feature Measured to
		Manual Door	Auto-Door		
z47 ^{#1}	8, 9, 11	210 ± 1 mm (8.27 ± 0.04 in.) for 13-wafer FOSB and 330 ± 1 mm (12.99 ± 0.04 in.) for 25-wafer FOSB		external horizontal datum plane	bottom of robotic handling flange
z48 ^{#1}	8, 9, 11	15 mm (0.59 in.) minimum		bottom of robotic handling flange	encroachment of FOSB top underneath robotic handling flange
z49 ^{#1}	8, 9, 11	8 mm (0.31 in.) maximum		bottom of robotic handling flange	top of robotic handling flange and upper door frame volume
z50 ^{#1}	11	5 mm (0.20 in.) minimum		bottom of robotic handling flange	encroachment of FOSB top underneath the center hole in the top robotic handling flange
z60	14	8.0 ± 0.5 mm (0.31 ± 0.02 in.)		external horizontal datum plane	top of slot in center retaining feature
z61	14	15 mm (0.59 in.) minimum		external horizontal datum plane	top of chamber above slot in center retaining feature
z62	14	18 mm (0.71 in.) minimum		external horizontal datum plane	top of front retaining feature
z63	14	7.5 ± 0.5 mm (0.30 ± 0.02 in.)		external horizontal datum plane	top of ramp on front retaining feature
z65	8, 9	7 mm (0.28 in.) minimum		horizontal datum plane	upper boundary of cylindrical fork-lift pin holes in left and right bottom conveyor rails

^{#1} These dimensions are for optional features.

^{#2} These dimensions pertain to the manual door only.

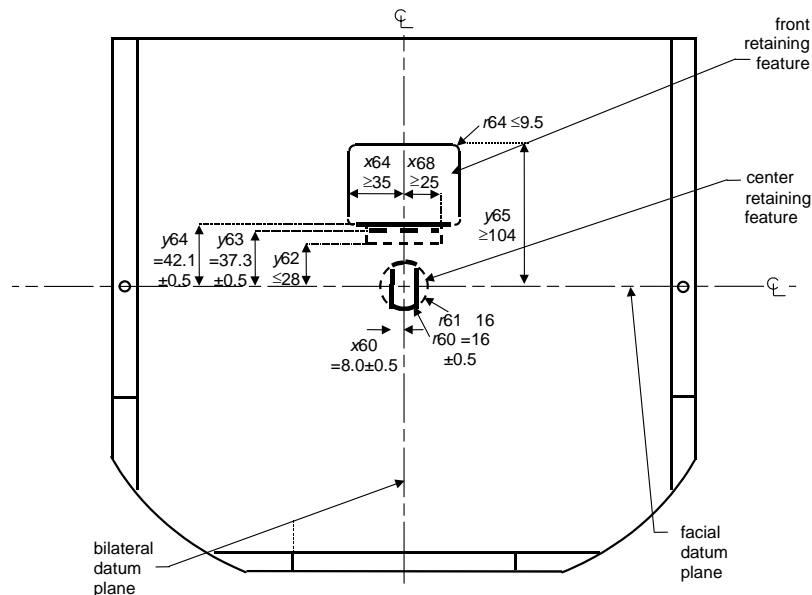


Figure 13
Bottom View of Retaining Features on Bottom of FOSB

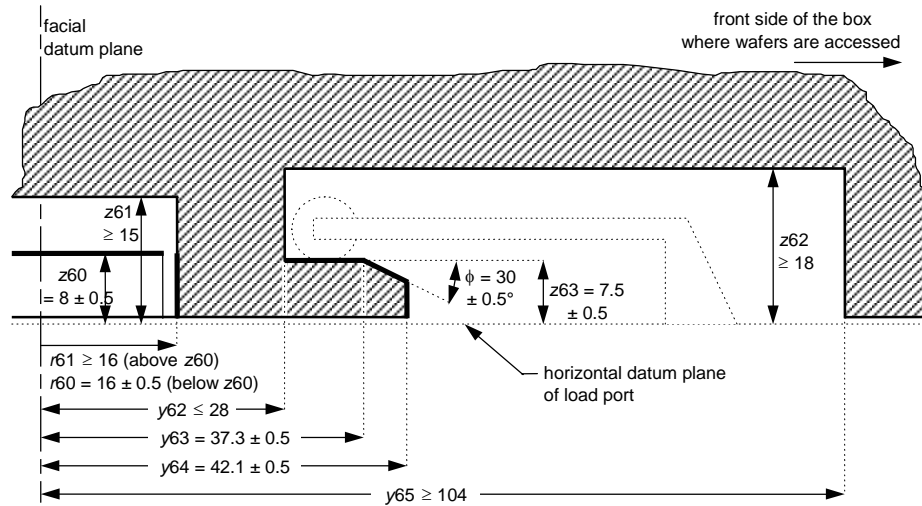


Figure 14
Side View of Retaining Features on Bottom of FOSB

6 Related Documents

6.1 SEMI Standards

SEMI E22.1 — Cluster Tool Module Interface 300 mm: Transport Module End Effector Exclusion Volume Standard

SEMI E63 — Mechanical Specification for 300 mm Box Opener/Loader to Tool Standard (BOLTS-M) Interface

SEMI M28 — Specification for Developmental 300 mm Diameter Polished Single Crystal Silicon Wafers

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

APPENDIX 1

APPLICATION NOTES

NOTICE: This appendix is an official part of SEMI M31 and was approved by full letter ballot procedures on July 15, 1999.

A1-1 Although FOSB parameters supporting effective reuse and cleaning (washing/drying) are not defined in this document, it is essential that these capabilities be considered for a successful overall shipping box design.

A1-2 It is important to note that shipping boxes containing wafers are typically bagged for shipment to the IC manufacturer. It is therefore important to design the outer surfaces of the shipping box to be compatible with this common practice.

A1-3 *Information about Automated-shippable Door*

A1-3.1 When Automated-shippable door is used, the following contents should be understood for wafer quality.

A1-3.2 Rear of Door (y_{51}): Increasing the value of y_{51} , might have impact to the capability for absorbing drop shock and wafer rotation during transportation, especially for x-direction since decreasing the area of holding wafer by front wafer retainer.

A1-4 Items which need to be considered for automated-shippable door closing and opening process:

A1-4.1 When close or open the automated-shippable door by SEMI E62 compliant load port, not only SEMI E62 defined f_{30} and f_{34} , but also consideration of other factors which may not be defined by SEMI E62, such as speed, acceleration and deceleration of door closing and opening, are needed.

A1-4.2 Excessive f_{34} may cause deformation of the box, as well as breakage of wafers which are contained in the box. Door may be closed with lesser f_{34} by deploying designs which utilize door and box related forces, such as latch key torque.

A1-4.3 It needs to be considered that door may rebound at door opening process.

A1-4.4 Retaining features force (f_{61}): It is noted that strong clamping force may produce plastic deformation.

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The user's attention is called to the possibility that compliance with this standard may require use of copyrighted material or of an invention covered by patent rights. By publication of this standard, SEMI takes no position respecting the validity of any patent rights or copyrights asserted in connection with any item 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.

SEMI M32-0998 (Reapproved 0704) GUIDE TO STATISTICAL SPECIFICATIONS

This guide was technically reapproved by the Global Silicon Wafer Committee and is the direct responsibility of the North American Silicon Wafer Committee. Current edition reapproved by the North American Regional Standards Committee on March 14, 2004. Initially available at www.semi.org May 2004; to be published July 2004. Originally published September 1998.

1 Purpose

1.1 Specifications are based on requirements negotiated between trading partners. This document describes an explicit specification form that defines the risk level as a part of parametric specifications. This approach uses process capability information to focus quality improvement efforts, reduce sampling, and maintain low risks. It is based on the fundamental belief that specifications should facilitate the movement toward processed-in quality instead of inspected-in quality.

1.2 It is important for users and suppliers to acknowledge and mutually agree on quality levels so the methods employed will satisfy their expectations. Statistical specifications provide a convenient way to do this.

1.3 Statistical specifications are designed to facilitate the movement toward processed-in quality. They are most appropriate for processes that have been statistically characterized. This means the shape of the statistical distribution that created the product is known, or can be approximated to the satisfaction of the user and the supplier. It also implies that the statistical control of the process and the measurement systems are defined to the level that is necessary to meet the current needs.

2 Scope

2.1 This guide may be used when changing or adding specifications to SEMI M18.

2.2 Statistical specifications apply to all processes that have been statistically characterized. Solutions are given for two product distribution shapes (normal & lognormal), and the advantages of these solutions are explained. Appendix 3 shows the statistically characterized shape for many common silicon wafer processes.

2.3 This guide applies to processes related to the production and use of silicon wafers. It may also be applied to the production and use of other materials.

2.4 This approach implies that the quality level shipped is the same as the quality level produced.

2.5 This methodology can be an effective tool for driving quality improvement.

2.6 This procedure can be coupled with other techniques for centering the mean and reducing the variation within the process distribution as deemed necessary by the user and supplier.

2.7 Appendix 4 further explains the rationale for this approach.

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 Outlier effects are beyond the scope of this document.

4 Referenced Standard

4.1 SEMI Standard

SEMI M18 — Format for Silicon Wafer Specification Form for Order Entry

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

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 *Cpk* — process capability index

5.1.2 *ppm* — parts per million

5.2 Definitions

5.2.1 *capability based sampling* — any method that uses the process capability as a factor in determining the required sampling.

5.2.2 *ECPK* — process capability index on a non-normal process which is corrected for non-normality.

5.2.3 *error* — the difference between the quality level committed to a user and the level that could be received.

5.2.4 *process capability index (Cpk)* — the smaller of (upper spec limit - mean) ÷ 3 sigma, or (mean - lower spec limit) ÷ 3 sigma.

5.2.5 *quality level* — The maximum defect level agreed upon by the user and the supplier.

5.2.6 *supplier risk* — The risk of rejecting material that is within the user specifications.

5.2.7 *user risk* — The risk of accepting material that is outside the user specifications.

6 Solutions

6.1 The following are examples of statistical specifications for normal and lognormal distributions.

6.1.1 *Normal* — The normal distribution describes processes that target a specific value and have symmetric random variation about that value. The first portion of the normal statistical specification is the familiar tolerance. It uses an upper specification limit (USL) and a lower specification limit (LSL), or the target plus and/or minus a value. The second portion, after the @ sign below, is a measure of the quality level, in ppm.

LSL to USL @ yy ppm, or

Target \pm xx @ yy ppm

6.1.2 *Lognormal* — The lognormal function describes many of the one-sided distributions that are encountered in the silicon industry. It applies to those parameters such as flatness and warp that are bounded by zero. For lognormal processes, the value of a parameter could be specified as:

\leq xx @ yy ppm

6.2 More details, and examples of use, are shown in Appendix 1 for normal applications and Appendix 2 for lognormal applications.

6.3 For process distributions not following normal or lognormal forms, Pearson or other distributions may be used.

APPENDIX 1

USING STATISTICAL SPECIFICATIONS FOR NORMAL PROCESSES

NOTICE: This appendix was approved as an official part of SEMI M32 by full letter ballot procedure.

A1-1 Statistical Specification Format for Normal Distributions

A1-1.1 The normal distribution is quite well-known. It describes processes that target a specific value and have symmetric random variation about that value. Below are examples of statistical specifications for normal processes. The first portion is the familiar tolerance, and the second portion is a measure of the quality level.

LSL to USL @ yy ppm, or

Target \pm xx @ yy ppm

Other standard tolerance definitions could be substituted, or other definitions of the quality level such as Cpk, Z-value, or percent could be used.

A1-1.2 Adding the quality level removes the potential for misunderstanding and makes the specification more meaningful.

A1-2 Example of Use

A1-2.1 Functionally, statistical specifications are similar to conventional tolerances, except that the quality level is stated rather than just implied. They can be directly substituted for tolerances or other forms of specifications. Statistical specifications are especially useful for focusing quality improvement efforts, achieving ship-to-stock relationships, promoting processed in quality, and reducing after the fact inspection. In this environment they could be used as follows:

A1-2.1.1 Through audits and capability reporting a particular parameter is targeted for improvement or chosen as a ship-to-stock candidate.

A1-2.1.2 The control methods, distribution shape, and statistical specification are agreed upon. The tolerance and quality level defined in the statistical specification completely define the needed process capability.

A1-2.1.3 Once it is shown that the required capability is consistently exceeded then reduced inspection sampling can be implemented without increasing the risk to the customer or supplier. In this way the process controls can gradually become the guarantee for quality, and after the fact inspection can be gradually reduced to the level that is needed for outgoing quality reporting.

A1-3 Discussion

A1-3.1 Statistical specifications remove ambiguity, allow small risks, and promote the movement toward better process controls and less after the fact inspection. The quality level (i.e., the yy portion) is often misunderstood. Some people say they want ppm level quality but introduce methods that allow 50,000 to 200,000 ppm in error. This causes confusion.

A1-3.2 Many people have the misconception that tolerances are goal posts that require 100% of the material to fall inside. Processes are usually described by statistical distributions, so specifications have little meaning if a quality level is not defined. For many years, 99.73% (i.e., ± 3 sigma) was considered to be satisfactory. "Within tolerance" was understood to mean within tolerance with a 99.73% confidence, or a 0.27% quality level. Later the 99.73% process was defined as "cruel". 0.27% was no longer an acceptable quality level, and process drift was understood to cause even higher reject rates. This led to the demand for better process capabilities (i.e., higher Cpk's), which demanded corresponding improvements in process characterization and control methodologies. At the same time other users tightened their tolerances to the point that led to over-control. Either extreme can cause a mismatch between expectations and capabilities if the risks are not carefully evaluated.

A1-3.3 Capability-based sampling is perhaps the only way to rigorously transfer from inspection-based quality to process control-based quality, without incurring high risks. Statistical specifications create the environment for this to work. Once the specification is clearly defined, it can be clearly achieved. The details of capability based sampling are beyond the scope of this document, but the basic concept is easy to understand. If a process is very capable and controlled, then the system can be relied upon to create the necessary quality level with less after the fact inspection. This is good for both sides. Users get more reliable quality, and suppliers get the information needed to focus quality improvement efforts and direct resources at the most critical processes.



A1-3.4 Once a process has been statistically characterized, everything becomes much easier. Calculations can be done in milliseconds instead of minutes. This includes spec acceptance, comparisons,

and many forms of analysis. Multiple levels like % < A, % < B, and % < C are also clearly unnecessary if the distribution shape is known. This prevents a large amount of duplicate work.

APPENDIX 2

USING STATISTICAL SPECIFICATIONS FOR LOGNORMAL PROCESSES

NOTICE: This appendix was approved as an official part of SEMI M32 by full letter ballot procedure.

A2-1 Statistical Specification Format for Lognormal Distributions

A2-1.1 The lognormal probability distribution function describes many of the one-sided distributions encountered in the silicon industry. It applies to those one-sided parameters like flatness and warp that are bounded by zero. Below is an example of a statistical specification for a lognormal process.

$\leq xx @ yy \text{ ppm}$

A2-1.2 Other standard tolerance definitions could be substituted, or other quality level definitions such as ECPK, Z-value, or percent could be used. Again, ECPK is the Equivalent normal Cpk that corrects for non-normality. More information on the Equivalent Cpk is shown at the end of this appendix.

A2-1.3 As with the normal distribution, adding the quality level removes the potential for misunderstanding and makes the specification more meaningful.

A2-2 Example of Use

A2-2.1 Again, the major objectives are to focus quality improvement efforts, achieve ship-to-stock relationships, promote processed in quality, and reduce after the fact inspection. The steps are the same as shown in Section A1-2 for the normal distribution. The major difference is that only the upper tail needs to be considered. However, since the lognormal tail goes so much farther out, it might be necessary to accept a less critical quality level.

A2-3 Discussion

A2-3.1 Statistical specifications work very well for processes with lognormal distributions. They have all the benefits described for normal distributions, and in some respects, they are even easier. Since lognormal processes only have one tail, checking each tail to decide which is the most critical is not necessary. Also, it has been empirically observed that lognormal processes are not as prone to mean drifting, so they tend to be more stable. The main hurdle is realizing how much error is introduced if the distribution shape is assumed to be normal when it is not.

A2-3.1.1 Figure A2-1 illustrates the difference between a lognormal and a normal process. The curve which has a solid line (and is clearly not symmetrical) is the lognormal distribution. The curve with the dashed line is the normal distribution. The error when mistakenly using a normal distribution to characterize a lognormal process is shown in Table A2-1. For values that increment by 1 sigma from the mean, the ppm greater than that value is given for each curve, and the difference (or error) is calculated. To make it easier to visualize, increments of the simple normal mean and sigma (1.8263 and 0.7568 respectively) are used in the "value" column. For calculating the lognormal statistics the correct lognormal geometric mean of 1.8258 and the lognormal geometric sigma of 0.7550 are used. The error between the curves increases as the point of interest moves toward the center of the distribution, but the most important issue is the length of the tail. The right tail of the lognormal distribution extends along with the histogram, but the normal distribution is much shorter. Visually, the significance might be overlooked in Figure A2-1, but when the tail probabilities are shown in ppm (Table A2-1) the difference is very apparent.

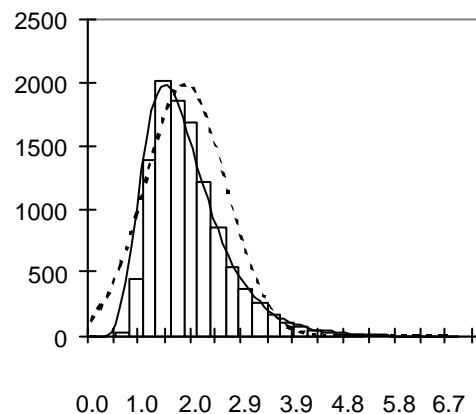


Figure A2-1
Lognormal vs. Normal Curves

Table A2-1 Lognormal vs. Normal Data

Value	Value Description	Normal ppm >	Lognormal ppm >	Error
1.8263	mean	500000	420997	79003
2.5831	+ 1 s	158655	141869	16786
3.3399	+ 2 s	22750	42836	20086
4.0967	+ 3 s	1350	12783	11433
4.8535	+ 4 s	32	3914	3882
5.6103	+ 5 s	0.3	1247	1247
6.3671	+ 6 s		415	415
7.1239	+ 7 s		144	144
7.8807	+ 8 s		52	52
8.6375	+ 9 s		20	20
9.3943	+ 10 s		8	8
10.1511	+ 11 s		3	3
10.9079	+ 12 s		1	1

A2-3.2 Lognormal distributions can be handled mathematically as easily as normal distributions, if the formulas are known. The difficulty in the past was that many of the calculations developed for the normal distribution were not available for lognormal. The equivalent normal Cpk (ECPK) was developed to address this issue. For the lognormal distribution, ECPK is calculated as shown below. It is an exact mathematical derivation with no estimations or assumptions. It was designed to allow people to see real data and keep all transformations and conversions inside the computer where they are totally invisible. Two cases are presented. Section A2-3.3 describes the case where a statistical software is available, and Section A2-3.4 describes a shortcut that may be used when the computation is derived from scratch. In both cases, it is important to remember that only the computer will see these formulas.

A2-3.3 Statistical software packages will usually output the geometric mean and geometric sigma. If μ is the lognormal geometric mean, σ is the lognormal geometric sigma, and \ln is the natural log function, then ECPK is calculated as:

$$ECPK = \frac{\ln[USL] - \ln\left[\frac{\mu^2}{\sqrt{\mu^2 + \sigma^2}}\right]}{3\left(\sqrt{\ln\left(\frac{\mu^2 + \sigma^2}{\mu^2}\right)}\right)}$$

For the example in Figure A2-1 the lognormal geometric mean is 1.826 and the lognormal geometric sigma is 0.755. If an upper spec limit (USL) of 6 is applied, then the ECPK is 1.06. This will usually be

done in a computer. A programming version of this formula is written as:

$$ECPK = ((\log(USL)) - \log(Gmean**2 / (\sqrt{(Gmean**2 + Gsigma**2)}))) / (3 * \sqrt{\log((Gmean**2 + Gsigma**2) / Gmean**2)})$$

A2-3.4 If the computation is programmed from scratch for raw data, it may be convenient to take the natural log of each data point (i.e., do a log transformation) then compute the mean of the transformed data (Tmean) and sigma of the transformed data (Tsigma). Again, \ln is the natural log function. In this case, the ECPK formula can be written as:

$$ECPK = (\ln(USL) - Tmean) / (3 * Tsigma)$$

The geometric mean and geometric sigma could then be calculated as follows:

$$Gmean = \exp(Tmean + (Tsigma**2)/2)$$

$$Gsigma = \sqrt{(\exp((2 * Tmean) + (Tsigma**2))) * (\exp((Tsigma**2)) - 1)}$$

A2-4 Conclusion

Lognormal calculations can be as easy as normal calculations. Again, the formulas reside only in the computer where they are never seen by the user. They allow the user to view the actual measures and the actual distributions.

APPENDIX 3

CURRENT STATISTICAL CHARACTERIZATION OF SILICON PROCESS PARAMETERS

NOTICE: This appendix was approved as an official part of SEMI M32 by full letter ballot procedure.

A3-1 Statistical Characterization of Silicon Process Parameters

A3-1.1 The following table describes the statistical characterization on a number of silicon wafer processes. The comments column indicates the level of characterization that has been achieved. “Characterized” means that the process should, under usual conditions, display the distribution shape shown. “Conditional” means that there are conditions that might need to be considered before deciding if the shape shown is satisfactory. The chi-square goodness of fit test was used to characterize the distribution shapes. Actual chi-square goodness of fit values will typically be proprietary information that is shared only between a given supplier and user.

Table A3-1 Characterization of Silicon Processes

<i>Process or Parameter Description</i>	<i>Distribution Shape</i>	<i>Comments</i>
Diameter	Normal	Characterized
Flatness/Global (GBIR, GF3R, GF3D, GFLR, or GFLD)	Lognormal	Characterized
Flatness/Site (SF3R, SF3D, SFLR, SFLD, SFQR, SFQD, SBIR, or SBID)	Lognormal	Characterized
Oxygen Concentration	Normal	<i>Conditional</i> — Non-normalities are mostly attributed to measurement error, so the normal distribution is usually satisfactory.
Shape, Bow (Reference SEMI M1, Figure A2-1.)	Normal	Characterized
Shape, Warp, or Sori (Reference SEMI M1, Figure A2-1.)	Lognormal	Characterized
Thickness (Polished or EPI)	Normal	Characterized

APPENDIX 4

RATIONALE FOR STATISTICAL SPECIFICATIONS

NOTICE: This appendix was approved as an official part of SEMI M32 by full letter ballot procedure.

A4-1 Introduction

A4-1.1 The purpose of a specification is either to define acceptance criteria or to assist in quality improvement planning. The basic intent is to quantify user need so suppliers can accommodate that need. Developing a clear link between user needs and the control methods used on the production floor is one of the most critical steps for creating a Total Quality Management (TQM) environment. Following are some key background concepts that allow the reader to understand the conclusions drawn in this document.

A4-1.2 For most manufacturing processes there is no such thing as “zero defects”. Processes are described by statistical probability distributions, and the tails of these functions can go all the way to infinity. For many years, 99.73% (i.e., ± 3 sigma) was used as the basis for tolerances. “Within tolerance” was understood to mean within tolerance with a 99.73% confidence, or a 0.27% quality level. When users requested better levels, then new standards such as 33 ppm or 3.4 ppm were made. In any case, this quality level needs to be agreed upon for a specification method to have meaning. It can be measured in terms of ppm, Z, Cpk (which is equal to Z divided by 3), or percent. Z tables or Cpk tables can be obtained which provide this information.

A4-1.3 Errors in the 10% or higher range can be generated if a percentile specification is based on the central portion of the distribution. An example of such a specification is “50% \leq 1.2 microns”. These errors are not obvious and require careful statistical analysis based upon real process variation. Multiple percentile specifications are also difficult to apply. Paragraph A4-3 provides more details on these issues.

A4-1.4 Conversely, if specifications get too far out on the tail, they tend to become abstract and are not used as the primary factor driving quality improvements. This is especially true for non-normal processes where the tail of the distribution goes out much farther than expected from a normal distribution. Figure A4-1 shows where a 3.4 ppm specification would be on a lognormal process. Users usually will not allow that much tolerance. However, if the specification is tightened while the process capability remains the same, then the consequence is a degradation in the quality level.

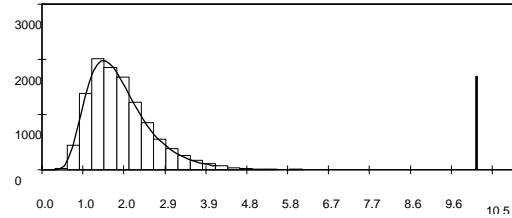


Figure A4-1

Lognormal Tolerance for 3.4 ppm Quality Level

A4-1.5 The mean and sigma specification is another proposed approach. Intuitively, this seems promising, but it has many of the same problems as multiple percentile specifications. More details are given in Paragraph A4-4.

A4-1.6 Errors in the 5% to 10% range can also be generated if process distributions are assumed to be normal when they are not. Knowing the actual distribution shape is a key factor that opens up a tremendous amount of knowledge. Figure A4-2 shows an example of real data that illustrates a lognormal process. In the past, this was considered to be difficult because non-normal distributions were only supported by high-level statistical software. Now even spreadsheets have them. It should also be noted that once the process characterization has been done, the shape of the distribution typically does not change, so this knowledge can be shared throughout the industry. Regularly monitoring the process by overlaying the distribution on the process histogram or cumulative frequency plot is extremely valuable to confirm that the process is not taking on unnatural bimodal or outlier effects. One-sided distributions such as flatness and warp are so well-characterized by the lognormal distribution that “goodness-of-fit” results are very close to 100%. Again, the error gets larger as the point-of interest moves toward the “center” of the distribution, but the major concern is the length of the tail. The lognormal distribution in Figure A4-2 (the curve with a solid line which is clearly not symmetrical) has a tail that extends much farther to the right than the normal distribution which is shown with a dashed line. This effect, and the impact, is shown in more detail in Appendix 2.

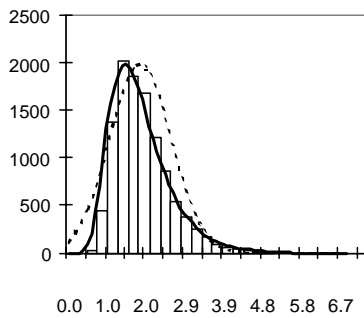


Figure A4-2
Normal vs. Lognormal Shape

A4-1.7 Statistical specifications quantify the quality level so it is not an abstract assumption left to conjecture. This allows both the user and supplier to optimize their control systems to that level. Capability based sampling is one example. Simply put, this means to use process capability information to help define the sampling plan for a process. A detailed discussion of this subject is beyond the scope of this document, but the basic concept is easy to understand. If a process is very capable and controlled it does not need as much sampling as one that is not. Implementing this strategy is a big step ahead of standard sampling theory. It might be the only way to rigorously transfer from inspection based quality to process control based quality, without incurring high risks. Statistical specifications create the environment which facilitates this improved strategy. Hopefully, the quality levels would be defined in ppm, but any level agreed upon by both the user and the supplier would work.

A4-2 Tolerance Specifications

LSL to USL, or Target \pm xx

A4-2.1 The main problem with a conventional tolerance is that many people perceive it as a goal post that requires 100% of the material to fall inside. This document has shown in detail that this is simply a wrong perception. Stating the quality level in the specification, instead of just implying it, corrects this problem.

A4-2.2 Another common misconception is that tolerances and tail probabilities divert attention away from centering the process. Of course, centering is important. Considering the impact of poor quality on all customers, it is clear that a well centered process is far more efficient than one that is not. It is also generally true that the suitability of the product is not significantly different immediately on one side of a tolerance line compared to the other. However, there are a number of issues that warrant discussion.

A4-2.2.1 First, centering is usually not difficult, so it usually does not need a major emphasis. Those who are experienced in quality improvement techniques would certainly not forget to center the process. Simply monitoring the mean trend gives an excellent measure of centering, and it keeps the focus on the process rather than the specification. Industry carries a long history where specifications prevented the attainment of good process control. Many of the issues have been explained earlier in this document. To summarize, process controls are the only way to truly maintain a centered process, and these controls can only work if there is enough tolerance in the specification to accommodate the sensitivity limitations of the control methods.

A4-2.2.2 The second issue is that it might not be possible to center. This is clearly the case in one-sided processes that are bounded by zero. Optimizing multiple parameters might also dictate that some parameters get worse.

A4-2.2.3 The final, and most important, issue is the challenge of teaching statistical methods to the factory population. It is very easy to teach averages and centering since they tend to be well understood already. It is not as easy to teach sigma and the fact that sigma trends must be thoroughly understood before much of anything can be said about averages. Confirming that the R or S chart is controlled before studying the Xbar chart and doing an F-test before doing a t-test are just two examples. These are very important concepts that must be fully understood in order to apply statistical methods. Over-stressing centering de-emphasizes sigma and creates an environment where it is not appreciated. Thinking in terms of sigma is the most important concept that most people will learn about process control methods. It deserves a major emphasis.

A4-2.2.4 Of course, centering would be a concern if mixing and matching of lots is the control method, but this can be easily spotted in the statistical characterization process. The fact that some of the alternatives to tolerances are much more likely to cause this practice will be further explained in Paragraphs A4-3 and A4-4.

A4-3 Multiple Distributional Percentile Specifications

$\% \leq A$, $\% \leq B$, and $\% \leq C$

A4-3.1 Errors in the 10% or higher range can be generated if a specification in the central portion of the distribution is used. An example of such a specification is “50% \leq 1.2 microns”.

A4-3.2 No control method can hold a process perfectly still. Even the best real-time control methods can allow a process to drift as much as ± 1.5 sigma. For this reason, a 6-sigma design was defined as 4.5 sigma to the nearest tolerance.

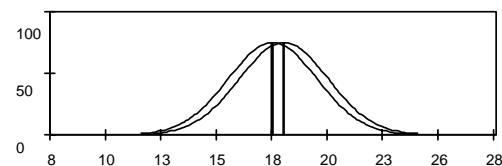
A4-3.3 Sampling issues are a major concern. Many kinds of variation can be quantified by rigorously studying the appropriate samplings (within batch samples for batch-to-batch variation, monthly samples for month-to-month variation, etc.). However, there are practical limits on how many kinds of variation can be continuously monitored. There is a large amount of work involved, and there are hundreds of potential sources of variation. Resource restrictions regularly force suppliers to concentrate on the known key variables and leave the rest as error in the system (at least for now). As sample periods get longer, there is more statistical sensitivity, but also more probability that the drift will be confounded with user-driven process improvements. For example, month-to-month random drift is hard to quantify because production processes are often improved before many months of data can be observed. Measurement error is another main contributor which further complicates the other sensitivity issues. These factors all combine to allow a certain amount of undetectable process drift. This process drift needs to be considered when defining the specification approach.

A4-3.4 These variations cannot be detected because of statistical sensitivity limitations. Table A4-1 shows the sample sizes needed to detect different levels of process shift. Delta will be defined as the number of sigma of undetectable mean drift. For simplicity, a one-way shift is shown, but in most practical cases, the shift could go plus or minus. Using the old standard of 5% supplier risk and 10% user risk, 72 samples are needed to detect a delta of 0.25 sigma. This example (0.25 sigma of mean drift) has been used throughout this document. Since most of the discussion will relate to process drift, the terms “drift” and “shift” will be used interchangeably. Clearly, 72 is too large a sampling for most real-time control systems, but it is still an understatement of the problem. Most users currently expect their risk to be much smaller than 10%. The last row shows that the sample size would need to be 311 to reach 0.1% user and supplier risks. It is generally agreed that 0.1% (i.e., 1000 ppm) is the lowest level that is feasible using standard probability theory. For lower levels, it is necessary to move farther out on the distribution tails where it is necessary to rely on more than just standard sampling probabilities.

Table A4-1 Sampling Requirements

(a = supplier risk, b = user risk)					
Detectable Mean Shift (in Sigma)	0.125	0.25	0.50	0.75	1.0
Min N a = 20% b = 20%	92	24	7	4	4
Min N a = 5% b = 10%	280	72	20	10	7
Min N a = 1% b = 1%	696	177	47	23	15
Min N a = 0.1% b = 0.1%	1228	311	82	40	25

A4-3.5 Figures A4-3, A4-4, and A4-5 show the error generated by 0.25 sigma of undetectable mean drift. Again, the number of sigma of undetectable mean drift will be defined as delta. Notice how the error grows as the point of interest moves toward the center of the distribution. At the four sigma point (out on the tail) there is very little error, so suppliers can be generous with internal buffer specifications to protect the user. This is not as feasible in the center of the distribution because there is so much material at stake. A percentile specification in the center of the process shown would have about 1000 times more undetected, out-of-spec product than a specification at the 4 sigma point. Since the shift could go either way, this could also be 1000 times more material that was rejected and should not have been.



**Figure A4-3
Error at 0 Sigma**

A4-3.6 The left curve in Figure A4-3 shows a distribution with an expected mean of 18. The right curve shows the same distribution with an undetectable drift of 0.25 sigma. If a specification limit is placed at 18, then 50% of the material is below the specification for the nominal distribution. However, only 40.13% is below the specification for the distribution that has drifted. The error, shown by the area between the vertical lines and below the right curve, is 9.87% or 98,700 ppm.

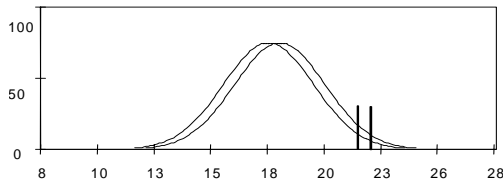


Figure A4-4
Error at 2 Sigma

A4-3.7 The error when the specification is 2 sigma from the mean, shown in Figure A4-4 as the area between the vertical lines and below the right curve, is 1.73% or 17,300 ppm.

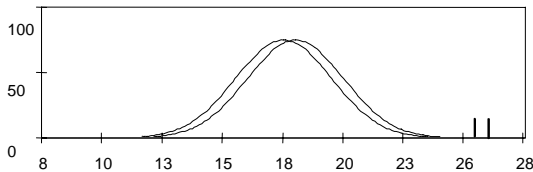
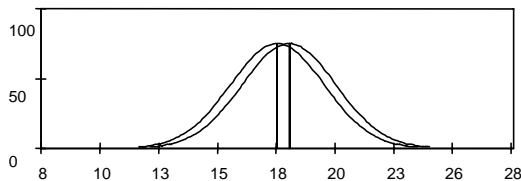


Figure A4-5
Error at 4 Sigma

A4-3.8 The error when the specification is 4 sigma from the mean, shown in Figure A4-5 as the area between the vertical lines and below the right curve (but indistinguishable), is 0.01% or 100 ppm.

A4-3.9 Figure A4-4 further quantifies this error. Percent-less-than calculations are shown for each curve at increments of 1 sigma from the mean. The starting mean is 18, and the sigma is 2.



Value	Value Description	Left Curve %	Right Curve %	Error %
10	- 4 s	0.01	0.00	0.01
12	- 3 s	0.13	0.06	0.07
14	- 2 s	2.28	1.22	1.06
16	- 1 s	15.87	10.56	5.31
18	mean	50.00	40.13	9.87
20	+ 1 s	84.13	77.34	6.79
22	+ 2 s	97.72	95.99	1.73
24	+ 3 s	99.87	99.70	0.17
26	+ 4 s	100.00	99.99	0.01

Figure A4-6
Percentage Error

A4-3.10 Please note that this is a very conservative example. The delta and the resulting error can get much larger.

A4-3.11 A major concern is what to do when the specification is not met. Users would certainly not want suppliers to reject material in the center of the distribution. Alternatives are to (1) reject the whole shipment, (2) reject nearby lots, (3) mix and match lots, or (4) translate the percentage hypothetically lost in the center back out to the tail in order to reject the worst material. The first two alternatives are really more like penalties and would lead to unnecessary loss of good material. The third is the worst form of inspecting in quality. It is generally agreed that this is the main thing to avoid. Translating the error back to the tail is possible but not necessarily a good approach. This would involve translating a reject percentage with a large potential error back out to a region that would have had a very small error. A multiple percentile specification can also be quite difficult in a production environment. Each of the percentile criteria must be evaluated to determine which one requires the highest reject rate. That reject rate must then be translated back to the tail, and 100% sample data must be used to determine which actual pieces to reject. If the statistical distribution is defined, one specification would give the same amount of information with much less work. If only one criterion is used, and it is well out on the tail (hopefully in the ppm range) then this method is very similar to a statistical specification.

A4-3.12 A commonly stated goal of multiple percentile specifications is to focus on centering rather than distribution tails. All of the discussion in Section A4-2.2 concerning centering is equally applicable here. Multiple percentile specifications are more likely to cause inspected-in quality which detracts from process control based centering.

A4-3.13 Ease of use is another stated goal, but for all of the reasons stated above, this method is one of the most difficult to use. Statistical calculations can be done in milliseconds while the potential of large samplings, raw data manipulation, and duplicate effort associated with multiple distributional percentile specifications create much more work. Characterizing with percentiles is an alternative for processes that have not yet been statistically characterized, but once that hurdle is crossed, everything gets many times easier.

A4-4 Mean and Sigma Specifications

Mean \leq Value, Sigma \leq Value, or
Low to High Mean, Sigma \leq Value

A4-4.1 First, please note that the term “sigma” is intentionally used, rather than “standard deviation”. This does not in any way imply 100% sampling. Instead, the implication is that the process would need to be monitored long enough to understand the “process sigma” (i.e., the state at which the process can be controlled).

A4-4.2 Mean and sigma specifications intuitively seem very promising, but they have many of the same problems as multiple distributional percentile specifications. Here, the issue of statistical sensitivity is particularly important. Table A4-1, and the discussion in Section A4-3.4 concerning sampling requirements, explain the central issue. The sample sizes required to detect smaller mean shifts are very large, so they usually are not feasible at the process control point. As a result, mean and sigma specifications could lead to much more sampling in an inspection area or in the warehouse, where larger quantities are available. To keep the sample sizes small, it is necessary to allow a specified amount of process drift. Therefore, some form of tolerance is necessary.

A4-4.3 Another factor that needs careful consideration is the movement toward controlling surrogate variables instead of outgoing parameters. Many types of variation can be controlled by carefully applying the appropriate samplings (within batch samples for batch-to-batch variation, within lot samples for lot-to-lot variation, etc.). However, there are practical limitations on how many types of variation can be continuously monitored. There is a large amount of work involved, and there are hundreds of potential sources of variation. Resource restrictions regularly force suppliers to concentrate on the known key variables and leave the rest as error in the system (at least for now). This practice, called homogeneous sampling, is designed to continuously home in on the variables that have the greatest impact on the distribution. Strictly speaking, for characterizing process capability, a random and over-time sampling which covers all sources of variation should be used. In practice, this is difficult to do, so engineering judgment is needed to select the most appropriate homogeneous sampling. This is yet another issue that could generate significant errors if it is not fully understood.

A4-4.4 From an ease-of-use standpoint, mean and sigma specifications have many of the same issues as multiple distributional percentile specifications. Mixing and matching of lots would be especially tempting with this approach because it might be the only practical alternative.

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SEMI M33-0998

TEST METHOD FOR THE DETERMINATION OF RESIDUAL SURFACE CONTAMINATION ON SILICON WAFERS BY MEANS OF TOTAL REFLECTION X-RAY FLUORESCENCE SPECTROSCOPY (TXRF)

1 Purpose

1.1 The test provides the analytical procedure to determine the trace level of contaminating elements of an atomic number higher than 15 on polished or epitaxial silicon wafer surfaces in native or thermally grown or tetraethylorthosilicate (TEOS) oxide or in residues of microdroplets of process chemicals or media as analyzed with TXRF on silicon wafer surfaces as described in Sections 15.1 and 15.2.

2 Scope

2.1 This document specifies a VPD-TXRF (Vapor Phase Decomposition Total Reflection X-Ray Fluorescence Spectroscopy) method to analyze the elemental composition and areal density of impurities, that include cations and anions with atomic numbers between 16 (S) and 92 (U) independent of their chemical state, with the exception of the X-ray source material, on polished or epitaxial silicon wafer surfaces in native or thermally grown oxide or in residues of microdroplets of process chemicals or media as analyzed with TXRF on silicon wafer surfaces.

2.2 This test is especially useful for analyzing metallic elements such as K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, (Mo), Pd, Ag, Sn, Sb, Ta, (W), Pt, (Au), Hg, and Pb and non-metallic elements such as S, Cl, As, Br, and I through their characteristic K and L lines. (Elements in brackets are usual X-ray sources.) For limitations in the nature of analytes refer to the note in Section 14.7.

2.3 This test method can be used to analyze areal surface contamination that can be collected in a microdroplet during the specified VPD preparation and the collection of the digested surface contamination in the range of 5×10^8 through 5×10^{12} atoms/cm².

2.4 Theoretically, the detection limit (LOD) of each analyte depends upon its atomic number. As defined by DIN 32645 "Limit of detection, determination and quantification" the LOD of TXRF is also depending upon many parameters, such as:

- excitation energy,
- intensity of incident X-ray,
- instrumental background,
- crystallographic interferences, such as Bragg diffraction conditions,

- impurities in the beam path,
- contamination of the blank scanning solution (see Section 4.5),
- contamination level in the analytical ambient,
- surface microroughness of wafer at the microdroplet (see Section 6.7), and
- integration time.

2.5 Concerning the surface conditions to be analyzed, the VPD-TXRF method is invasive. Nevertheless, the TXRF analysis of the microdroplet residue can be repeated many times provided that the prepared specimen is stored in a clean environment. The substrate and/or surrogate wafers can be recycled for monitoring purposes.

2.6 The user of this test method must assure that the metrology equipment is under control by the procedures commonly utilized in the performing laboratory. In the absence of established control procedures the use of 4.11.2 EN-ISO 9001 is recommended.

NOTICE SAFETY PRECAUTIONS — This standard does not purport to address the safety concerns, associated with its use. It is the responsibility of the user of this standard to establish and maintain appropriate safety and health practices and comply with the local regulatory ordinance. X-ray irradiation and handling of HNO₃, HF and H₂O₂ are dangerous. Operators must comply with X-ray safety regulations and be trained to wear protective garments and glasses when handling HNO₃, HF and H₂O₂. These chemicals should be handled in a ventilated area (under exhaust.)

3 Referenced Documents

3.1 SEMI Standards

SEMI C7.3 — Standard for Hydrofluoric Acid, Grade 2

SEMI C7.5 — Standard for Hydrogen Peroxide, Grade 2

SEMI C7.6 — Standard for Nitric Acid, Grade 2

SEMI C10.1 — Guide for Determination of Method Detection Limits for Trace Metal Analysis by Plasma Spectroscopy

SEMI E45 — Test Method for the Determination of Inorganic Contamination from Minienvironments

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M20 — Specification for Establishing a Wafer Coordinate System

3.2 *ASTM Specifications*¹

ASTM D 5127 — Standard Guide for Electronic Grade Water (Type E-1)

ASTM E 691 — Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

ASTM F 1526 — Test Method for Surface Metals/TXRF

3.3 *DIN Specifications*²

DIN-ISO 5725 — Precision of Test Methods, Evaluation of Round-robins

DIN 12650 Part 6 — Gravimetric Test for Piston Operated Volumetric Apparatus

DIN 12650 Part 6 (Apr. 1983) — Gravimetric Test for Piston Operated Volumetric Apparatus

DIN 32645 — Limit of Detection and of Quantification

3.4 *ISO Specifications*³

EN-ISO-DIN 9001 — Quality Systems; Quality Assurance

3.5 *Other Specification*⁴

U.S. Federal Standard 209 — Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones

4 Terminology

4.1 *anglescan* — A measurement of the emitted fluorescence signal as a function of the glancing angle of incident X-ray beam.

4.2 *areal density* — Amount of impurities in a unit area of native or thermally grown silicon oxide as converted from the detected amount of analytes into the whole analyzed (i.e., scanned surface area).

4.3 *as-polished wafer* — Mirror-finished wafer planarized by chemi-mechanical polishing.

4.4 *azimuthal position* — Orientation around the z-crystal/ingot axis as specified in SEMI M20.

4.5 *contamination collection* — Microanalytical method to collect the VPD decomposition products from the silicon surface by rolling a scanning microdroplet on the hydrophobic silicon wafer surface after VPD preparation as originally described in Sections 15.2, 15.4, and 15.5 (also see Section 8.3 of this document).

4.6 *critical angle* — The incident X-ray glancing angle below which total reflection of the incident X-ray occurs. At the critical angle the X-ray reflection equals 0.5.

4.7 *detection spot area* — The surface area where above the fluorescence counts are integrated.

4.8 *epitaxial wafer* — As-polished wafer covered with a layer of monocrystalline silicon deposited from a heterogeneous phase.

4.9 *glancing angle* — Incidence angle of X-ray excitation.

4.10 *hydrophobic surface* — Contact angle of wafer > 60° (e.g., virgin epitaxial or HF- or HMDS (hexamethyldisilazane) -treated surface as described in Section 15.3).

4.11 *impurities* — Elements in/on the specimen other than silicon or elements in ultra pure process media as listed in Section 2.2.

4.12 *native oxide* — Compound of silicon, oxygen, and water on as-polished or epitaxial wafer, grown in air or in cleaning solutions.

4.13 *recovery rate* — The ratio of analytes found after the first VPD and contamination collection procedure to the sum of the analytes found after two or more repeated scanning with unused scanning droplet of unchanged chemical composition.

NOTE: Recent efforts of the Statistical Task Force of the SEMI Chemicals and Gases Committee may result in a new definition (see Section 14.2 of this document).

4.14 *spurious peaks* — Peaks that are detected but not originated from impurities of the silicon wafer (c.f., 6.1).

4.15 *thermally grown oxide* — SiO₂ up to 1000 nm thickness deposited or grown in thermal processing in oxygen containing atmosphere.

4.16 *vapor phase decomposition (VPD)* — Vapor phase decomposition of silicon oxides using HF vapor at room temperature as a surface preparation method for

1 American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

2 Deutsches Institut für Normung e.V., Beuth Verlag GmbH, Burggrafenstrasse 4-10, D-10787 Berlin 30, Germany

3 ISO Central Secretariat, C2.P2 56 Clf-1211 Geneve 20, Switzerland, available in the U.S. from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036

4 Available from Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Attn: NPODS

microanalysis, as originally described in Sections 15.2, 15.4, or 15.5 (also see Sections 5.1 and 11 of this document).

5 Summary of Method

5.1 The native or thermally grown oxide layer of the silicon surface is converted with HF vapor into fluid droplets that contain the impurities of the oxide layer. With a scanning droplet the fluid reaction products are collected in one microdroplet. That microdroplet is dried on the wafer under controlled conditions and analyzed with TXRF.

5.2 Similarly, a microdroplet of process chemicals or media can be dried on hydrophobic polished or epitaxial silicon wafer under controlled conditions and analyzed with TXRF.

5.3 Preferably, monochromatic and collimated X-rays irradiate a planarized and chemi-mechanically polished, monocrystalline silicon wafer surface. The X-rays impinge the surface at a glancing angle that is below the angle for total reflection of the X-rays, preferably, at an incident angle 70% of the angle of total reflection [1.3 mrad (or 0.07 degrees) for Mo target and 2.0 mrad (or 0.11 degrees) for W target].

5.4 The evanescent waves excite the fluorescence energy levels of the surface atoms, which then emit fluorescence X-rays characteristic of their atomic number. The emitted X-rays are detected by a solid state detector that is an energy dispersive spectrometer. In the range of specified areal density (compare with Section 2.3 of this document) the integrated count rate (cps) is linearly proportional to the elemental areal density.

5.5 For quantification, the linear regression must be established (c.f., Section 15.6) or a linear proportionality is anticipated between the cps data that are measured above the certified reference microdroplet(s) and the cps data that are measured above the microdroplet of the unknown analytes without changing the anglescan conditions, according to Sections 9.1, 13.6, and 15.7.

6 Interferences

6.1 The known interferences in X-ray fluorescence spectroscopy also affect TXRF. Thus, overlapping fluorescence lines, escape peak, energy gain drift, X-ray source stability, beam path background contamination must be evaluated according to Section 15.7 of this document.

6.2 Baseline corrections due to varying background contamination must be controlled by the rules of

statistical analysis (e.g., as described in Section 15.8 of this document).

6.3 Under the specified conditions, no corrections are required for secondary fluorescence or for oscillations or for matrix absorption as described in Sections 15.9–15.11 of this document.

6.4 Accuracy of the standard reference specimen and positioning accuracy and precision of the detector define the bias in the assigned areal density.

6.5 Mechanical vibration may degrade the detector resolution and it can also decrease the selectivity.

6.6 Multielement contamination degrades the LOD compared with monoelement contamination.

6.7 Increased surface microroughness and/or high-total signal count rates result in high deadtime and can lead to non-linearity of detected fluorescence signal versus areal density (i.e., to degradation of LOD).

6.8 Under optical conditions satisfying the Bragg reflections the background noise depends upon the azimuthal orientation of the sample. Before quantification, a determination of the azimuthal angular range, that shows minimum Bragg reflection background, is recommended. Otherwise the LOD may degrade due to high background and spurious peaks.

6.9 During handling and measurement particles or volatile contamination (e.g., NH_3) from the analytical environment must be controlled and avoided.

6.10 During measurement Ar must be excluded from the analytical ambient (e.g., by evacuating the chamber or flushing it with He).

6.11 Curve smoothing and evaluation algorithms with controlled Fourier parameters or Digital Filtering are preferred to direct count rate evaluation because these algorithms provide a higher level of statistical confidence than a software that directly quantifies cps as described in Section 15.12 of this document.

6.12 Recovery rates as defined in Section 4.13 of this document depend upon the distribution of the analytes between the scanning solution (solubility) and silicon surface (adsorption and plating). Therefore, recovery rates depend on the:

- applied scanning solution (Sections 4.5, 8.3),
- chemical nature of the different analytes/elements, and
- physical and physicochemical state of the silicon surface.

6.13 Automated contamination collection procedure (scanning) increases the wafer-to-wafer reproducibility

of the described method as reported in Section 15.13 of this document.

7 Apparatus

7.1 The VPD treatment and contamination collection particularly, but also the handling and measurement of the specimen wafer is to be carried out in a specified and controlled ambient (e.g., Cl. 10 (U.S. Federal Standard 209)).

7.2 TXRF system equipped with:

- an X-ray source,
- a monochromator (preferable),
- a sample stage capable of manipulating in the x-, y-, and z-direction,
- automated test specimen handling,
- an energy-dispersive spectrometer X-ray detector,
- software sub-routine for glancing angle calibration,
- software for baseline setting and for peak-fitting and/or range-of-interest (ROI) peak finding identification and evaluation, and
- analysis ambient without Ar background (see Sections 6.10 and 7.1 of ASTM F 1526). The system is preferably equipped with a flat/notch-finder and quick-search option. For details, see Section 6.10 of this document and Section 7.1 of ASTM F 1526.

7.3 The VPD and the advisable drying chamber(s) will have opening(s) made of polyvinylidene fluoride (PVDF), polyfluoroalkoxyethylene (PFA), polyfluoroethylene (PTFE) or similar resistant and pure polymer materials that will not be attacked by HF. The chamber(s) may contain one or more wafers on stacks. The use of a drying chamber is advisable for the preparation of the calibration reference microdroplet (c.f., Section 10.1), but optional for the analysis procedure. When a drying chamber is used, it must be evacuable to below 1 kPa. After evacuation the chamber is to be flushed with filtered N₂ until the complete drying of the microdroplet residue is achieved (see Section 9.1 of this document).

7.4 For the aliquots of standard stock and scanning solutions validated micropipettes must be used. Validation procedure can follow the requirements of DIN 12650 Part 6.

8 Reagents and Materials

SAFETY PRECAUTIONS — Handling HNO₃, HF and H₂O₂ is dangerous. Operators must comply with X-ray safety regulations and be trained to wear protective garments and glasses when handling HNO₃, HF and H₂O₂ under efficient exhaust.

8.1 *Ultra Pure Water, HNO₃, HF, H₂O* — As specified in ASTM D 5127, SEMI C7.3, C7.5, and C7.6, respectively.

8.2 *Standard Stock Solution* — Certified and traceable standard reference “stock” solution with known amount(s) of nitrate salt of the metals and sodium salt of the non-metallic elements to be analyzed. Dilutions have to be acidified with HNO₃ at pH ≤ 2. Note that the shelf life of diluted solutions in the ppb-range of µg/L or ng/L is less than 2 days.

8.3 *Tested Scanning Droplet (Sections 4.5 and 6.12)* — 50 to 100 µL of ultra pure water or other scanning solutions (e.g., aqueous HF (1 volume %) and H₂O₂ (30 volume %)). The composition of the scanning droplet must provide a controlled recovery rate above 90% for each analyte, including Cu.

8.4 *Blank Scanning Solution* — The composition and the amount of a scanning droplet without surface impurities.

8.5 *Microdroplet Residue* — Microdroplet calibration standard reference solution and/or scanning or microdroplet of a liquid process medium dried at room temperature under controlled conditions according to Section 7.3. Above the microdroplet residue the fluorescence count rate remains independent of azimuthal position and of varying incident angle for angles below 80° of the critical angle as described in Section 15.6 of this document.

8.6 *Surrogate Wafers* — Polished or epitaxial wafers used as carrier plates for scanning droplets collected from other specimen wafers.

9 Preparation of Certified Reference Microdroplet for Calibration Standard

9.1 *Tested Preparation Conditions* — Deposit microdroplets containing 0.01 ng, 0.1 ng and 1 ng Ni in Ni (NO₃)₂ in 100 µL of a diluted standard stock solution onto (a) hydrophobic (see Section 4.12 of this document) polished or epitaxial wafer(s). Dry it (them) under controlled conditions (e.g., in a drying chamber at room temperature). When a drying chamber is used, flush the chamber with a slow flow of N₂ for 20 minutes, then evacuate it (see Section 7.3 of this document). The droplets must not explode or extend during drying. They should not exceed an areal dimension of 1 mm in any direction. Elements forming

volatile compounds must not be applied (see the note in Section 14.7).

10 Calibration Procedure

SAFETY PRECAUTIONS — X-ray irradiation is dangerous. It is the responsibility of the user of this standard to establish and maintain appropriate safety and health practices and comply with the local regulatory ordinance. The X-ray source must be inactivated when beam path is unshielded. Operators must be trained to avoid exposure to X-ray irradiation.

10.1 The calibration standard is a microdroplet of 100 μL of a diluted certified standard reference “stock” solution. Note that the shelf life of diluted solutions in the sub-ppb-range of $\mu\text{g/L}$ or ng/mL is less than 2 days.

10.2 Locate the calibration standard microdroplet residue and place it under the detector. Adjust the glancing angle into the range where the fluorescence count rate is independent of varying incidence angle (see Section 8.5 of this document).

10.3 Position the detector window as follows. Set mapping or quick search parameters for covering the residue(s) with 3×3 detection spots (see Figure 1), which are placed around the residue(s) as described in Section 15.6 of this document. The mapped surface must cover at least 95% of the square around the residue(s) that is lying about in the center of the detection spot. The analyzed part of microdroplet residue under the detection spot must be higher than 95%.

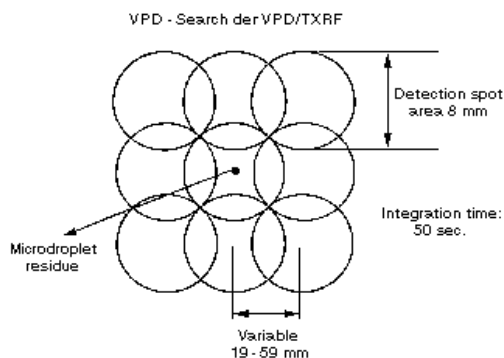


Figure 1
VPD-Search VPD/TXRF

10.4 Set for mapping around the microdroplet residue with a 50-sec integration time program at each detection spot. Integrate at the maximum position(s) for at least 1000 sec. These data provide the final result of calibration due to the algorithm given in Section 13.6 of this document.

10.5 Repeat calibration cycle (load-analyze-unload) at least 3-times.

10.6 In order to distinguish relevant results from particle contamination from the environment and from inefficient contamination collection, repeat measurement on blank surface adjacent to the microdroplet solution. The data are to be considered as background data in the quantification algorithm (see Section 15.12 of this document). For valid calibration, background fluorescence counts must remain less than 20% of the fluorescence counts of microdroplet residues, particularly, at lower areal densities ($< 1 \times 10^9$ atoms/ cm^2).

10.7 The integrated fluorescence counts measured with the specified Ni calibration standard can be converted by known sensitivity factors into other elements of interest as described in the References section (see Sections 15.14 and 15.15 of this document).

10.8 Keep the calibration standards in closed, identifiable wafer holders in a clean room at room temperature under conditions that will not change the fluorescence reproducibility.

10.9 Optional linearity tests should deploy the methods described in References section (see Section 15.16 of this document). Similar statistical linearity tests can also be applied.

10.10 Upon the users request, the absolute instrumental calibration factor can be obtained. Due to the Fresnel theory of X-ray absorption and enhancement on pure metal (Ni) surfaces, the absolute calibration can be carried out under specific optical conditions. (See Referenced Documents section and specifically Section 15.17.). Then, that absolute calibration can be correlated to the external microdroplet calibration.

11 Preparation Procedure

11.1 VPD treatment of the wafer surface (Section 4.16) and the collection of contamination collection with a scanning microdroplet (Section 4.5).

SAFETY PRECAUTIONS — Handling HF is dangerous. It is the responsibility of the user of this standard to establish and maintain appropriate safety and health practices and comply with the local regulatory ordinance. Operators must be trained to wear protective garments and glasses when handling HF under efficient exhaust.

11.2 In the VPD chamber wafers are treated with HF vapor (e.g., isothermally distilled at room temperature from an aqueous solution (20–50 volume %) within the VPD chamber). The analytical specimen, the calibration

droplet and the scanning droplet must be handled, prepared and dried under specified and controlled conditions. Drying means the evaporation of the solvents on the wafer surface in a clean and controlled environment without losing analytes from the microdroplet residue.

11.3 The wafers are exposed to the HF vapor in the VPD chamber at room temperature. The exposure time depends on the concentration of the HF used and on the preceding wafer treatment. The time has to be long enough to ensure that the wafer surface will become hydrophobic. After the HF treatment the solubilized reaction products are collected by scanning a microdroplet over the whole surface. Automatic scanning is preferable (see Section 6.13 of this document). The composition of the scanning solution is optional but its volume and drying conditions should be the same as under the preparation of calibration standards (see Sections 8 and 15.18 of this document).

11.4 An example for tested preparation conditions according to Section 15.18 of this document. A PTFE or PFA petri dish of a diameter > 25 cm is filled with 20 volume % HF by mixing DI ultra pure water and 40 volume % HF of ULSI grade in a clean room ambient of Cl 10 by U.S. Federal Standard 209. The petri dish is positioned in the bottom of the VPD chamber, loaded with specimen wafers. The wafers are exposed to the HF wafer at room temperature. Exposure time is between 30 minutes and 6 hours. Longer exposure times can lead to deliberate etching. After the HF treatment the solubilized, reaction products are collected by rolling a scanning microdroplet over the whole surface. Automatic scanning is preferable. Please refer also to Section 4.5 and Section 8.3 of SEMI E45.

11.5 Rinse the validated micropipette at least 5 times with ultra pure water or with the selected scanning solution. Then fill the micropipette with the required amount of ultra pure water or with the scanning solution. For scanning surfaces with thicker silicon oxide (> 300 nm) only about 50 μL of scanning solution is sufficient. The microdroplet to be dried for analysis should not extensively (+10%) exceed 100 μL together with the VPD reaction products.

11.6 Put the scanning microdroplet on the wafer surface and roll the scanning microdroplet around the wafer edge 2 times and then over the whole surface in a zigzag pattern. Automatic equipment can scan in a spiral pattern with overlapping paths (see Section 6.13). An edge exclusion of less than 1 mm is attainable for manual or automatic scanning. Edge exclusion is well below 1 mm at automatic scanning.

11.7 Position the scanning microdroplet in the center of the wafer.

11.8 For monitoring the cleanliness of the VPD preparation and contamination collection and that of the analytical ambient, put the same volume of the blank scanning solution, as applied to the preparation of the calibration standard (100 μL under tested preparation conditions), with the validated micropipette onto the scanned specimen surface at least 3 cm off the position of the scanning solution. For valid results fluorescence counts above the blank must remain less than 20% of the fluorescence counts above the droplet residues. Use ultra pure water (100 μL) for blanks of process chemical and media samples. If the scanning solution consists only of ultra pure water of controlled quality, no blanks are required.

NOTE: In the absence of oxidation agent(s), Cu recovery rates can be reduced (see Section 15.18).

11.9 Dry the wafers as specified in Sections 7.3, 9.1, and 11.2 of this document.

12 Analysis Procedure

12.1 Localize the microdroplet residues of the collected scanning solution or the microdroplet residues of the liquid process medium and the microdroplet residue of the blank scanning solution. Detect fluorescence counting rates above these microdroplet residues and above the scanned blank surface under the instrumental parameter adjusted for calibration. The quantification algorithm is given in Section 13.6. Integrated counts above both the blanks and the VPD prepared surface must not exceed 20% of the integrated counts above the microdroplet residue of the collected scanning solution (see Section 9.6 of this document).

13 Quantification Procedure

13.1 The instrument must run under established statistical process control (e.g., as described in Section 15.19 of this document).

13.2 Before releasing results, quote instrumental parameters such as:

- rotating or sealed anode,
- voltage and current applied to the X-ray source,
- characteristic excitation line(s) of the incident X-ray,
- glancing angle(s),
- type of monochromator,
- amount [ng] or [number of atoms] of e.g., Ni in the calibration standard reference microdroplet,
- location of the microdroplet(s) analyzed,
- peak evaluation technique (ROI or peak-fitting),

- measurement time,
- analysis results on the blank microdroplet,
- compositions and amount of the scanning droplet,
- running time since last calibration or frequency of SPC measurement,
- lab environment classification by U.S. Federal Standard 209,
- edge exclusion, if any (c.f., Sections 4.2 and 11.6).

13.3 Quantification of areal density is in units of 10^{10} atoms/cm².

13.4 Detection spot area is the surface area where above the fluorescence counts are integrated.

13.5 Scanned surface area is the surface area where the impurities are collected from, according to Section 9.1.

13.6 Calculate the areal density of impurity i according to the following algorithm:

$$c_{i,VPD} = \frac{c_i}{\frac{A_w}{A_m} \cdot R_i} \text{ (atoms/cm}^2\text{)}$$

$$= \frac{n_i}{A_w \cdot R_i} \text{ (atoms/cm}^2\text{)}$$

where;

$c_{i,VPD}$ = density of impurity (i) at scanned area of wafer surface in [atoms/cm²]

c_i = measured concentration of impurity i at measured spot [atoms/cm²]

A_w = VPD - scanned wafer area in [cm²]

A_m = measuring spot area in [cm²]

R_i = recovery rate of the collected impurity ($0 < R_i < 1$) c.f., Section 4.13

n_i = measured number of atoms of analyte i

The measured concentration c_i of impurity (i) can be related to the reference standard by means of the following expression.

NOTE: The reference standard element is assumed to be Ni in this section.

$$c_i = RSF_i \cdot c_{Ni} / I_{Ni} \cdot I_i \text{ [atoms/cm}^2\text{]}$$

where;

$$c_{Ni} = n_{Ni} / A_m$$

n_{Ni} = number of impurity atoms (Ni)

in the standard reference specimen

I_i = measured fluorescence intensity of impurity (i) in counts per second [cps]

I_{Ni} = measured fluorescence intensity of the standard reference specimen (Ni) in counts per second [cps]

RSF_i = instrumental sensitivity factor of the analyte i relative to the standard element (Ni)

This formula provides the areal density for the impurity of interest with LOD as given in Section 13.7.

13.7 Calculation of LOD_i , the lowest detectable number of impurity atoms i from a scanned surface, is:

$$LOD_i(t) \equiv 3 \cdot c_{i,VPD} \cdot \frac{\sqrt{N_{bg}(t)}}{N_{netto,i}(t)}$$

where;

$N_{bg}(t)$ denotes the background fluorescence cps, integrated over time (t)

$$N_{bg}(t) = I_{bg} \cdot t,$$

with

I_{bg} = intensity of the background in cps, and

where;

$N_{netto,i}(t)$ denotes the netto number of the impurity fluorescence [cps], integrated over the time,

$$N_{netto,i}(t) = I_i \cdot t$$

The equation for the $LOD_i(t)$ can be rewritten as :

$$LOD_i(t) = 3 \cdot \frac{c_{i,VPD}}{I_i} \cdot \sqrt{\frac{I_{bg}}{t}}$$

14 Bias and Precision

14.1 Relative error of the described VPD-TXRF method must be assessed according to Section 15.11 of this document. Under the given measurement conditions the accuracy of the results is limited by the error summarized in Section 14.2.

14.2 Under given solute amounts and measurement conditions the accuracy of the results is limited only by

the recovery rate of the VPD treatment and the scanning solution as described in Section 15.19 of this document. The relative error is to be calculated by:

$$\frac{dc_{i,VPD}}{c_{i,VPD}} = \left[\left| \frac{dR_i}{R_i} \right|^2 + \left(\frac{dRSF_i}{RSF_i} \right)^2 + \left(\frac{dA_w}{A_w} \right)^2 + \left(\frac{dn_{Ni}}{n_{Ni}} \right)^2 + \left(\frac{dI_i}{I_i} \right)^2 + \left(\frac{dI_{Ni}}{I_{Ni}} \right)^2 \right]^{1/2}$$

14.3 Relative error of the reference droplet standard is determined by the error of the micropipette aliquot (V) and of the stock solution (c_s).

$$\frac{dn_{Ni}}{n_{Ni}} = \left[\left(\frac{dV}{V} \right)^2 + \left(\frac{dc_s}{c_s} \right)^2 \right]^{1/2}$$

14.4 The relative error of areal concentrations below the concentration of the calibration standard reference are strongly dependent upon the relative error of the micropipette aliquots. In the given range bias due to crystallization and/or mass absorption can be anticipated to be less than 1% as described in Sections 15.6 and 15.11 of this document.

14.5 Reproducibility of the measurement system must be tested with calibration standard reference in five complete analysis cycles (load-analyze-unload). The standard deviation of the 5 results shall not exceed more than 10% of the theoretical value of the standard deviation of the respective Poisson statistics Nx . For long term reproducibility, please refer to Section 2.6.

14.6 The minimum sample size for controlling the wafer-to-wafer reproducibility of the complete procedure must consist of a group of 3 wafers of the very same polishing and/or cleaning batch as described in Section 15.20 of this document. Tolerated standard deviation of 3 groups should be defined by the interested parties.

14.7 In interlaboratory tests (round robin), the reproducibility of the method can preferably be evaluated in accordance with DIN ISO 5725 or ASTM E 691.

NOTE: Report reproducibility in accordance with this document. Calibration accuracy was found to be within 10% relative standard deviation for K, Ca, Ti, Cr, Fe, and Cu among five TXRF stations as stated in Section 15.21 of this document. W and other compounds forming volatile fluorides shall not be analyzed after VPD because of low recovery rates.

15 References

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Verfahren Zum Schutz Von Polierten Oberflächen — I. Lampert, Europe Patent 0 222 400 (11/13/86)

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SEMI M34-0299

GUIDE FOR SPECIFYING SIMOX WAFERS

1. Purpose

1.1 This guide is for specification of SIMOX (separation by implantation of oxygen) wafers with less than 0.5 μm silicon film thickness used for semiconductor device manufacture. These specifications define the generic characteristics of SIMOX SOI wafers; the specific values for measured parameters will be determined by agreement between the user and supplier for the application. By defining parameters, inspection procedures, and acceptance criteria, both users and suppliers may uniformly define product characteristics and quality requirements.

2. Scope

2.1 The primary standardized properties set forth in this specification relate to physical and electrical characteristics of SIMOX wafers.

3. Referenced Documents

3.1 SEMI Standards

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M22 — Specification for Dielectrically Isolated (DI) Wafers

3.2 ASTM Documents¹

Practice E 122 (vol. 14.02) — Practice for Choice of Sample Size to Estimate Average Quality of a Lot or Process

F 154 (vol. 10.05) — Standard Practices and Nomenclature for Identification of Structures and Contaminants Seen on Specular Silicon Surfaces

F 523 (vol. 10.05) — Standard Practice for Unaided Visual Inspection of Polished Silicon Slices

3.3 Other Standards²

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

4. Terminology

4.1 Acronyms

4.1.1 *BOX* — Buried Oxide

4.1.2 *SIMOX* — Separation by Implantation of Oxygen

4.1.3 *SOS* — Silicon on Sapphire

4.2 Definitions

4.2.1 *buried oxide* — The oxide layer that is formed by the oxygen implant.

4.2.2 *SIMOX layer* — The thin silicon, layer above the BOX. This is also referred to as top silicon or superficial silicon.

4.2.3 *substrate* — The supporting material: silicon for SIMOX.

5. Requirements

5.1 The complete specification for the starting substrate to produce SOI wafers includes all general requirements of SEMI M1 or SEMI M3, as applicable.

5.2 In addition, the parameters listed in Table 1 shall be specified, as applicable. For example, specification of BOX thickness is not applicable for SOS. The specific values for parameters listed are to be specified by agreement between user and supplier for specific uses and specific wafer technologies.

5.3 The parameters of Table 1 apply to the final SOI wafer. Parameters for the starting material may be specified by agreement between user and supplier using other standards (e.g., SEMI M1 or SEMI M3, as appropriate). Additional parameters shall be negotiated between user and supplier, as needed.

6. Sampling Plan

6.1 Unless otherwise specified, ASTM Practice E 122 shall be used. When so specified, appropriate sample sizes shall be selected from each lot in accordance with ANSI/ASQC Z1.4. Each quality characteristic shall be assigned an acceptable quality level (AQL) of lot tolerance percent defective (LTPD) value in accordance with ANSI/ASQC Z1.4 definitions for critical, major, and minor classifications. If desired and so specified in the contract or order, each of these classifications may alternatively be assigned cumulative AQL or LTPD values. Inspection levels shall be agreed upon between the user and supplier.

¹ American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

² American Society for Quality Control, 611 East Wisconsin Avenue, Milwaukee, WI 53202

7. Test Methods - Dimensions

7.1 SIMOX Layer Thickness Measurements

7.1.1 Measurements Methods — Two non-contact, non-destructive optical characterization techniques, spectroscopic reflectometry and spectroscopic ellipsometry, have proven useful for SIMOX layer thickness measurements. Both techniques use reflected light to allow deduction of the thickness and refractive index of thin film layers. In both cases, film thickness and index of refraction data must be "backed out" of the measured optical data by a process of successive approximation. In both cases, the fitting procedure is more straightforward and more accurate the as-annealed SIMOX wafers with abrupt silicon/oxide interfaces than for the implanted SIMOX wafers with extended

interface zones. Silicon islands and interface nonuniformities make these techniques problematic for SIMOX wafers with oxygen implant doses below the "stoichiometric dose", roughly $1.6 \times 10^{18} \text{ O}^+/\text{cm}^2$ for a 375 nm oxide layer.

7.1.1.1 The measurement strategy is to make a detailed measurement with an accurate fit on at least five wafer sites, including the center as illustrated in Figure 1. The number of wafer sites to be monitored should be agreed on between customer and vendor. Generally, the greater the variability relative to the mean, the larger the number of sites that should be monitored. In each case, the measurement system supplies a "goodness-of-fit" parameter which indicates a level of confidence in the fit to the measured data.

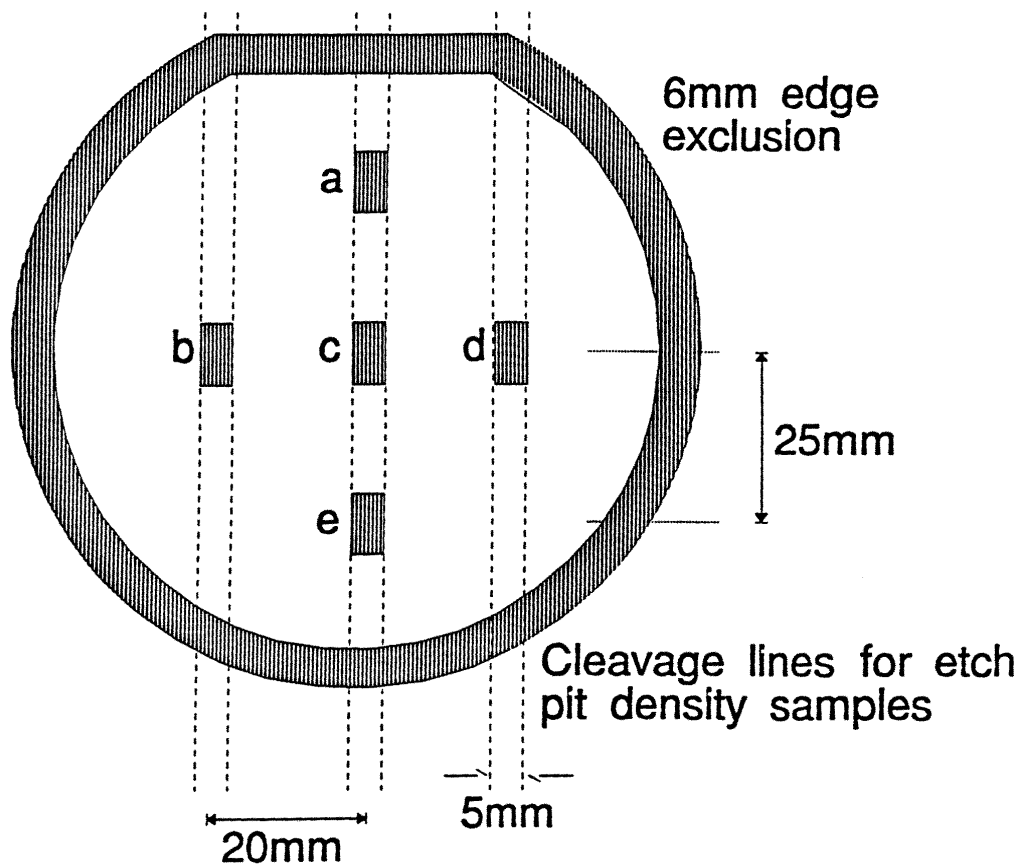


Figure 1
Schematic of Measurement Sites, Cleavage Lines, and Edge Exclusion for 100 mm SIMOX Wafer Inspection

7.1.2 Spectroscopic Ellipsometry Measurement — In this measurement, white light from a xenon arc lamp passes through a polarizing rotating filter and illuminates the sample site under study; reflected light passes through an analyzer to a monochromator and photomultiplier detector. For each wavelength, reflectivity oscillates with polarizer rotation; the magnitude and phase of reflectivity changes are measured to determine ellipsometric angles, δ and ψ . The two measured spectra are fit by successive approximation to allow determination of the silicon and oxide layer thickness and oxide composition. Ellipsometry measurements are only specified for the annealed SIMOX wafers. For spectroscopic ellipsometry, the choice of instrument and associated model and fitting parameters affect the confidence-of-fit, so they should be taken into account in the user/supplier agreement. For example, with the SOPRA SE system, the goodness-of-fit error estimator shall be less than 0.025 for accurate structural models.

7.1.3 Optical Reflectance Measurements — In this measurement, light from a xenon arc lamp passes through a grating monochromator and illuminates the sample site under study; reflected light is gathered by an intrinsic silicon detector. Specular reflectivity is plotted as a function of wavelength from 0.4 micron to 1.1 micron. The analysis proceeds by making successively better approximations to the oxygen content, index of refraction, and absorption of each layer until an acceptable fit is achieved. Measurements are made with a reflectance mode optical interferometer.

7.1.4 Optical Model Fitting and Correlation — There are slight, systematic differences between layer thickness measured by reflectance and by spectroscopic ellipsometry (SE). Because of this, user and supplier should specify the actual measurement method to be used. The two methods offer results which are reproducible and well-correlated with each other over a wide range of conditions. If both measurement techniques are used, it is recommended that the reflectance system measurements be calibrated to fit the results of the SE. Figure 2 shows conversion curves for top silicon and oxide layer thickness measurements made with the two measurement techniques.

7.1.5 Top Silicon Layer Thickness — See Section 7.1.4 on correlation of reflectance and spectroscopic ellipsometry (SE) measurements. Optical measurements will be made on five wafer sites as shown in Figure 1. Spectra for each site will be fit independently with both the top silicon and oxide layer thickness as adjustable parameters. Both the mean thickness and the uniformity should be specified. Depending on the type of SIMOX wafer being specified, the mean thickness of

the top silicon layer will be from 50 nm to 500 nm. Following is an example specification: Mean top silicon layer thickness for the five sites will be 215 ± 10 nm with acceptable goodness-of-fit at all five sites. Top silicon non-uniformity will be less than ± 5 nm.

7.1.6 Buried Oxide Layer Thickness — See Section 7.1.4 on correlation of reflectance and spectroscopic ellipsometry (SE) measurements. Optical measurements will be made on five wafer sites as shown in Figure 1. Spectra for each site will be fit independently with both the top silicon and the buried oxide layer thickness as adjustable parameters. Both the mean thickness and the uniformity should be specified. Depending on the type of SIMOX wafer being specified, the mean thickness of the buried oxide layer is from 50 nm to 500 nm. Following is an example specification: Mean buried oxide layer thickness for the five sites will be 380 ± 20 nm with acceptable goodness-of-fit at all five sites. Buried oxide uniformity will be less than ± 10 nm.

7.2 Crystallographic Defect Measurements - Test Methods — The evaluation of threading dislocation density in the top Si layer will be made by destructive chemical etching and microscopic etch pit density measurements. The appropriate evaluation procedure for given SIMOX wafer, which depends on the threading dislocation density and the thickness of top Si and buried oxide layers, will be determined by the agreement between user and supplier.

7.2.1 Optionally, other crystallographic defects which may be formed in the top Si layer of SIMOX wafers, such as oxide precipitates or micro stacking faults, silicon crystal defects induced by surface particles prior to epi growth when epi is used to increase the thickness of the top silicon. A sampling plan should be established based on experience with the supplier.

7.2.2 Following are examples of the evaluation of threading dislocations in two kinds of SIMOX wafers:

7.2.2.1 Example 1. Threading dislocation evaluation in SIMOX wafers with 200 nm thick top Si layer and 400 nm thick buried oxide: Samples are handled with plastic tweezers throughout the etching procedure. Samples are first stripped of native oxide by dipping in Bell 2 or HF stripping solutions. Immediately after stripping, wafers are dipped in freshly prepared standard Secco Etch: one part (by volume) of a 0.15 molar solution of $K_2Cr_2O_7$ in distilled water and two parts HF (49%). Samples are dipped in the Secco etch until 50 nm of silicon remains, and then they are rinsed thoroughly in distilled water and blown dry. The thickness of the remaining silicon ensures that stacking fault pyramids found in multiple implant material are counted. The threading dislocation density may vary over a wide range, depending on the

type of material. The Secco Etch, as described, creates etch pits that appear as dark circles roughly 50 nm in diameter, and pictures should be taken at 2500X to 20,000X magnification in order to unambiguously identify and count the etch pits. This is suitable for high density defect samples. For lower dislocation densities typical of recent SIMOX material, a third etch in

buffered HF (1 HF (49%): 6 NH₄F (40%)) for 10 minutes will etch the buried oxide under each Secco etch pit, creating a characteristic circular shape 2 μ m in diameter that can be seen at 500X magnification.

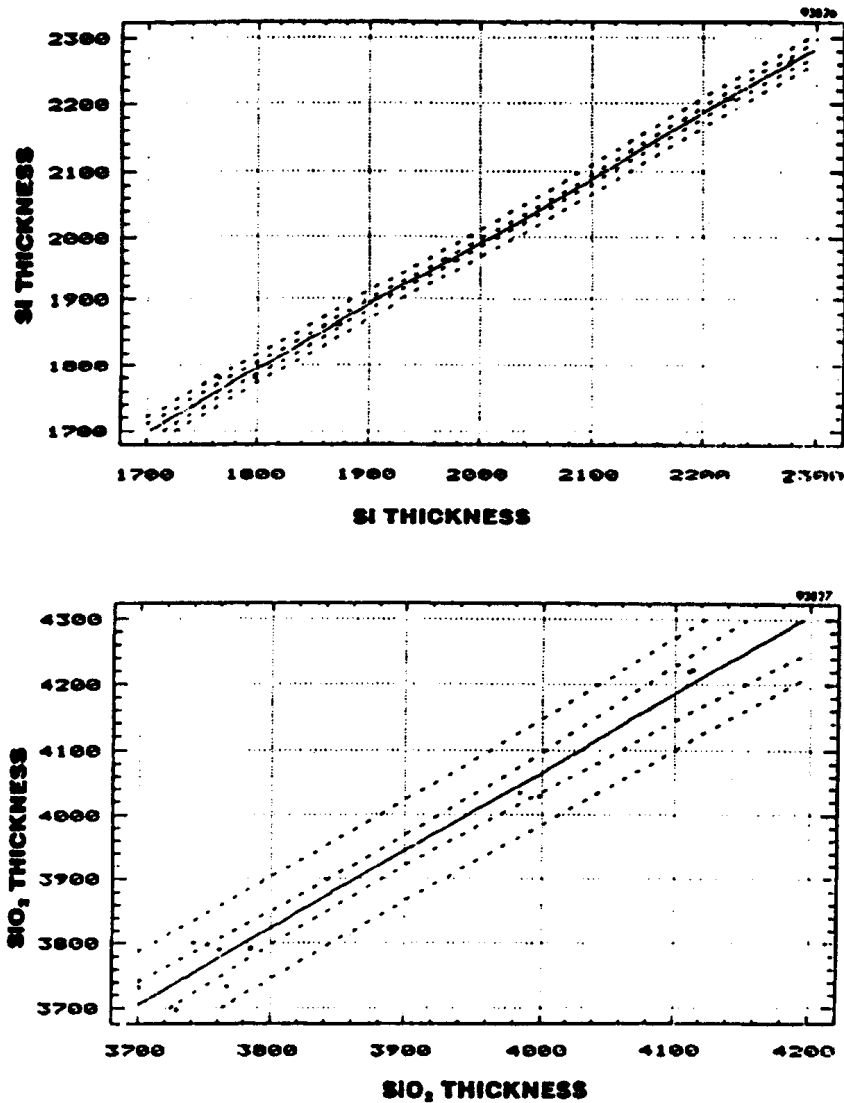


Figure 2
Calibration Curves Relating Reflectance Measurements to Ellipsometry Measurements for Top Silicon and Buried Oxide Layer Thickness

NOTE: Dashed lines are at ± 1 sigma and ± 3 sigma.

7.2.2.2 Example 2. Threading dislocation evaluation in SIMOX wafers with 170 nm thick top Si layer and 100 nm thick buried oxide: Samples are first immersed in HF to remove oxide from the surface. Then the samples are etched for 30 seconds in the solution:³ 50 ml of HF (49%) plus 80 ml of HNO₃ (61%) plus 160 ml of H₂O [K₂Cr₂O₇ 1g + Cu(NO₃)₂·3H₂O 4g]. The thickness of removed silicon is about 1/3 of the initial top Si layer thickness, i.e., about 60 nm. After rinsing in water, samples are dipped in HF (49%) for 5 minutes. The HF etches the buried oxide and creates cavities under the etch pits. The cavities are around 10 µm in diameter. Each cavity corresponds to one dislocation threading the top Si layer. The cavities can be seen at 50X magnification.

7.2.2.3 A recommended protocol for the microscopic etch pit density measurement is to take enough pictures to count at least 50 etch pits, and then divide the number counted by the area scanned to get the defect density. The pictures taken should be non-overlapping areas of the sample far from the tweezer marks and far from the edges of the sample. Following is an example specification: Of the five samples prepared from the test wafers, none should have threading dislocation densities higher than $1 \times 10^7 \text{ cm}^{-2}$.

7.3 Buried Oxide

7.3.1 *Buried Oxide Pinhole Measurements* — Buried oxide pinhole evaluations shall be made by CuSO₄ plating or copper decoration methods.

7.3.1.1 In the evaluation done by CuSO₄ plating method the wafer under study is placed (front face down) on a paper towel soaked in 20% CuSO₄ solution on top of a copper plate. An aluminum plate is placed on the back of the wafer. The copper plate is grounded, and -25 VDC is applied to the aluminum plate. Small (sub-micro Angstrom) leakage currents through pinholes in the insulator cause copper to plate out onto the towel at the pinhole density.

7.3.1.2 In the evaluation done by copper decoration method the top Si layer is first etched off by KOH solution to expose the buried oxide layer. Then the wafer is immersed in methanol and brought downward into direct contact with the gold-coated cathode. A copper mesh as an anode is immersed in the liquid 5 mm above the wafer. Required voltage is applied, such as the electric field in the buried oxide layer is 1MV/cm. The voltage is measured at the oxide surface with a surface voltage probe. Localized copper decorations at pinhole sites in the oxide are observed with a low power optical microscope.

7.3.1.3 Allowable pinhole density depends on the application for SIMOX wafer and will be determined by the agreement between user and vendor. Typical allowable pinhole density is $0.1/\text{cm}^2$.

7.4 SIMOX Wafer Surface Inspection

7.4.1 *Total Reflectance X-Ray Fluorescence Measurements* — The preferred test methodology is described in ASTM F 1526.

7.4.1.1 The instrument provides a map of impurity element distribution. As an example specification, surface contamination for elements within the detection limits (typically S to Zn) shall be less than 10^{10} cm^{-2} per element or $< 10^{11} \text{ cm}^{-2}$ total.

7.4.1.2 The customer and vendor should be aware that most TXRF systems will contaminate a wafer -slightly on front and significantly on the back. (Reference: DXRC, Denver CO, July 1996, abstract 5.1 "Particulate Contamination from TXRF Instrumentation", Dennis Werho, et al.)

7.4.2 *Automated Particle Counter Measurements* — Automatic production tools are available for accurate particle counting on fully processed SIMOX wafers for particles greater than 0.25 micron. Alternatively, particles down to 0.1 micron can be detected on as-implanted SIMOX wafers prior to anneal. Any specification of particle count should include the point in the process at which the measurement is to be made. Following is an example specification:

7.4.2.1 Instrument settings shall allow detection of particles from 0.3–10 micron size. Maximum allowable particle count, with a 6 mm edge exclusion, is 20 particles greater than 0.25 micron size per 150 mm wafer, or 0.1 particles/cm², just prior to shipping.

7.4.3 *Visual and Microscopic Inspection* — Visual inspection techniques will be in accordance with ASTM F 523, when possible, by automatic inspection equipment. Alternatively, slices will be inspected visually under fluorescent light for chips, fractures, scratches, fragmentation, saw marks, grinder marks, and dimples and also under a narrow beam high intensity light (> 6000 footcandles), for fractures, film haze, contamination, and scratches. SIMOX wafers typically exhibit uniform light haze due to light scattering from the rough silicon/oxide interface and from silicon precipitates in the BOX. A light, uniform haze is typically acceptable, while patches of moderate or heavy haze typically are not acceptable.

7.4.3.1 Standards for specification of haze are being developed for bulk silicon. A modification of that specification will be required for SIMOX material. It may be necessary to iterate between customer and vendor to agree on specification of acceptable haze.

³ Refer to L. F. Giles, A. Nejim, and P. L. F. Hemment, *Materials Chemistry and Physics*, 1993, vol. 35, p. 129

7.4.4 Surface Roughness — Surface roughness is a measure of the microscopic topology of the wafer surface. The effect of this parameter may be in Gate Oxide Integrity (GOI) on MOS devices, depending on the design and process. The measurement of surface roughness is done on an atomic scale by an Atomic Force Microscope (AFM). With AFM, it is suggested that four measurement areas of greater than $2\text{ }\mu\text{m}^2$ be measured at each of five measurement locations, with the measurement locations distributed as in Figure 1. Because of the expense of this measurement, a sampling plan should be established with the supplier.

7.4.4.1 Standards for specification of surface roughness are being developed for bulk silicon and shall be applicable here when adopted.

7.4.5 HF Defect Measurements - Test Methods — Measurement of the microscopic etch pit density following an HF etch is a method commonly used to disclose defects in SOI material. Pitting of the top silicon surface may be present before the HF etch or be caused by HF etching. For this destructive measurement, at least one quarter of a wafer should be used and preferably a whole wafer. The sample is placed in concentrated (49%) HF for 10 to 15 minutes, then removed, rinsed and dried. If there are pits in the SI surface, metal particles embedded in the surface or silicides formed in the top Si layer, the HF will etch the metals/silicides and then etch the buried oxide. This results in a section of the buried oxide being etched out that is 25–50 μm diameter (depending on the etch time) centered on the original pit or particle. The defect density is then measured in an optical microscope using a 5X objective and 10X eyepiece or comparable setup. The sample should be scanned 2–3 times near the center of the wafer if a whole wafer is used to get sufficient statistics. If a piece of a wafer is used, the scan should be adjusted accordingly. The total area scanned should be at least 10 cm^2 . Care should be taken to exclude edge density depending on the expected impact on yield versus material cost. A typical specification is that the HF defect density should be less than $1/\text{cm}^2$.

Table 1. Specification Summary

<i>Parameter</i>	<i>Reference</i>	<i>Example Values</i>	<i>Method</i>
Wafer diameter (D)	ASTM 613	150 mm, 200 mm	Optical comparitor
Wafer thickness	ASTM 533		Thickness gauge
Thickness variation	ASTM 533	< 3 μm	Thickness gauge
Wafer warp	ASTM F 657, F 1390	$\leq 30 \mu\text{m}$ for D = 150 mm	Jig + gauge
Crystal orientation	ASTM 26		X-ray diffraction
a) front surface		(100) $\pm 1^\circ$	
b) back surface			
Substrate type/dopant	ASTM 42		Hot point probe
Substrate resistivity	ASTM 84		4-point probe
Substrate RRG	ASTM 84		4-point probe
Surface Si thickness	Section 7.1.5	50 nm to 500 nm	SE/optical reflectance
Surface Si uniformity	Section 7.1.3	$\pm 5 \text{ nm}$	SE/optical reflectance
Buried oxide thickness	Section 7.1.6	50 nm to 500 nm	SE/optical reflectance
Buried OX uniformity	Section 7.1.3	$\pm 10 \text{ nm}$	SE/optical reflectance
Crystal defect (EPD)	Section 7.2	< 10 E7/cm^2	SEM examination
			Secco etch
Buried OX pinholes		< $0.1/\text{cm}^2$	a) CuSO_4 plating
			b) BOX capacitor @ 1 nA
Metal contamination	Section 7.4.1	total < $10^{11} \text{ atoms/cm}^2$	TXRF
a) per unit area			
b) per unit volume			
Particles	Section 7.4.2	$\leq 20 (> 0.25 \mu\text{m}) / \text{wafer}$	Automated particle counter
Haze	Section 7.4.3	See Table 2.	Visual inspection
Slip	ASTM F 523*	See Table 2.	Visual inspection
Scratches	ASTM F 523*	None	Visual inspection
Chips	ASTM F 523*	See Table 2.	Visual inspection
Surf Spot Discolor	ASTM F 523	See Table 2.	Visual inspection
Foreign matter	ASTM F 523	See Table 2.	Visual inspection
Backside contamination	ASTM F 523		Visual inspection
Surface roughness	Section 7.4.4	5	Atomic force microscope (AFM)
Inclusions	Section 7.4.5		

* The user and supplier may agree on an edge exclusion for these specifications. For example, the area within 6 mm proximity of the wafer edge may be excluded.

Table 2. Example SIMOX Wafer Surface Inspection Criteria

<i>Criterion</i>	<i>Allow Quantity</i>	<i>Description</i>
Slip	0.3 mm: NONE 0.1–0.3 mm: < 15 mm total < 0.1 mm: OVERLOOK	6 mm edge exclusion
Scratch	NONE	6 mm edge exclusion
Contamination	NONE	Backside
Stain	< 5 spots	< 0.05 cm ² total area
Edge Chips/Cracks	< 1.5 mm circumferential < 1.8 mm radial	combined length 1 × bright light
Pits and Dimples	< 0.5 mm - 10/wafer > 0.5 mm - NONE	1 × bright light
Haze	Moderate haze - NONE Heavy haze - NONE Non-uniform haze - NONE	Light uniform haze is acceptable. (Iterate between user and vendor.)
Foreign Matter (embedded particles)	< 0.05/cm ²	< 3 embedded particles per 150 mm wafer

Table 3. SIMOX Electrical Parameters

<i>Parameters</i>	<i>Reference</i>	<i>Value</i>	<i>Method</i>
Photoconductivity Lifetime (Backside)	Section 8.1	> 1 msec.	microwave
Photoconductivity Lifetime (Front side)	Section 8.1	TBD	microwave
BOX Breakdown	Section 8.2	> 5 MV/cm	I-V
BOX Pinholes	Section 8.3	< 0.2 cm ²	I-V
BOX Charge	Section 8.4	<	C-V
BOX Surface States	Section 8.5	< 5 × 10 ¹⁰ /cm ²	C-V
Doping Density Sub, Surface	Section 8.6	TBD	4-point probe

8. Electrical Parameters

8.1 Photoconductivity Lifetime — This is measured by creating an excess of carriers (typically by using a light source) and measuring the slope of the decay curve. Several pieces of commercial equipment are available for this purpose. This requires that polysilicon is not deposited on the backside, as is sometimes done for gettering. Also, surface passivation may be needed for lifetime measurements. Backside measurements indicate the quality of the substrate and can be performed by traditional methods. Frontside measurements are more difficult and must be performed

using incident light which can be entirely absorbed before reaching the underlying substrate.

8.1.1 Typically, the sample is placed on a micro-wave wave guide post, forming part of a transmission line circuit. The microwave reflection is determined by the total conductivity of the sample and the conductivity is modulated by an intense light pulse. When the light is turned off, the microwave detects an exponential decay in conductivity from which a decay constant is determined. The photoconductivity lifetime is a result of the recombination velocity at the surfaces, volume recombination in the silicon layer, and any trapping. Measurements are made independently on the front and

back sides of the wafer. The mean value on the backside of the wafer will typically be at least 10 microseconds for N-type material and 3 microseconds for P-type material. These values correspond to about a 100 micron diffusion length (SPV value).

8.1.2 The relevance of photoconductivity lifetime to the users requirement should be discussed. The use of this measurement should be negotiated between customer and vendor.

8.2 *BOX Breakdown* — This parameter can be measured with a buried oxide capacitor (BOX-CAP). The buried oxide thickness and the intended application will affect both the test procedure (such as capacitor area and voltage criterion) and the allowable values of measured parameters. These should be determined by agreement between the user and vendor. Example procedure and values for standard evaluation of 400 nm thick buried oxide are given in the following paragraphs.

8.2.1 *Test Structure* — Buried oxide capacitor (BOX-CAP) having an area of 0.01 cm^2 for standard (400 nm) BOX. The electrode material and thickness affect the breakdown phenomena due to thermal effects, and so should be included in the agreement between customer and vendor.

8.2.2 *Test Method: Staircase I-V Measurement* — Voltage is stepped in one-volt increments from zero to 400 volts, or until destructive breakdown is sensed. Tests are done for both bias polarities. The test detects the onset of high field conduction, as well as the point of destructive or massive charge injection and trapping.

8.2.3 *Typical Values*

$J_{\text{ox}} < 10^{-8} \text{ A/cm}^2$ at $E_{\text{ox}} = \pm 2 \text{ MV/cm}$ [onset of hi-E regime]

$E_{\text{ox}} > 5 \text{ MV/cm}$ at $J_{\text{ox}} = 0.01 \text{ A/cm}^2$ [breakdown/injection]

8.3 *BOX Pinhole Density* — This parameter can be measured with a buried oxide capacitor (BOX-CAP). The buried oxide thickness and the intended application will affect both the test procedure (such as capacitor area and voltage criterion) and the allowable values of measured parameters. These should be determined by agreement between the user and vendor. Example procedure and values for standard evaluation of 400 nm thick buried oxide are given in the following paragraphs.

8.3.1 *Test Structure* — Buried oxide capacitor having an area equal to or greater than 0.05 cm^2 .

8.3.2 *Test Method: Staircase I-V* — Measurement testing can be done for both Type I and Type II defects

where Type I defects are silicon pipes traversing the buried oxide, and Type II defects are local regions of thin buried oxide. If Type II defect density is sought, capacitors are subjected to a series of 30 voltage steps of 3.3 volts, with current monitored after each step, using a failure criterion of 1 nA.

8.3.2.1 Arrays of at least 200 capacitors per wafer are tested. Bias polarity of the voltage ramp is chosen so as to accumulate the substrate portion of the capacitor (positive for *n*-silicon, negative for *p*-silicon).

8.3.2.2 Type I defect density is determined using the same test procedure, except that the failure current criterion is $1 \mu\text{A}$.

8.3.2.3 Any capacitor displaying the failure current or more for voltages less than 100 volts is considered defective. Defect density of either type is calculated from the yield of good capacitors, ($Y = 1 - \# \text{ failed} / \# \text{ tested}$), using Poisson statistics;

$$D = -\ln(Y)/A,$$

where A is the total area of the capacitors tested.

8.3.2.4 For thin buried oxide (films less than 360 nm), the voltage criteria above need to be adjusted to account for the onset of high field conduction in defect-free capacitors.

8.3.3 *Values*

$$D (\text{Type I}) < = 0.2 \text{ defects/cm}^2$$

8.3.3.1 No standardized criterion for Type II defects has been established.

8.4 *Buried Oxide Charge* — This parameter can be measured with a buried oxide capacitor (BOX-CAP). The buried oxide thickness and the intended application will affect both the test procedure (such as capacitor area and voltage criterion) and the allowable values of measured parameters. These should be determined by agreement between the user and vendor. Example procedure and values for standard evaluation of 400 nm thick buried oxide are given in the following paragraphs.

8.4.1 *Test Structure* — Buried oxide capacitor having an area of 0.01 cm^2 .

8.4.2 *Test Method* — MOS high frequency C-V measurement of a buried oxide capacitor normally yields a flat band voltage less than one volt in magnitude. For a previously untested 400 nm film, this implies an effective fixed charge density of less than $5 \times 10^{10} \text{ charges/cm}^2$.

8.4.3 *Values*

$$Q_f/q < = 5 \times 10^{10} / \text{cm}^2$$

8.5 Buried Oxide Fast Interfaces State Density — This parameter can be measured with a buried oxide capacitor (BOX-CAP). The buried oxide thickness and the intended application will affect both the test procedure (such as capacitor area and voltage criterion) and the allowable values of measured parameters. These should be determined by agreement between the user and vendor. Example procedure and values for standard evaluation of 400 nm thick buried oxide are given in the following paragraphs.

8.5.1 Test Structure — Buried oxide capacitor having an area of 0.01 cm².

8.5.2 Test Method — High-Low Frequency MOS C-V. If care is taken in their fabrication to minimize oxide surface damage and contamination during silicon etching, good quality quasi-static MOS C-V curves can be measured on BOX-CAP's. From comparison of high and low frequency C-V curves, midgap interface state density can be determined exactly as for normal MOS capacitors.

8.5.3 Values

$$D_{it}(0) \leq 5 \times 10^{10} \text{ states/cm}^2\text{-eV}$$

8.6 Doping Density in the SIMOX Layer

8.6.1 Test Structure — The untreated SIMOX wafer. Substrate: Buried oxide capacitor, area = 0.01 cm²

8.6.2 Test Method — Spreading Resistance Probing (SRP) offers a way of determining the resistance profile in the Si layer as a function of distance from the top surface. The carrier concentration can be calculated directly from this data.

8.6.2.1 The four point probe method of SIMS can also be used. The four point probe test is liable to punch through and should be considered a destructive test as is SIMS. SIMS will allow for an understanding of compensation effects, if any.

8.6.3 Values — The acceptable dopant values are to be determined by agreement between the user and vendor.

8.7 Doping Density in the Substrate

8.7.1 Test Structure — A buried oxide capacitor (BOX-CAP) area = 0.01 cm².

8.7.2 Test Method — The electrically active dopant concentration in the substrate immediately beneath the buried oxide can be determined from the standard analysis of high frequency MOS C-V curves measured on BOX-CAPs, dependent on oxide charge and interface properties.

Values — The acceptable dopant values are to be determined by agreement between the user and vendor.

9. Packing and Marking

9.1 Special packing requirements shall be subject to agreement between the user and supplier. Otherwise, all wafers shall be handled, inspected, and packed in such a manner as to avoid chipping, scratches, and contamination and in accordance with the best industry practices to provide ample protection against damage during shipment.

9.2 The wafer supplied under these specifications shall be identified by appropriately labeling the outside of each box or other container, and each subdivision thereof, in which it may reasonably be expected that the wafers will be stored prior to further processing. Identification marks, codes, symbols and content shall be agreed upon between user and supplier.

NOTICE: These guidelines do not purport to address all of the safety issues associated with their use. It is the responsibility of the users of these guidelines to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. SEMI makes no warranties or representations as to the suitability of the guidelines set forth herein for any particular application. The determination of the suitability of these guidelines 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 mentioned herein. These guidelines are subject to change without notice.

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SEMI M35-1104

GUIDE FOR DEVELOPING SPECIFICATIONS FOR SILICON WAFER SURFACE FEATURES DETECTED BY AUTOMATED INSPECTION

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1 Purpose

1.1 Inspection of silicon wafer surfaces is a standard outgoing test on all commercially sold silicon wafers.

1.2 Older specifications referred to visual inspection of wafer surfaces, but with advanced technologies, the sizes of many important surface features are too small to be seen visually and so other types of surface inspection become necessary.

1.3 This guide provides a specification framework for reporting measurements of silicon wafer surface features through the use of scanning (or automated) surface inspection systems (SSIS).

2 Scope

2.1 This guide addresses specifications related to localized light scatterers (LLSs) as well as extended light scatterers (XLSs). Examples of LLSs are particles and pits. Examples of XLSs are scratches and regions of high roughness (surface haze).

2.2 Surface scanners, which have discriminated between XLSs and LLSs for several years, are now discriminating (and selectively reporting) between different types of LLSs (for example: pits and particles).

2.3 Specific numbers limiting feature levels and/or densities are to be agreed upon between suppliers and customers. This guide provides a framework for that communication.

2.4 The resulting specifications will be flexible enough to accommodate variations in measurement due to different SSIS models.

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 Discussion

3.1 Discussion of LLS Measurement Issues

3.1.1 Because there is considerable variation in the scatter characteristics of different LLSs, they have been historically sized in latex sphere equivalents (LSE). In other words, the signal received from an unknown LLS is equivalent to that which would be obtained from a polystyrene latex (PSL) sphere of known size.

3.1.2 Automated scanning systems typically display a map of LLS location as well as a histogram of LSE size.

3.1.3 The instrumentation industry is building SSISs that discriminate some LLSs from others based on differences in measured scatter that depend on feature size, shape and material. This raises the question of whether identified LLSs should continue to be sized using latex sphere equivalents, or if some new (more accurate) standard would be more acceptable. For example, if an LLS signal could be identified as coming from a pit, then it might become appropriate to develop a standard pit wafer. In this case, pits (either manufactured or found naturally) could be measured via atomic force microscope (AFM) and be made available on a calibration wafer to size pits via their measured scatter. Another option, would be to use a model-based standard that resides in the SSIS software.

3.2 Discussion of XLS Measurement Issues

3.2.1 Identification of scratches is typically done (in part) through software that identifies a string of connected LLS signals. Defects with dimensions such that the length is at least five times the width are defined as scratches. Customers and suppliers may agree on scratch aspect ratios different from 5:1. SSIS software often provides a customer-settable aspect ratio, as well as a minimum overall length, as criteria for classification of an SSIS defect or group of defects as a scratch. Depending on SSIS design, scratch sensitivity may also be a function of scratch orientation. Currently, scratch signals are also calibrated in latex sphere equivalents; however, in the future it may become useful to calibrate scratch signals with a standard obtained from a scratch that has been either

manufactured to a known size, or has been measured via AFM.

3.2.2 Haze is specified as parts per million (ppm) of measured scattered optical power relative to the incident optical power on the surface. All of the associated measurement conditions must be given (or implied) with the specified haze value. These conditions include: source incident angle (measured as a polar angle from surface normal), source polarization (S, P, other), source wavelength (or wavelength band), nominal source spot size at the wafer, haze collection angles (given as solid angles with directions). All of these quantities must be part of a haze specification, either by description, or by implication to specific instrumentation (with known or fixed parameters).

3.2.3 Haze is quantified by measuring scattered light power over one or more solid angles and then normalizing by the light power incident on the surface. It is nothing more than the diffuse reflectance of a surface in specified directions for a known source (incident angle, polarization, spot size, wavelength band) and receiver (or detector) configuration (solid angles and locations). Measured haze can be expected to change if the surface is changed, or if any of the measurement parameters change.

3.2.4 Under special conditions, where the source of the haze is known, it may be possible to use a model to predict the haze reading on one instrument from the haze reading on another. For example, if on the basis of product experience and measurements on a few wafers, the surface power spectral density function can be determined, then the haze due to surface roughness can be calculated for an instrument with different parameters. Haze caused by a large number of small particles and/or film contamination is more difficult to model.

3.2.5 An SSIS often reports haze as the arithmetic average of a grid of local haze measurements taken over the FQA. This average can be, and often is, biased by wafer haze distributions that exhibit long, positively skewed tails. SSIS software is being developed that automatically calculates other haze statistics, such as the median haze value, the standard deviation of the haze distribution, and so on.

3.3 The SSIS used for automated inspection of silicon wafer surfaces should be calibrated in terms of latex sphere equivalents in accordance with SEMI M53 or another method agreed upon between supplier and customer.

4 Limitations

4.1 The following measurement considerations impose limitations on the guidelines.

4.1.1 Histograms calculated in latex sphere equivalents may be distorted, because a given surface has in general LLSs of different size, shape, and material.

4.1.2 Measurement results do not always compare well between systems, because different SSIS designs employ different geometries and gather light scattered in different directions. Haze maps may have different levels and localized surface features may have different calculated sizes.

4.1.3 All scanning systems have a minimum LSE size of LLSs that can be reliably mapped and sized. The limitation is due to a combination of system electrical noise and the detection of non-particle light scatter signals, such as those created by Rayleigh scatter, surface roughness and system optics. Operation near this noise floor limits the utility of this guide for LLSs of those sizes.

4.1.4 Measurements made near the wafer edge often result in large numbers of false counts called edge blast. These counts are caused by small amounts of stray light propagating near the incident beam that scatter from the relatively rough wafer edge back into the detector optics. Under certain combinations of sensitivity and edge exclusion, light scattered from these effects may cause false counts within the FQA.

4.1.5 Types of LLS signals that may be mis-identified as scratches include lines of particles, pits, false counts, stacking faults, slip, and spin dry residue.

4.1.6 Closely spaced features may be counted as a single scattering event because the scanning spot size is generally much larger than the feature diameter.

4.1.7 Scratch orientation usually affects scanner response. Thus the minimum detectable scratch cross-section may vary with orientation.

5 Referenced Standards

5.1 SEMI Standards

SEMI M1 — Specifications for Polished Monocrystalline Polished Silicon Wafers

SEMI M53 — Practice for Calibrating Scanning Surface Inspection Systems using Depositions of Monodisperse Polystyrene Latex Sphere on Unpatterned Semiconductor Wafer Surfaces

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

6 Terminology

6.1 Most terminology used in this guide is defined in SEMI M1 and/or SEMI MF1241.

6.2 Other terms are defined as follows:

6.2.1 *extended light scatterer (XLS)* — a feature larger than the spatial resolution of the inspection equipment, on or in a wafer surface, resulting in increased light scattering intensity relative to that of the surrounding wafer, sometimes called an *area defect* (see SEMATECH # 95082941A-TR, Section 8).

6.2.2 *power spectral density* — statistical function that shows how the mean-square (rms)² of a given quantity is distributed among the various surface spatial frequencies inherent in the profile height. Also known as *power spectrum*.

NOTE 1: For additional information see the extended discussion of this term in SEMI MF1811.

6.2.3 *scanning surface inspection system (SSIS)* — an instrument for rapid examination of the entire quality area on a wafer to detect the presence of localized light scatterers or haze or both, also called *particle counter* and *laser surface scanner*.

7 Specifications

7.1 Specification guidelines are given below for several different LLSs and XLSs.

7.1.1 *Generic LLS* — There shall be no more than N LLSs (particles or pits) of size greater than or equal to D nm latex sphere equivalent (LSE) diameter on the wafer within the fixed quality area (FQA).

7.1.1.1 Options: Size ranges and counts may be specified using an edge-referenced edge exclusion, if agreed upon between supplier and customer.

7.1.2 *Particles* — There shall be no more than N particles of size greater than or equal to D nm LSE diameter on the wafer within the FQA. Size ranges and counts may be specified.

7.1.2.1 Options: Size ranges and counts may be specified using an edge-referenced edge exclusion, if agreed upon between supplier and customer.

7.1.3 *Pits* — There shall be no more than N pits of size greater than or equal to D nm in LSE diameter on the wafer within the FQA. Size ranges and counts may be specified.

7.1.3.1 Options: Size ranges and counts may be specified using an edge-referenced edge exclusion, if agreed upon between supplier and customer.

7.1.4 *Scratches* — There shall be no more than N scratches of length greater than or equal to L nm on the wafer within the FQA.

7.1.4.1 Options: Size ranges and counts may be specified using an edge-referenced edge exclusion, if agreed upon between supplier and customer.

7.1.4.2 Scratch aspect ratios different than 5:1 and minimum lengths may be used by agreement of supplier and customer.

7.1.5 *Generic XLS* — There shall be no generic XLSs of N ppm or greater in an area larger than A mm² within the FQA.

7.1.6 *Haze (Using Defined Conditions)* — Either local haze or average haze may be specified as follows: The haze shall not exceed N ppm over the wafer surface when measured over a solid angle of Ω sr of circular cross section centered about the surface normal with a λ nm laser source of a specified polarization incident on the sample at θ degrees. Suppliers and customers may agree to use other statistics of the wafer haze distribution in haze specifications.

NOTE 2: For example: the median wafer haze shall not exceed M ppm; the standard deviation of wafer haze shall not exceed S ppm; the inter-quartile range of wafer haze shall not exceed IQR ppm. Statistics based on the log of the haze distribution may also be used.

7.1.7 *Haze (Using an Instrument Definition)* — Either local haze or average haze may be specified in the following way. The haze shall not exceed N ppm over the wafer surface when measured with a model XXX particle scanner under YYY operating conditions. Suppliers and customers may agree to use other statistics of the wafer haze distribution in haze specifications (see Note 2).

7.2 Specifications may be selected from Table 1.

8 Related Document

8.1 Many terms associated with examination of wafer surfaces are defined in the following SEMATECH report:

8.1.1 *Glossary of Terms*, SEMATECH Technology Transfer Document # 95082941A-TR¹

¹ Available from SEMATECH, 2706 Montopolis Drive, Austin, TX, tel.: 512.356.3500, fax: 512.779.2826, website: www.semiatech.org.

Table 1 Specification Elements Related to Automatic Inspection of Silicon Wafer Surfaces

<i>Parameter</i>	<i>Specification Elements</i>	<i>Specified Measurement Conditions</i>
1. Generic LLS	___, max number	with LSE dia \geq ___ nm, nominal edge exclusion of ___ mm
2. Particles	___, max number	with LSE dia \geq ___ nm nominal edge exclusion of ___ mm
3. Pits	___, max number	with LSE dia \geq ___ nm nominal edge exclusion of ___ mm
4. Scratches	___, max number	length \geq ___ μ m nominal edge exclusion of ___ mm
5. Generic XLS	___ ppm, max	with area \geq ___ mm ² nominal edge exclusion of ___ mm
6. Haze (conditions)	___ ppm, max	with ___ degree incident angle, at ___ nm wavelength, at ___ polarization, over ___ sr solid collection angle, in ___ degree polar direction and ___ degree azimuthal direction, nominal edge exclusion of ___ mm
7. Haze (instrument)	___ ppm, max (or other statistics)	with model XXX SSIS under YYY conditions

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SEMI M36-0699

TEST METHOD FOR MEASURING ETCH PIT DENSITY (EPD) IN LOW DISLOCATION DENSITY GALLIUM ARSENIDE WAFERS

This test method was technically approved by the Global Compound Semiconductor Committee and is the direct responsibility of the Japanese Compound Semiconductor Materials Committee. Current edition approved by the Japanese Regional Standards Committee on March 17, 1999. Initially available at www.semi.org April 1999; to be published June 1999.

1 Purpose

1.1 This document provides a method to measure etch pit density (EPD) in low dislocation density GaAs wafers.

2 Scope

2.1 This test method describes a procedure to measure EPD of 50 mm and 76 mm diameter round GaAs wafers with an EPD of less than 5000/cm².

2.2 This test method does not include GaAs wafer preparation, such as wafer slicing, polishing and pit etching. The preparation of GaAs wafer can be found in a Referenced Document.

2.3 This standard does not purport to address all of the safety issues. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulations prior to use of the test method.

3 Referenced Document

3.1 ASTM Standard

F 140-92 — Test Method for Crystallographic Perfection of Gallium Arsenide by Molten Potassium Hydroxide (KOH) Etch Technique.

4 Apparatus

4.1 Microscope - Measuring field should be 1 mm² or larger.

NOTE: For accurate EPD measurement, accurate area of the measuring field should be measured by a standard scale.

5 Procedure

5.1 The counting positions for 50 mm diameter wafers and for 76 mm diameter wafers are shown in Figure 1

and Figure 2 respectively. The counting points are located in the center of each mesh. In the case of a 50 mm diameter wafer the mesh size is 5 mm. The total number of counting positions is 69 and position 35 is located at the center of the wafer. In the case of 76 mm diameter wafer the mesh size is 10 mm, and the total number of counting position is 37. Position 19 is located at the center of the wafer.

5.2 Count and record the number of etch pits for which the cores are in the measuring field. If the pits are crowded and are difficult to count, increase the magnification. After that count the etch pits and record the results as well as the microscope magnification.

5.3 Repeat Section 5.3 for all other positions, 2 through 69 positions in the case of 50 mm diameter wafers and 2 through 37 positions in the case of 76 mm diameter wafers.

6 Calculations

6.1 The EPD in each measuring field is the number of pits counted divided by the area.

$$\text{EPD} = (\text{Number of pits}) / \text{Area}$$

For example, if the size of measuring field is exactly 1 mm × 1 mm, the area is 0.01 cm².

7 Report

7.1 There are several forms that are possible for reporting the EPD, for example the average EPD of all the positions or the area less than some specified value or map of EPD for the entire wafer, etc. An appropriate report form should be decided between the supplier and the user.

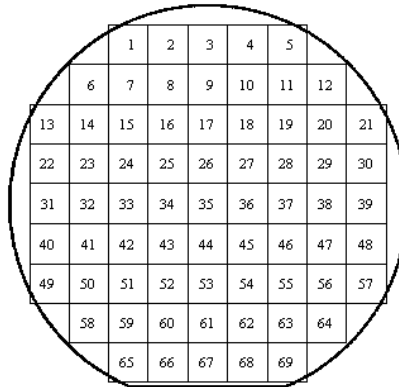


Figure 1
Counting positions for a 50 mm diameter wafer

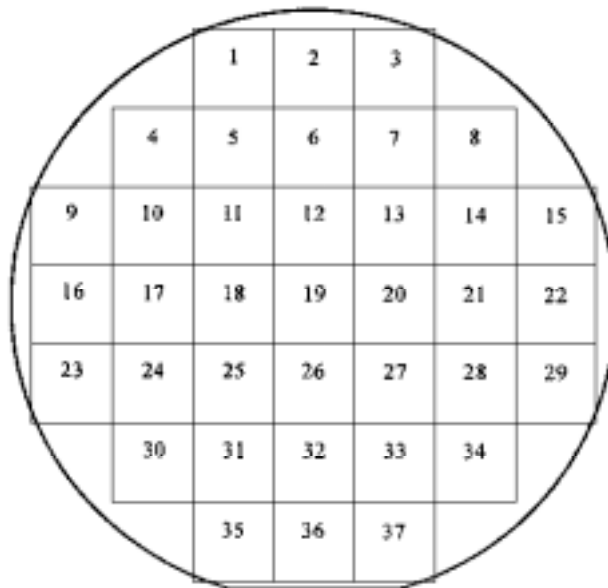


Figure 2
Counting positions for a 76 mm diameter wafer

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SEMI M37-0699

TEST METHOD FOR MEASURING ETCH PIT DENSITY (EPD) IN LOW DISLOCATION DENSITY INDIUM PHOSPHIDE WAFERS

This test method was technically approved by the Global Compound Semiconductor Committee and is the direct responsibility of the Japanese Compound Semiconductor Materials Committee. Current edition approved by the Japanese Regional Standards Committee on March 17, 1999. Initially available at www.semi.org April 1999; to be published June 1999.

1 Purpose

1.1 This document provides a method to measure etch pit density (EPD) in low dislocation density InP wafers.

2 Scope

2.1 This test method describes a procedure to measure EPD of 50 mm diameter round InP wafers with an EPD of less than 5000/cm².

2.2 This standard does not purport to address all of the safety issues. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulations prior to use of the test method.

3 Referenced Document

3.1 *ASTM Standard*

F 140-92 — Test Method for Crystallographic Perfection of Gallium Arsenide by Molten Potassium Hydroxide (KOH) Etch Technique.

4 Apparatus

4.1 Microscope — Measuring field should be 1 mm² or larger.

NOTE: For accurate EPD measurement, accurate area of the measuring field should be measured by a standard scale.

5 Procedure

5.1 Orient the ingot so that the front surface normal direction of the sample is parallel to the <100> within 5°, and then cut a wafer from the ingot.

5.2 Polish the wafer to form a mirror finish. Afterwards, the wafer must be cleaned and dried.

5.3 Mix phosphoric acid (H₃PO₄) and hydrobromic acid (HBr) in a beaker. The ratio of each acid is H₃PO₄:HBr=2:1.

5.4 Immerse the wafer in the mixed acid for 3 minutes at room temperature.

5.5 Rinse the wafer with deionized water and then dry.

5.6 The counting positions are shown in Figure 1. The counting points are located in the center of each mesh. The mesh size is 5 mm and the total number of counting positions is 69. Position 35 is located at the center of the wafer.

5.7 Count and record the number of etch pits for which the cores are in the measuring field. If the pits are crowded and are difficult to count, increase the magnification. After that count the etch pits and record the results as well as the microscope magnification.

5.8 Repeat Section 5.8 for all other positions, 2 through 69.

6 Calculations

6.1 The EPD in each measuring field is the number of pits counted divided by the area.

$$\text{EPD} = (\text{Number of pits}) / \text{Area}$$

For example, if the size of measuring field is exactly 1 mm × 1 mm, the area is 0.01 cm².

7 Report

7.1 There are several forms that are possible for reporting the EPD, for example the average EPD of all the positions or the area less than some specified value or map of EPD for the entire wafer, etc. An appropriate report form should be decided between the supplier and the user.