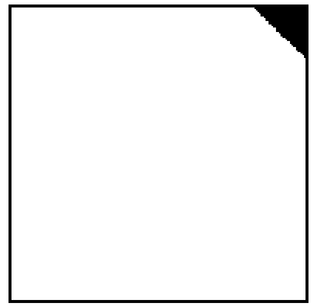


Figure 5
Substrate Identification by Corner Chamfer(Non-Critical Side)

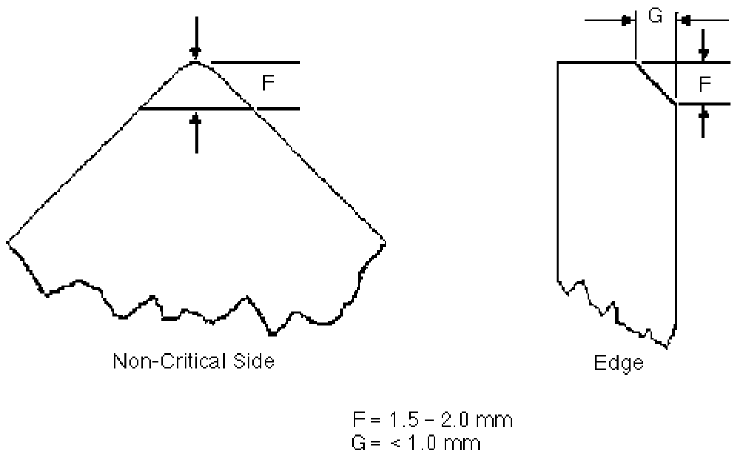


Figure 6
Dimension of Corner Chamfer

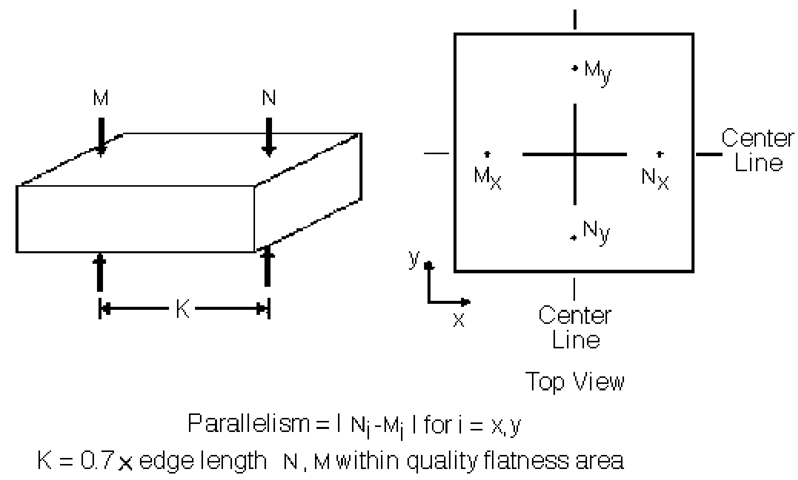


Figure 7
Measurements for Calculation of Parallelism with Approximate Positions

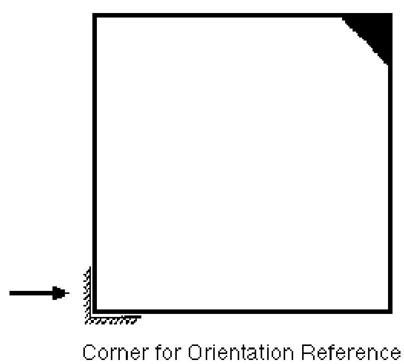


Figure 8
Corner Diagonally Opposite of Chamfer

APPENDIX 1
HARD SURFACE PHOTOMASK MATERIAL PROPERTIES

NOTE: This appendix was approved as an official part of SEMI P33 by full letter-ballot procedure.

Table A1-1 Material Properties

Property	
Ultra Low Thermal Expansion (ULTE)	
Modulus of Elasticity	6.7–7.4 × 10^3 kg/mm^2
Poisson's Ratio	0.16–0.19
Specific Gravity	2.18–2.20 g/cm^3

RELATED INFORMATION 1
TERMS AND DEFINITIONS

NOTE: This related information is not an official part of SEMI P33. The following terms and definitions are provided for information only. The Microlithography-related definitions identified herein were compiled from the Terminology sections of the Standards in the SEMI Microlithography Volume. The SEMI Microlithography Committee is currently updating all terminology through the Microlithography Terms and Definitions Task Force, and will eventually include the updated terminology in the SEMI Compilation of Terms.

SEMI makes no warranties or representations as to the suitability of the terms and definitions set forth herein for any particular application. The determination of the suitability of the terms and definitions is solely the responsibility of the user.

array rotation — the total array set rotated relative to substrate edges.

cavity — in pellicle technology, an unfilled space between the photomask and the optically transparent film within the mounted pellicle frame area.

coherence, spatial — the correlation of the electromagnetic fields at different points in space. Can be achieved with a non-monochromatic source.

coherence, temporal — the correlation of electromagnetic fields at different points in time but the same point in space (related to the non-monochromaticity of the source).

composite drawing — a large-scale drawing comprising all geometric forms required for a single device, arranged in proper relative positions. It is used as a guide for manual cutting by Rubylith, or for a digitizing guide for Computer Aided Design (see CAD). The set of colored overlay films made as work progresses to the reticle stage, can also be considered a composite, suitable for checking design errors. (SYN: Master Drawing, Engineering Drawing, Design Drawing.)

contact mask — in semiconductor fabrication, after the major diffusions, gates, and other active areas have been deposited, a glass insulating layer is placed over the whole die. Small holes are etched through this glass at points where the interconnecting metal conducts must 'contact' the active areas. The mask that defines these holes is characterized by many small squares (~0.2–0.4 mil) scattered throughout the die area.

contact printing — a process of reproducing an original by placing a photomask so that the coated side is in contact with the photoresist (or emulsion) surface of the area to be printed and then exposing the photoresist (or emulsion).

cure, photoresist — the process of eliminating undesirable properties of photoresists, such as tackiness, softness, the tendency to flow, lack of adhesion, etc.

dark area — an opaque area.

defect, gross photomask — a photomask defect that can be easily seen with the naked eye or under magnification no greater than 10×. Examples: large scratches, cracks in the glass substrate, drying marks, etc.

defect, photomask — any flaw or imperfection in the opaque coating or functional pattern of a photomask that will reproduce itself in a photoresist film to such a degree that it is pernicious to the proper functioning of the microelectronic device being fabricated.

degradation — reductions in image quality (measured as resolution, edge acuity, dimensional shifts, defect density, etc.) experienced in each generation of reproduction, as compared to the original or preceding generation. Generally, degradation increases with each generation, in a predictable manner.

diffraction pattern, spatial — intensity variations of light in the viewing plane caused by interference of waves undergoing diffraction.

element — a member of the set that makes up the photomask array; used either as a functional layer member for the fabrication of a single, integrated circuit or for test purposes. (Replaces chip, die, bar.)

emulsion — a suspension of a salt of silver in gelatin or collodion that is coated onto a photoplate and is exposed and developed to produce a photomask.

energy, minimum exposure — the energy corresponding to the total integrated energy of actinic radiation necessary to just completely render soluble a positive photoresist for a given replacement film thickness or just completely render insoluble a negative photoresist for a given single resist film thickness.

energy, optimum exposure — the energy per square centimeter corresponding to the total integrated energy of actinic radiation necessary to accurately reproduce photomask pattern dimensions in a photoresist of given thickness after exposure and development.

etch resistance — the ability of a photomask coating or protecting material, such as photoresist, in which the pattern is imaged or photoprinted.

etch time — the time required for the removal of a coating in an etching medium.

etchant — the chemically reactive solution used for removal of unwanted metallic coating from a substrate.

field — the background area of a device is defined as the area not being acted upon during the fabrication process. Thus, if a mask is to be used to produce metal interconnects, the area representing non-metal is the “field.” The image polarity is named by the appearance of this field; thus, clear field, dark (opaque) field. This definition is very carefully stated because, in some devices, their gross appearance is very deceiving in that “field” cannot always be denoted as the major area. Some devices may have diffusion of buried layers, for instance, covering 80% of the area, the remaining 20% being the field. Some knowledge of the fabrication process is essential when determining field, as many of these ambiguous conditions exist where the field is less than 50% of the area. (ANT: active area; geometry; trace: diffusion area.)

film adhesive — adhesive between frame and film.

film thickness, dirt — fingerprint; mark touched by something; stain by liquid.

film thickness, particle — the particle state materials that can be distinguished from the film itself on the film surface or inside the film.

film thickness, pinhole — a small opening completely through a polymer film.

fixer — a chemical solution which makes an image permanent. In the case of silver emulsion processes, it dissolves and removes the unexposed/undeveloped silver halide crystals so that further darkening of the image cannot occur.

frame adhesive — adhesive between frame and photomask.

functional element — any contiguous fragment of a device that is necessary to the electrical operation of the finished device. Examples include diffused areas, traces, gates, contacts, etc.; excludes scribe lines, alignment marks, labels, etc. (SYN: active geometry.)

gel slug — a piece of clear, dried gelatin that has been trapped in a silver/gelatin emulsion during coating. A gel slug has the appearance, under a microscope, of a clear lens-like lump, generally 0.5 – 2 mils in size, and about twice as long as wide.

isolation layer — a partitioning, especially of bipolar devices, usually by diffusion, to electrically insulate functional components of an integrated circuit device. Isolation masks are usually layer 1 or 2, and characterized by thin lines defining open boxes all over the die area. (SYN: isolation mask.)

latent image — the invisible image formed on any photosensitive material after exposure. It requires some type of development to produce a useful, visible image.

layer — one of a sequential series of overlaying photomasks that make up a device series.

mask set — the complete series of masks for all layers, necessary to fabricate any given device.

master drawing — the original drawing from which the artwork is made.

master mask — original photomask, at 1× (final) scale, generated with a photorepeater from which submasters are printed. (SYN: master.)

matrix — the rectangular arrangement of die on a photomask. (SYN: array.)

mechanical strength — the physical condition a pellicle must meet to withstand a specified force from a blow-off gun without suffering any damage to the film.

mouse bite — see *mouse nip*.

mouse nip — in semiconductor imaging technology, a semicircular intrusion.

objective lens — in a microscope system, it is the lens closest to the test specimen (object). Usually provides the greatest amount of the total magnification and also limits system resolution. Most commonly several objectives, in typical powers of 10×, 20×, and 40×, are mounted on a turret for rapid magnification changes. See also *ocular*.

ocular — the set of microscope lenses closest to the observer’s eye that produces final magnification of microscope. It usually contains graticules or filar-measuring apparatus. See also *objective lens*.

opacity — a direct measure of the light-stopping power of a semitransparent medium, as glass photographic emulsion or a thin chrome coating. Represented as the reciprocal of transmittance, $O = 1/T$. The common logarithm of opacity if used as Optical Density. $D = Log_{10}O$.

pellicle — a thin, optically transparent film, typically of nitrocellulose, attached to, supported by a frame, and attached to a photomask (or photomask reticle). NOTE: Its purpose is to seal out contaminants and reduce printed defects caused by contamination in the image plane of an optical exposure system.

photorepeater — a combination of a high-resolution reduction (usually 10× or 5×) camera and a programmable precision stage. The image from the camera is projected onto a photoplate, attached to the stage, and exposed in as many positions as required by moving the stage between exposures. The product of a photorepeater is the master mask. (SYN: image repeater; step-and-repeat camera.)

printing — the transfer of an image from one surface (substrate) onto another at 1× scale. Usually “printing” refers to the contact method, but it also can be accomplished using a 1-to-1 projection optical system. (SYN: contact printing.)

printing, contact — photoprinting photomask patterns by exposure of a photosensitive material coated on a supporting substrate to radiation passing through the photomask, which is in contact with the photosensitive material.

printing, off-contact — see *printing, proximity*.

printing, projection — a method of optically projecting an image onto a photosensitive material, thus eliminating the need for photomask/photosensitive-coating contact.

printing, proximity — photoprinting photomask patterns by exposure of photosensitive material coated on a supporting substrate to radiation passing through the photomask which is in the proximity of, but not in contact with, the photosensitive material being exposed.

reduction camera — a mechanism used to optically reduce the size of images and record them photographically. In two-step reduction, a copy camera is used for the range of 100× to 1000× reduced to 10×; the photorepeater reduces from 5× or 10× to 1×. Both are reduction cameras. See also *photorepeater.*

registration mark — a mark used to control placement of one layer relative to another.

repetitive defect — a defect (spot, pinhole, protrusion, or intrusion) introduced on the reticle so that in generating a master, it reproduces on every die.

reversal process — a photographic emulsion process that produces an image which is the same as the input image (i.e., clear areas remain clear, and opaque remain opaque). It is named ‘reversal’ because it yields the ‘reverse’ of the standard ‘negative’ process. Accomplished by developing the negative image, destroying this image by bleaching, and then subsequently developing all the original silver halide that represents the positive image. (SYN: positive-acting, process, positive process. ANT: negative acting process, normal process.)

rotation, of array — whole array is properly arranged (die relative to die), but placed on a blank which is rotationally mis-aligned. May occur during stepping or contact printing.

rotation, of die — on a master, misplacement of die by an angular displacement around the Z-axis. Usually caused by mispositioning of the reticle in a photorepeater so that it does not lie parallel to X- and Y-axis of stage travel.

run-in — a die placement error, where the die increment is less than the design dimension. This can occur during stepping, due to nonlinearity of miscalibration of the photorepeater stage scan scale, or during contact printing due to plate warpage.

shelf life — the period of time, at specified conditions of storage, in which the physical and chemical properties that affect a material’s performance remain acceptable.

smear — a large area of partially removed coating or deposited foreign material.

space — area between image geometries; field between close-lying images. The space is often specified as the critical dimension. (SYN: field. ANT: digitized area; geometry.)

spinner — a device for holding a substrate and spinning it at a controlled rate of speed (usually 1000 to 6000 RPM), for applying extremely thin coating, as with photoresist.

submaster — a photomask printed in limited quantities from masters, and from which the working plates are printed. Used to reduce wear and tear on masters.

test device — a simplified, functional device (of the same process type as the majority die), inserted in several positions in any array, used for process control and monitoring during wafer fabrication.

torn image — image broken by movement of the image medium. Most often seen on emulsion images.

variable aperture — an aperture whose open area may be increased or decreased by movement of the elements forming the aperture.

visual defects — defects that can be identified by a skilled observer (with or without the aid of a microscope) without having to measure or compare (e.g., pinholes, slugs, spots, protrusions, etc.).

working plate — mask used selectively to expose photoresist on a wafer for IC fabrication. Usually printed from submasters or masters, thus preserving the master from excessive handling damage.

NOTICE: These standards do not purport to address safety issues, if any, associated with their use. It is the responsibility of the user of these standards 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 standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature respecting any materials mentioned herein. These standards are subject to change without notice.

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 P34-0200
SPECIFICATION FOR 230 mm SQUARE PHOTOMASK SUBSTRATES

This specification was technically approved by the Global Mask and Mask Equipment Committee and is the direct responsibility of the North American Microlithography Committee. Current edition approved by the North American Regional Standards Committee on September 3, 1999. Initially available at www.semi.org November 1999; to be published February 2000.

1 Purpose

1.1 To define the standard requirements for nominally square photomask substrates of 230 mm nominal edge length.

2 Scope

2.1 This specification covers information pertaining to substrates for 230 mm square photomasks. This information includes, but is not limited to, physical dimensions, material properties, and testing and measurement criteria.

2.2 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 limitations prior to use.

3 Referenced Standards

3.1 *ANSI Standard*[1]

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

3.2 *ASTM Standard*[2]

ASTM E228 — Standard Test Method For Linear Thermal Expansion of Solid Materials With a Vitreous Silica Dilatometer

3.3 *ISO Standard*[3]

ISO 14644-1 — Cleanrooms and associated controlled environments

NOTE 1: As listed or revised, all documents cited shall be the latest publications of adopted standards.

4 Terminology

4.1 *230 mm* — the nominal edge length for the reticle generation defined in this specification. Also referred to as “9 inch” size.

4.2 *corner chamfer* — the bevel found in one corner of the substrate, in excess of the edge chamfer, as defined in Section 9.3 and Figure 6.

4.3 *critical side* — major side intended for patterning. The critical side has no chamfered corner(s) (see Section 9.3), and has flatness requirement equal or better than the non-critical side (see Section 8.1).

4.4 *edge chamfer* — the bevel found on all intersections between major and minor sides, as defined in Section 6.2 and Figure 3.

4.5 *non-critical side* — major side not intended for patterning. Any and all chamfered corners are on the non-critical side (see Section 9.3 and Figures 5 and 6).

5 Ordering Information

5.1 Purchase orders for photomask substrates furnished to this specification shall include the following:

5.1.1 Nominal edge length, nominal thickness, edge criteria including straightness and squareness, and parallelism of major sides (see Section 6); straightness shall be measured on all four minor sides;

5.1.2 Material (see Section 7);

5.1.3 Flatness quality area and flatness Total Indicated Reading (T.I.R.; see Section 8);

5.1.4 Visual quality area and defect limits (see Section 9); and

5.1.5 Lot acceptance criteria (see Section 10).

6 Dimensions and Permissible Variations

6.1 The substrates shall conform to the dimensional tolerances appropriate to the nominal edge length and thickness as listed in Table 1. Dimensions are illustrated in Figure 1 and a fixture for measuring the squareness dimensions is shown in Figure 2.

6.2 Substrates shall have chamfered edges between major and minor sides, and rounded corners between minor sides. The edges shall conform to the dimensional tolerances appropriate to the nominal thickness listed in Table 2. Dimensions are illustrated in Figure 3.

6.3 The major sides of substrates shall be parallel within 5.0 µm along both major axes. Measurements

1 American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036

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

3 ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Genève 20, Switzerland

are taken within the flatness quality area, along both major axes. Calculation of parallelism is illustrated in Figure 7.

7 Material Specifications

7.1 Substrate material shall be specified as fused silica (quartz). Fused silica is considered to be ultra low thermal expansion (ULTE) class material.

7.2 Substrate materials shall conform to thermal expansion and optical transmittance tolerances specified in Table 3.

7.3 Selected physical properties of fused silica are provided for information only in Appendix 1.

8 Flatness Specifications

8.1 Substrates shall be supplied with two major sides having a flatness (T.I.R.) of 1, 2, or 5 µm over a flatness quality area as defined in Figure 4a or Figure 4b. Sides are not required to have equivalent flatness.

NOTE 2: Flatness of 0.5 µm is very desirable for semiconductor production, and equipment suppliers may want to consider this in their designs.

9 Visual Criteria

9.1 A visual quality area, which may or may not correspond with the flatness quality area, shall be agreed upon between the user and supplier.

9.2 Each substrate shall not have more defects than listed in Table 4. This table includes limits for the following types of defects:

9.2.1 Internal defects in the visual quality area,

9.2.2 Critical side surface defects in the visual quality area,

9.2.3 Non-critical side surface defects in the visual quality area, and

9.2.4 Defects outside the visual quality area.

9.3 Fused silica substrates shall be identified with one corner chamfer as shown in Figure 5. Dimensions of the chamfer shall be as specified in Figure 6. The corner chamfer is made only on the non-critical side of the substrate.

NOTE 3: This configuration of corner chamfers is different than the configuration used for smaller ULTE class material substrates as defined in SEMI P1.

10 Sampling

10.1 Unless otherwise 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) 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 values. Inspection levels shall be agreed upon between user and supplier.

11 Test Methods

11.1 Thermal Expansion — Determine in accordance with ASTM E228.

11.2 Transmission (to be agreed upon between user and supplier).

11.3 Flatness (to be agreed upon between user and supplier).

11.4 Visual (to be agreed upon between user and supplier).

11.5 Parallelism (to be agreed upon between user and supplier; non-contact methods are preferred).

12 Handling

12.1 Substrates are to be handled on the edges only. When human handling is required, substrates are to be handled with gloves approved for cleanroom use.

13 Orientation

13.1 For fused silica substrates with a single corner chamfer (see Section 9.3), it is recommended that all orientation be performed referencing the corner of the non-critical side diagonally opposite the corner chamfer. The corner for orientation signifies two orientation edges for positioning of the substrate. One edge shall be used for rotation baseline by two points. The other edge shall be used for positioning by one point. See Figure 8 for more information.

14 Certification

14.1 Upon request of the purchaser in the contract or order, a manufacturer's or supplier's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

15 Packing and Marking

15.1 Substrates shall be packed in a class 5 environment as defined by ISO 14644. Carriers shall be designed to prevent substrate-to-substrate contact, and to protect the substrates from contamination in handling and transit. Substrates shall be shipped with the critical side toward the front or bottom of the shipping carrier, depending on carrier configuration. The substrate shipping position shall be indicated on each carrier. Packaging shall comply with the applicable international, national, state, and local laws and regulations required for shipping.

15.2 Containers shall be labeled "Warning: Open and Handle Under Cleanroom Conditions Only" as well as identified by user purchase order number (if applicable), drawing number (if applicable), quantity, supplier lot number, and material identification.

16 Related Documents

16.1 *SEMI Standard*

SEMI P1 — Specification for Hard Surface Photomask Substrates

Table 1 Specifications for Edge Length, Squareness, Straightness, and Thickness for Square Substrates

Nominal Edge Length	*Edge Length Minimum*	*Edge Length Maximum*	*Squareness*	*Straightness (T.I.R.)*	*Thickness Minimum*	*Thickness Maximum*	*Units*
230 mm (virgin)	229.6	230.0	0.186/213	0.050	8.90	9.10	mm
230 mm (repolished)	229.6	230.0	0.186/213	0.050	8.80	9.10	mm

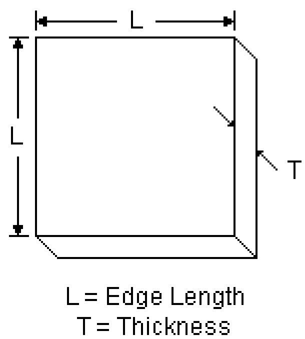
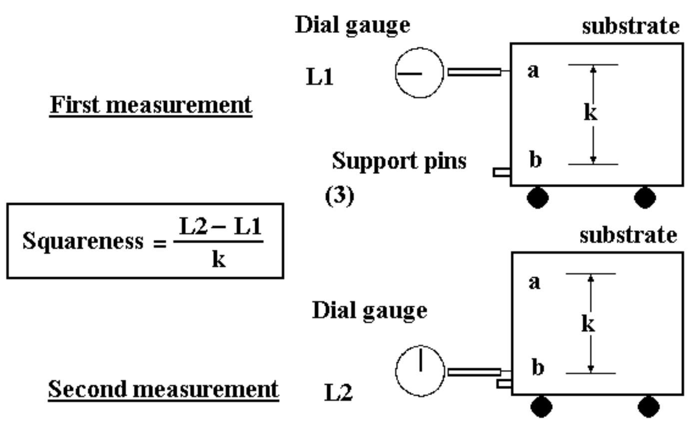


Figure 1
Square Photomask Substrate



K ≥ nominal edge length × 0.7

Figure 2
Measurement Fixture and Calculation to Determine Substrate Squareness

Table 2 Specifications for Chamfered Edge Dimensions

T	*A*	*A*	*B*	*B*	*C*	*C*	
Nominal	Min.	Max.	Min.	Max.	Min.	Max.	Units
9.00	0.20	0.60	0.20	0.60	2.00	3.00	mm

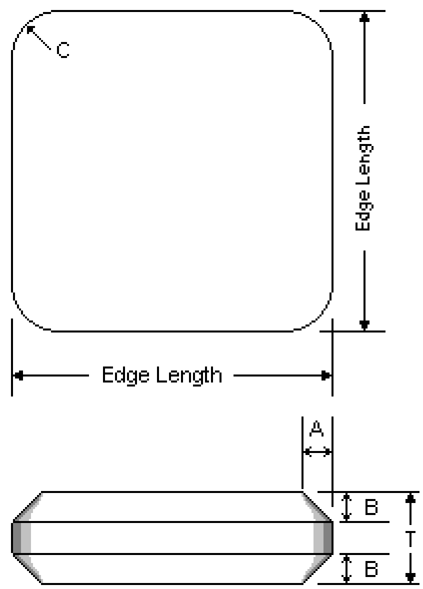


Figure 3
Dimensions for Chamfered Edge and Rounded Corners

Note: "C" is radius of curvature of corners.

Table 3 Substrate Material Characteristics

Fused Silica	*Coefficient of Expansion (°C^{-1}) between 0°C and 300°C*	*Minimum Transmittance (%) of 9 mm Thick Substrate at Wavelengths of:*					
		193 nm	248 nm	254 nm	365 nm	405 nm	436 nm
Virgin	$< 7.5 \times 10^{-7}$	90	90	90	90	90	90
Repolished	$< 7.5 \times 10^{-7}$	89	90	90	90	90	90

Table 4 Fused Silica Substrate Defect Limits

Bulk Defects Within the Visual Quality Area

Opaque Spots	*Bubble*	*Total Defects (per cm^2)*	*Notes*
> 1 µm	> 1 µm	0	1, 2
≤ 1 µm	≤ 1 µm	0.0078	

Surface Defects Within the Visual Quality Area

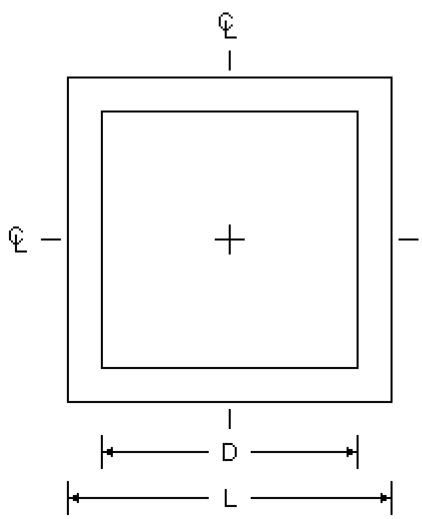
	Residue	*Scratch Size*	*Total Scratch Defects*	*Sleek Size*	*Total Sleek Defects (per cm^2)*	*Opaque Spot Size*	*Total Opaque Spot Defects (per cm^2)*
Critical side	None	> 1.0 µm	0	> 1.0 µm	0	> 1.0 µm	0
		≤ 1.0 µm	no limit	≤ 1.0 µm	0.0465	≤ 1.0 µm	0.0155
Non-critical side		> 1.0 µm	0			> 3.0 µm	0.0465
		≤ 1.0 µm	no limit			≤ 3.0 µm	no limit

Defects Outside the Visual Quality Area

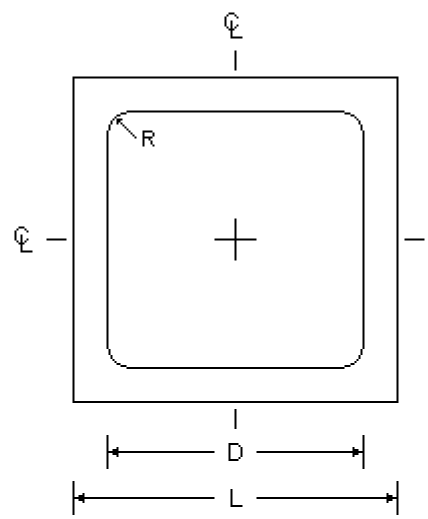
		Defect Limit	*Total Number*	*Notes*
Edge Chips	Radial Depth	≥ 0.76 mm	0	3
	Peripheral Chord	≥ 0.76 mm	0	3
Other		Shall be negotiated between user and supplier.	Shall be negotiated between user and supplier.	

NOTES:

1. The size of internal defects is defined as 1/2 (long axis + short axis).
2. This table is based on the assumption that defects < 1 µm will fall outside the focal depth of the lens systems and should not print.
3. None of any size permitted that break the surface.



Square Corners



Relaxed Corners

D ≥ 213 mm

R ≤ 6.5 mm (radius of curvature)

Figure 4a
Square Flatness Quality Area

Figure 4b
Relaxed Square Flatness Quality Area

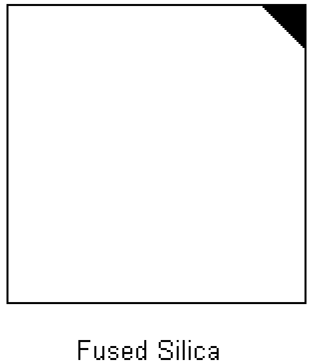
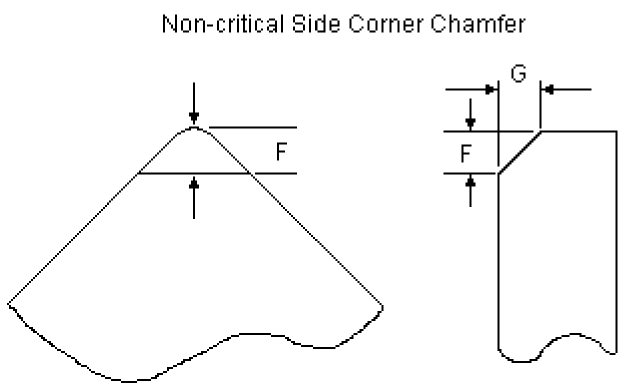


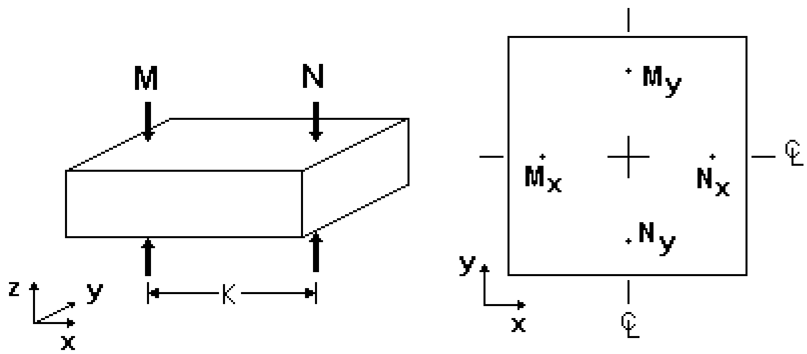
Figure 5
Substrate Identification by Corner Chamfer
(Non-critical Side)



F = 1.5–2.0 mm

G = 0.6–1.0 mm

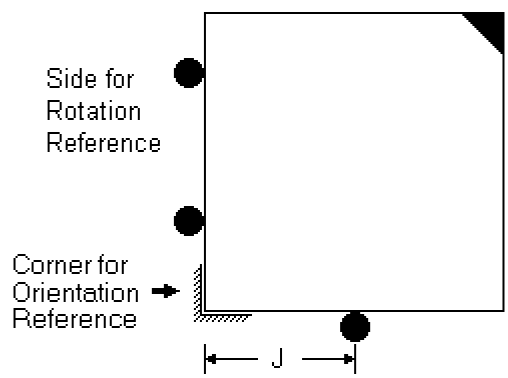
Figure 6
Dimension of Corner Chamfer
(Edge Chamfer Not Indicated)



Parallelism = | $N_i - M_i$ | for i = x, y

K = 0.7 × edge length   N, M within flatness quality area

Figure 7
Measurements for Calculation of Parallelism with Approximate Positions



J = 115 ± 15 mm

Figure 8
Corner Recommended for Orientation, Diagonally Opposite of Chamfer (Non-critical Side Shown)

APPENDIX 1
PHOTOMASK FUSED SILICA PROPERTIES

NOTE: The material in this appendix is an official part of SEMI P34 and was approved by full letter ballot procedures on September 3, 1999 by the North American Regional Standards Committee.

Table A1-1 Fused Silica Properties

Property	
ULTRA LOW THERMAL EXPANSION (ULTE)	
Modulus of Elasticity	65.7-72.6 GPa
Poisson's Ratio	0.16-0.19
Specific Gravity	2.18-2.20 g/cm^3
Index of Refraction @ λ = 436 nm	1.4667
Index of Refraction @ λ = 365 nm	1.4746
Index of Refraction @ λ = 248 nm	1.5086
Index of Refraction @ λ = 193 nm	1.5608
Thermal Optical Coefficient @ λ = 436 nm	10.6 ppm/°C @ 22°C
Thermal Optical Coefficient @ λ = 365 nm	11.2 ppm/°C @ 22°C
Thermal Optical Coefficient @ λ = 248 nm	14.2 ppm/°C @ 22°C
Thermal Optical Coefficient @ λ = 193 nm	20.6 ppm/°C @ 22°C

NOTE 1: Thermal Optical Coefficient is the same as Temperature Coefficient of Index of Refraction.

SEMI P35-0704
TERMINOLOGY FOR MICROLITHOGRAPHY METROLOGY

This standard was technically approved by the Global Micropatterning Committee and is the direct responsibility of the North American Microlithography Committee. Current edition approved by the North American Regional Standards Committee on April 22, 2004. Initially available at www.semi.org June 2004; to be published July 2004 Originally published February 2000; previously published June 2000.

NOTICE: This document was entirely rewritten in 2004.

1 Purpose

1.1 Clear and commonly accepted definitions are needed for efficient communication and to prevent misunderstanding between buyers and vendors of metrology equipment. The purpose of this document is to provide a consistent terminology for the understanding and discussion of metrology issues important to microlithography.

2 Scope

2.1 The scope of this document is limited to the definitions of metrology terms used in microlithography. Every attempt is made to keep these definitions consistent with relevant international standards and common usage. This document is not intended to describe a measurement procedure, but rather an approach to defining a measurand in a useful and unambiguous way.

2.2 This document does not attempt to discuss statistical considerations, which are covered in SEMI E89 and elsewhere.

2.3 This document is expected to grow as more terms are added in future revisions.

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 Referenced Documents

3.1 *SEMI Standards*

SEMI P28 — Specification for Overlay-Metrology Test Patterns for Integrated-Circuit Manufacture

SEMI E89 — Guide for Measurement System Capability Analysis

3.2 *ANSI/NCSL Standards*[1]

Z540-2-1997 — US Guide to the expression of Uncertainty in Measurement, ANSI/NCSL standard (the US version of Guide to the expression of uncertainty in measurement, ISO, 1995, 110 p., ISBN 92-67-10188-9)

4 Some Metrology Issues

4.1 *Measuring Linewidth* — Any measurement of length or position contains an unknown error whose influence on subsequent application of the measurement data is best described by the measurement uncertainty [reference Section 3.2]. The problem of measuring feature sizes on photomasks or integrated circuit wafers (*e.g.*, linewidth) is complicated by the fact that a feature is a 3-dimensional object whose exact shape is generally not known. The metrology problem is further complicated when the object is microscopic and only its magnified image can be measured.

4.2 Feature measurement data are usually reduced to one or a few parameters because the additional data needed to describe the complex actual feature shape are seldom available and may be immaterial to the subsequent application of the measurement data.

4.3 The first rule of metrology is to define exactly what is to be measured. The approach used here, in light of the previous paragraphs, is to construct a simple idealized geometric shape, or *feature model* (Figure 1), which approximates a real object of complex shape. This model, whose size and center position are well defined, is substituted for the real feature in application of the measurement data. A model can be refined to better approximate the actual feature shape by adding degrees of freedom, requiring more parameters to describe the measurement. For example, a line might be represented by a rectangular cross section (with width and height) or better represented by a trapezoidal cross section (with base width, height, and two wall angles). The differences between the model and the actual shape of the feature contribute to the overall measurement uncertainty of the size or position of that feature.

1 American National Standards Institute, Headquarters: 1819 L Street, NW, Washington, DC 20036, USA. Telephone: 202.293.8020; Fax: 202.293.9287, New York Office: 11 West 42nd Street, New York, NY 10036, USA. Telephone: 212.642.4900; Fax: 212.398.0023, Website: www.ansi.org

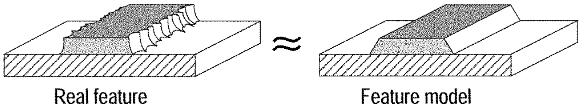


Figure 1
The Feature Model Approximates the Size and Shape of the Feature

4.3.1 The feature model may be further abstracted to suit the purpose of the measurement by defining bounding boxes to represent the inner and outer limits on the space occupied by the feature. In the nonexistent case of an ideal feature, the feature, the feature model, and the bounding boxes would all coincide.

4.4 The aim of the approach embodied here is to facilitate interpretation of metrology results for a feature (and the feature's subsequent performance — see section A1) in the most realistic terms, and in light of any possible additional knowledge about that feature.

4.5 There are many possible reasons for measuring a feature's size or placement. Consequently the following definitions may include options or alternatives, to be selected by the user to best fit the purpose of the measurement.

5 Definitions

5.1 Defined terms appearing in the definitions of other terms are *italicized*. Where more than one definition is given for a term, the one most appropriate to the application is to be chosen. Some of these definitions describe certain usage options as "the default." That option is assumed to apply unless otherwise specified.

5.1.1 *bounding box* — a user-specified geometric shape with a planar face lying in the *reference plane* and with user-specified orientation in the *reference plane*, intended to represent limits or bounds on the position and size of the *feature*. See Figure 2 for an example. The bounding box need not be rectangular.

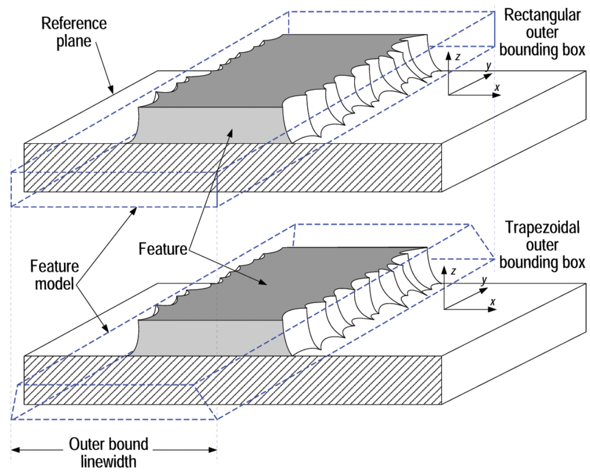


Figure 2
Two Possible *Bounding Box* Choices for a Line *Feature*

NOTE 1: The term "bounding box" is used here for convenience, but the word "box" may not always be considered appropriate. Terms like "bounding figure" or "bounding surface" may be used instead, if desired. A *bounding box* may coincide with a *feature model.*

5.1.1.1 *outer bounding box* — smallest bounding box encompassing the feature.

5.1.1.2 *best fit bounding box* — *bounding box* best fitting the *feature*, with user-defined criteria of best fit.

5.1.2 *calibration* — set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or reference material, and the corresponding values realized by standards [reference Section 6.1].

5.1.3 *centerline* — (*a*) The locus of the *centroids* of successive line segments, in the limit as the segment length vanishes. (*b*) a line or surface midway between opposing *feature edges*.

5.1.4 *centroid* — The geometrical center of an object. The coordinates of the centroid of an object are $C_u = \iiint u\, dV \big/ \iiint dV$, where the integral is over the volume V of the object and u can be x, y, or z.

5.1.4.1 *centroid measurement uncertainty* — parameter that characterizes the dispersion of the values that could reasonably be attributed to the position of the *centroid* or the *placement* of an object in the reference plane coordinate system (see *measurement uncertainty*).

NOTE 2: The edges of the feature form part of the boundary of the integral defining the centroid; edge position uncertainty leads to integral boundary uncertainty and thus to centroid uncertainty. The *centroid measurement uncertainty* of a *feature* described by *inner* and *outer linewidth bounding* *boxes* is the combined uncertainties of the measured centroid position of the *mean linewidth bounding box* and of the positions of the line's edges between these *linewidth bounding box*es, taking into account possible opposite edge correlations. (These correlations can result in *feature placement* or *pitch uncertainty* that is less than the corresponding *linewidth uncertainty* because many features have some degree of mirror image symmetry between opposite edges.)

5.1.5 *feature (lithographic)* — region within a single continuous boundary, and attached to a *reference plane*, that has a defining physical property (parameter) that is distinct from the region outside the boundary. [Adapted from SEMI P28.]

NOTE 3: In general a feature is a 3-dimensional object, but some features can be adequately modeled as 2-dimensional objects.

5.1.5.1 *feature boundary* — surface defined by a user-specified property, such as a threshold, maximum gradient, etc., of the parameter distinguishing that *feature* from its surroundings. Open features, such as vias or spaces between lines, may be bounded in height by an additional plane parallel to the *reference plane*.

5.1.5.2 *feature edge* — that part of the *feature boundary* used to define the feature size or linewidth. The criteria used must be specified.

5.1.5.3 *feature height* — dimension of the specified *bounding box* perpendicular to the *reference plane*. May also refer to feature depth below the substrate, as in contact holes. Although *feature height* is sometimes referred to as *feature* thickness, this usage is not recommended because "thickness" sometimes alludes to "width."

5.1.5.4 *feature model* — a solid geometrical shape, with well-defined parameters, *e.g.*, length, width, height, centroid, etc. (Figure 1), meant to approximate the actual shape of a *feature boundary*.

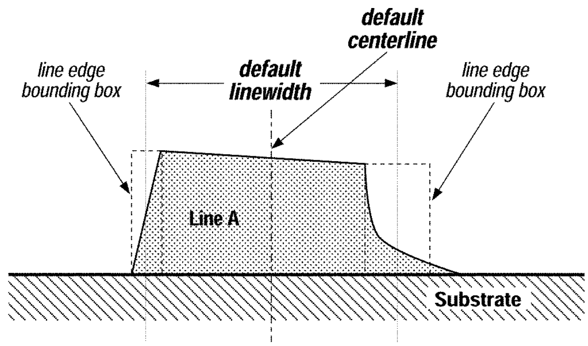


Figure 3

Examples of *line edge bounding boxes* and the resulting default *centerline* and *linewidth*. Since the top of Line A is not parallel to the substrate, the generalized *linewidth bounding box* definition (*b*) is used. Line edge asperities at the substrate were judged not to be relevant to the function of this feature and were excluded from the *outer line edge bounding boxes*.

NOTE 4: A rectangular solid is often used to represent a line; a different extruded polygon may better represent the shape of the line. A hemisphere may best represent a solder bump.

The more complex the model, more degrees of freedom are available to better fit the model to the feature, and more dimensional parameters are needed to describe the feature's size. The *feature model* is a simplified geometric approximation of the actual *feature*, the *bounding boxes* represent limits on the space occupied by the *feature model*.

The size or position of a *feature* can be described by the size or position of the *feature model* with appropriate uncertainties, or by the sizes or positions of the *bounding boxes*. This choice is left to the user, and in many of these definitions the terms can be interchanged. *Bounding box*es are useful because they make the measurement uncertainty explicit, and because an application of the measurement data may require only inner or outer bounds.

5.1.5.5 *feature placement* — (*a*) coordinates describing the position of the *centroid* of the specified *bounding box* projected onto the *reference plane* relative to a coordinate system in that plane. (*b*) coordinates describing positions of the *feature's edges*.

5.1.5.6 *feature size* — dimensions of the specified feature model or bounding box.

5.1.5.7 *nominal feature size* — the intended or specified dimension of a *feature*.

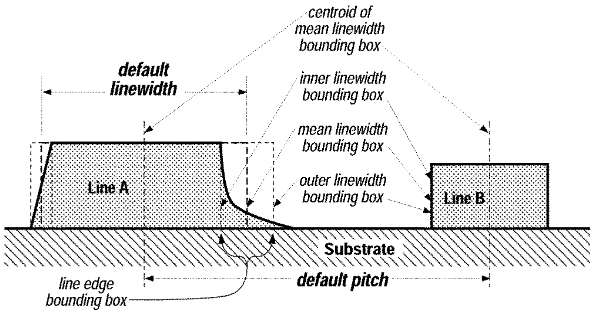


Figure 4
Examples of *inner*, *outer*, and *mean linewidth bounding box*es, and the corresponding default *linewidth* and *pitch*. Line edge asperities at the substrate were judged not to be relevant to the function of this feature and were excluded from the *outer linewidth bounding box*.

5.1.6 *line edge bounding box* — (*a*) the region, for each edge, between specified *inner* and *outer linewidth bounding box*es encompassing the edge of the feature. (*b*) user-specified *bounding box* intended to encompass the *feature* edge. See Figure 3.

NOTE 5: The underlying concept here is the same as for a feature *bounding box*; only the perspective is different. If a feature is described using a pair of *inner* and *outer linewidth bounding box*es, then the widths of the corresponding *line edge bounding box*es illustrate the component of the *linewidth measurement uncertainty* arising from the definition of the feature's edge, and "the *linewidth bounding box*" describing the feature is taken to mean the *mean linewidth bounding box* by default.

5.1.7 *line edge position* — expectation value of the position of the edge within the *line edge bounding box* used to define the linewidth. If the probability distribution of the edge within the *line edge bounding box* is symmetric, this will be at the center of the *line edge bounding box*.

5.1.8 *linewidth bounding box* — (*a*) if the feature height is unambiguous, a specified rectangular *bounding box* constrained to the line *height* and bounding a specified line length segment; (*b*) appropriate parameters describing a different *bounding box*. Additional constraints, such as orientation parallel to a defined length direction, may be placed on the *bounding box*. See Figure 4.

5.1.8.1 *linewidth* — (*a*) width of a specified *linewidth bounding box*. See Figures 3 and 4. (*b*) distance between the two opposing *line edge positions* of a *feature*. See Figures 5, 6, and 7.

NOTE 6: Linewidth is sometimes referred to as critical dimension or CD.

5.1.8.2 *best fit linewidth* — width of constrained best fit linewidth bounding box.

5.1.8.3 *mean linewidth bounding box* — a bounding box between *inner* and *outer linewidth bounding box*es, whose right and left edge positions at any height above the substrate are the means of the edge positions of the *inner* and *outer linewidth bounding box*es at that height. See Figues 4 and 5.

5.1.8.4 *inner bound linewidth* — width of largest *linewidth bounding box* entirely inside the line segment. Its width is the smallest linewidth that is ordinarily associated with the feature.

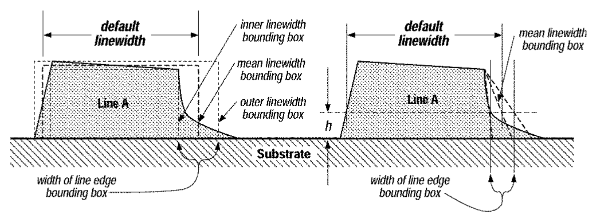


Figure 5
Example of using rectangular and trapezoidal *linewidth bounding boxes* to describe Line A in Figure 4. The trapezoidal case requires an additional specification for the linewidth, such as at the distance *h* above the *reference plane*, but it probably better represents the real *feature* and the width of its *line edge bounding box* is smaller.

5.1.8.5 *outer bound linewidth* — width of smallest *linewidth bounding box* encompassing the line segment. Line edge asperities may reasonably be excluded. Its width is the largest linewidth that is ordinarily associated with the feature.

5.1.8.6 *section linewidth* — width of the planar rectangle defining the intersection of a *linewidth bounding box* and a plane parallel to and a specified distance from the *reference plane*.

5.1.8.7 *linewidth measurement uncertainty* — parameter that characterizes the dispersion of the values that could reasonably be attributed to the *linewidth* of an object (see *measurement uncertainty*).

5.1.8.7.1 One option here is to choose *inner* and *outer linewidth bounding boxes* so that there is a 95% chance that the line's true edges lie between them. Then the linewidth measurement uncertainty will be the combined uncertainties of the measured width of the *mean linewidth bounding box* and of the positions of the line's edges between these *linewidth bounding box*es, taking into account possible right-left edge correlations. This option is the default.

5.1.9 *measurand* — particular quantity subject to measurement [reference Section 6.1].

5.1.10 *measurement error* — result of a measurement minus a true value of the *measurand* [reference Section 6.1].

NOTE 7: The *measurement error* is unknown because the *true value* is unknown. Otherwise there would be no need to measure.

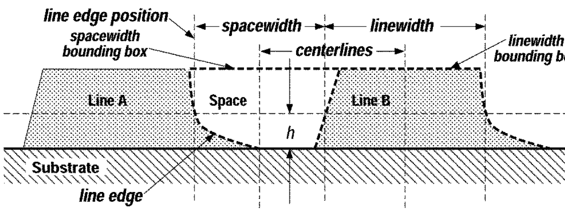


Figure 6
Example of *linewidth* (and spacewidth) after the definition in SEMI P19. Since the intention in this case is to conform to the irregular shape of the edge, the generalized *linewidth bounding box* definition (*b*) is used. The *inner, outer,* and *mean linewidth bounding box*es coincide, and the *linewidth* is defined to be the width of the *mean linewidth bounding box* at a specified distance *h* above the substrate. Alternatively, the *line edge bounding box* approach can be used here, giving the same results.

5.1.11 *measurement uncertainty* — parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the *measurand* [reference Section 6.1]. Numerically, it is the square root of the sum of the variances of the probability distributions of all the possible errors (both random and systematic), multiplied by a stated factor chosen to represent the desired confidence interval (usually 2 for 95% or 3 for 99% for normally distributed errors), as described in *ANSI/NCSL Z540- 2-1997* [reference Section 3.2].

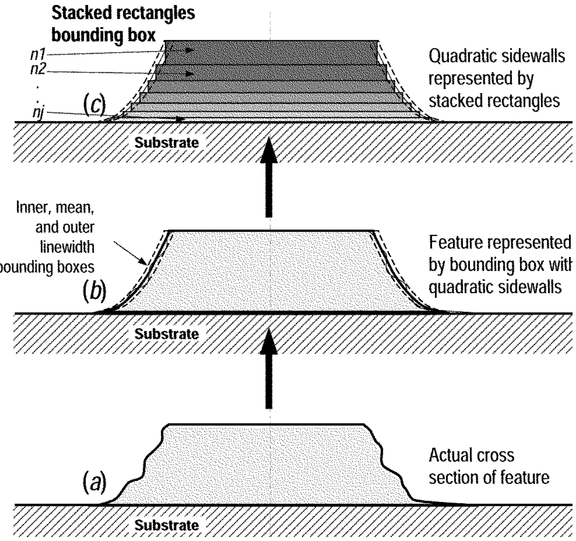


Figure 7
Example of stacked-rectangle linewidth *feature model* for a chrome photomask line, consistent with common imaging models. For an optical metrology system the stacked rectangles may have different complex indices of refraction. For an SEM they may have different atomic numbers. The edge bounding box will have some additional width to account for line edge roughness.

5.1.12 *overlay* — vector distance between the *feature placements* of two corresponding *features* created at different processing levels, in the *reference plane* coordinate system.

5.1.13 *pattern* — set of one or more *features*.

5.1.13.1 *pattern placement* — coordinates describing the centroid of the set of *features* comprising the *pattern* in the *reference plane* relative to a coordinate system in that plane.

5.1.14 *pitch*

5.1.14.1 *pitch in general* — the *centroid-to-centroid* distance between the feature models describing two features, *i.e.*, the distance between the two *feature placements*.

5.1.14.2 *pitch between parallel lines* — (*a*) the *centroid*-to-*centroid* distance between the *linewidth bounding boxes* describing two parallel lines, over a specified length segment common to both, and perpendicular to their edges. (*b*) right edge to right-edge or left-edge to left-edge distance between corresponding *line edge bounding boxes*, or the *centerline*-to-*centerline* (preferred) distance, can also be used where appropriate, if so specified.

5.1.14.3 *pitch measurement uncertainty (between parallel lines)* — parameter that characterizes the dispersion of the values that could reasonably be attributed to the *pitch* between two parallel lines (see *measurement uncertainty*).

5.1.14.3.1 One option here is to choose *inner* and *outer linewidth bounding boxes* so that there is a 95% chance that the features' true edges lie between their respective *inner* and *outer linewidth bounding boxes*. Then the pitch measurement uncertainty will be the combined uncertainties of the measured distance between the centroids of the feature *mean linewidth bounding boxes* and the uncertainties of the differences of the positions of the left edges and of the right edges within their respective *line edge bounding box*es. This option is the default.

5.1.15 *precision*

5.1.15.1 static precision — *repeatability*

5.1.15.2 dynamic precision — *reproducibility*

5.1.16 *reference plane* — in the context of this document, a user-defined plane approximating the surface of a substrate and containing a coordinate system.

NOTE 8: All dimensional measurement data are referred to the reference plane coordinate system.

5.1.17 *repeatability (of results of measurements)* — closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement [reference Section 6.1].

5.1.18 *reproducibility (of results of measurements)* — closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement. [reference Section 6.1]

5.1.19 *resolution*

5.1.19.1 *measurement resolution* — smallest difference in the measurand that can be meaningfully distinguished (usually limited by noise or quantization). Adapted from [reference Section 6.1].

5.1.19.2 *quantization resolution* — smallest possible change in indicated value of a measurement device (*e.g.*, the least significant bit of a digital instrument)

5.1.19.3 *imaging resolution* — qualitatively, the smallest distance between two object points that allows them to be distinguished in an image (limited, for example, by λ/NA in an optical microscope, beam shape in a scanning electron microscope, or tip shape in a scanning probe microscope).

5.1.20 *self calibration (coordinate)* — set of operations that establish, under specified conditions, the relationship between relative values of quantities indicated by a measuring instrument or measuring system, using self-consistency techniques as a function of the geometry's group of motions, or one-to-one mappings of a feature onto itself, that preserve the geometrical properties of features in that geometry.

NOTE 9: Self calibration is a mapping of the coordinate system of a measuring instrument or calibration artifact to an ideal coordinate system using self-consistency techniques (redundant measurements of the same object in different orientations and different positions relative to the instrument coordinate system, including reversal techniques)[reference Sections 6.2, 6.3], requiring only a stable artifact and instrument. This procedure can map errors in scale linearity and orthogonality. A length standard is still required for calibrating the length scale of the instrument or artifact in order to measure *feature* size or *placement*.

5.1.21 *traceability* — property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated *uncertainties* [reference Section 6.1].

5.1.22 *true value* — value consistent with the definition of a particular quantity [reference Section 6.1].

6 Related Documents

6.1 *ISO Document*[2]

International vocabulary of basic and general terms in metrology, ISO, 1993, 60 p., ISBN 92-67-01075-1.

6.2 Chris Evans and Robert Hocken, "Self-Calibration: Reversal, Redundancy, Error Separation, and 'Absolute Testing'", *Annals of the CIRP*, vol. 45/2/1996.

6.3 Raugh, Michael R., "Two-dimensional stage self-calibration: Role of symmetry and invariant sets of points," *Journal of Vacuum Science Technology B* 15(6), (Nov/Dec 1997)

6.4 J. Potzick, "The problem with submicrometer linewidth standards, and a proposed solution," *Proceedings of SPIE 26th International Symposium on Microlithography*, vol. 4344-20 (2001).

2 International Organization for Standardization, ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30, Website: www.iso.ch

APPENDIX 1
SOME GENERAL NOTES ON LINEWIDTH METROLOGY

NOTICE: The material in this appendix is an official part of SEMI P35 and was approved by full letter ballot procedures on April 22, 2004.

A1-1 A metrology process can be represented by the operation

process model $\oplus$ feature model $\rightarrow$ output model.

A1-1.1 Here the *process model* represents the metrology process. These models are abstractions of the complex realities they represent, a simplification usually required in order to make the modeling tractable and the measurement practical. The output model of this metrology process is the *feature model* (Section 5.5.4) with the metrology results attached, including the associated measurement uncertainty. Measurement uncertainty arises from inevitable differences between both the process and feature models and their respective realities. The *measurement error* (Section 5.10) is the difference between the measurement result and the unknown true value, and the *measurement uncertainty* (Section 5.11) is expressed as a confidence interval representing the variance of the measurement errors. The measurement uncertainty includes components from model infidelity in addition to scale calibration, repeatability, environmental factors, etc. A confidence interval of 95% (or 2σ for normally distributed errors) is used in the examples, in accordance with international custom. That is, the likelihood that the true value of the *measurand* (Section 5.9) lies within the range (measurement result ± measurement uncertainty) is 95%.

A1-1.2 A manufacturing process can be represented in a similar manner. In particular, if that process is wafer exposure, then the same feature model for the photomask features can be used for both the mask metrology and exposure processes:

exposure model $\oplus$ photomask feature model
$\rightarrow$ wafer feature model.

A1-1.3 Errors and uncertainties in the photomask feature model propagate through the exposure model to become manufacturing errors—differences between a wafer feature's size or placement and its target value—and manufacturing uncertainties. In analogy with measurement uncertainty, tolerances on wafer features encompass mask measurement uncertainties, including differences between the models and their respective realities, as well as the effects of tolerances for exposure parameters and photomask features. The mask error enhancement factor (MEEF) and other optical proximity effects are good examples of the wafer exposure model operating on photomask feature size and placement variations to produce nonlinear variations in wafer feature size and placement under some conditions.

A1-2 Real microlithographic *features* (Section 5.5) often have irregular shapes and rough edges; it is neither possible nor necessary to know the exact shape of a feature to be measured. The purpose of the feature *bounding boxes* (Section 5.1) defined here is to account for such edge details as top-to-bottom runout and along-the-line irregularities that are often observed. In such cases the *bounding boxes* help define the *measurand* (Section 5.9). To the extent that such details are not known, not relevant, or too complex to be considered, the bounding boxes represent the feature with a simpler geometry and mix these disregarded details into the measurement uncertainty. For the ideal line with known edge geometry and no edge irregularities, the *inner*, *mean*, and *outer linewidth bounding boxes* (Sections 5.8.3–5.8.5) can be identical and the *line edge bounding box* (Section 5.6) can have zero width. The bounding box approach simplifies metrology issues for the quasi-thin-film features often encountered in microlithography. Extension of the concept to structures with nonplanar top surfaces or extending below the *reference plane* (Section 5.14) becomes more complicated.

A1-3 A great deal of flexibility has been incorporated into some of these definitions. This is because the definition of a *measurand* (Section 5.9) can depend on the purpose for which a measurement is made, and the *measurement error* depends on the definition of the measurand. It is up to the user to specify or define the measurand in a way that suits his present purpose and in an unambiguous way. Otherwise interpretation of the measurement result may be in error and the measurement uncertainty may be meaningless or impossible to ascertain. In other words, the "true values" of feature edge positions, *centerline* (Section 5.3), *centroid* (Section 5.4), and *linewidth* (Section 5.8.1), can depend on the purpose to which the corresponding measurement results are put. The definitions given here allow for some flexibility so they can be made consistent with the ultimate purpose of the measurements.

A1-4 The inner and outer linewidth bounding boxes need not have the same shape, but their widths must be unambiguously defined. A rectangular shape for both will result in a centerline, centroid, and linewidth independent of height above the substrate, but may also result in a larger interval between the inner and outer linewidth bounding boxes. The figure 95% represents 2 standard deviations of the Gaussian probability distribution of possible values for the linewidth. The multiplier value of 2 (the “coverage factor”) is also often used even if the distribution is not Gaussian [reference Section 3.2], but then the interpretation of 95% confidence no longer applies. Three standard deviations or some other multiple may be used if so specified.

A1-5 The probability distribution and expectation value for the position of an edge within the line edge bounding box are determined as described in *ANSI Z540-2* [reference Section 3.2]. Default values for these assume the edge is equally likely to be anywhere inside the line edge bounding box. In that case the expectation value of the line edge location is the center of the line edge bounding box (*i.e.*, the linewidth is the width of the *mean linewidth bounding box* [Section 5.8.3]), and the edge position uncertainty (at the 95% confidence level) is 0.577 × width of line edge bounding box. The corresponding *linewidth measurement uncertainty* (Section 5.8.7) component is 0.816 × width of line edge bounding box if the right and left edge location uncertainties are uncorrelated, and 1.154 × width of line edge bounding box if they are mirror-image correlated (as is often approximately the case). See reference Section 3.2, page 13.

A1-6 In most cases, the width or centroid or edge positions of the bounding box is measured from its image in a metrology tool; inferring the width of the bounding box from this image usually requires modeling of the image-forming process. The bounding box should be constructed so that its image in the metrology tool can be modeled with the modeling tools available. If the image is not modeled accurately, additional measurement uncertainty will accrue [reference Section 6.4].

SEMI P36-0600
GUIDELINE OF MAGNIFICATION REFERENCE FOR CRITICAL DIMENSION MEASUREMENT SCANNING ELECTRON MICROSCOPES (CD-SEMS)

This guideline was technically approved by the Global Metrology Committee and is the direct responsibility of the Japanese Metrology Committee. Current edition approved by the Japanese Regional Standards Committee on March 1, 2000. Initially available at www.semi.org May 2000; to be published June 2000.

1 Purpose

1.1 The purpose of this guideline is (1) to define common and important specifications of magnification references which are used for calibrating magnifications of critical dimension measurement scanning electron microscopes (CD-SEMs), and as the result (2) to provide magnification references which are easy for anyone to use.

2 Scope

2.1 It is preferable that design, manufacture and purchase specifications for CD-SEM magnification references conform to this guideline.

2.2 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 limitations prior to use.

3 Referenced Standards

3.1 None.

4 Terminology

4.1 *CD-SEM magnification reference* — a CD-SEM magnification reference is defined as a standard for calibrating magnifications of a said CD-SEM through mounting the standard on the specimen stage, measuring the dimensions of reference patterns formed on the standard, determining the difference between the measurement value and the true or reference value of the reference patterns, and adjusting the CD-SEM parameters to bring the difference zero.

4.1.1 There are two types of CD-SEM magnification references: one is a wafer on which reference patterns are formed; another is a chip on which reference patterns are formed. Hereinafter, the former will be referred to as "wafer-type magnification reference," and the latter will be referred to as "chip-type magnification reference."

4.2 *edge roughness* — Edge roughness refers to edge variations seen in the SEM images, and is defined as the distance, within a field of view, between the peak line and the valley line, where the peak line means the line which runs through the highest peak and is parallel to the pattern-edge mean line, the valley line means the line which runs through the lowest valley and is parallel to the pattern-edge mean line, and the pattern-edge mean line conforms to the expected pattern-edge line. Here, a peak is the tip of a convex section, and a valley is the deepest part of a concave section (See Figure 1).

5 Ordering Information

5.1 Specify whether a said CD-SEM magnification reference is a wafer-type magnification reference or a chip-type magnification reference.

6 Requirements

6.1 *CD-SEM Magnification References and Their Structure*

6.1.1 CD-SEM Magnification References are either wafer type or chip type. Chip types are composed of a chip (or chips) and a stub to hold the chip (or chips). Wafer type include a 'drop-in' wafer which is a wafer with a thinned section where a die with the reference calibration pattern can be dropped in.

6.2 *Shape, Size and Mounting Method of CD-SEM Magnification References*

6.2.1 Shape and size of wafer-type magnification references, and method of mounting them on the specimen stages in CD-SEMs must follow the shape, size and mounting method of product wafers.

6.2.2 Shape and size of chip-type magnification references, and method of mounting them on the specimen stages of CD-SEMs are defined as follows:

6.2.2.1 Size and shape of chip-type magnification references: See Figure 2.

6.2.2.2 Mounting method of chip-type magnification references:

6.2.2.2.1 A magnification reference should be mounted on a specimen stage as markers made on the stub fit in markers made on the specimen stage, and be fixed by using a screw. The markers made on the stub should show the direction of reference patterns at an accuracy of within ± 1°.

6.2.2.2.2 The markers made on the specimen stage should show the X- and Y-direction of specimen-stage movement, and the angle between the two markers should be 90° ± 0.1° (See Figures 2 and 3).

6.2.2.3 Chip surface height for chip-type magnification references:

6.2.2.3.1 The height of chip surface (or reference pattern surface) from the specimen stage surface should be 1.7 ± 0.05 mm as the magnification reference is mounted on the specimen stage.

6.3 *Materials for Magnification References* — Materials for magnification references must be non-magnetic and conductive.

6.3.1 Wafers for wafer-type magnification references and chips for chip-type magnification references are preferable to be silicon.

6.3.2 Materials of the stub for chip-type magnification references are preferable to be aluminum, copper, or carbon.

6.4 *Properties of Magnification Reference Pattern*

6.4.1 Reference patterns do not change or degrade in use.

6.4.2 The block area of reference patterns (or every block area, in the case where there are some reference pattern blocks) must be larger than 100 µm × 100 µm, and the block should be placed so that it is easily recognizable.

6.4.3 The pattern-edge roughness must be within the calibration uncertainty described in Section 6.5.5.

6.5 *Report*

6.5.1 Suppliers of CD-SEM magnification references must report the following to the purchaser.

6.5.2 Wafer material for wafer-type magnification references, or chip and stub materials for chip-type magnification references: e.g., silicon chip, aluminum stub, etc.

6.5.3 Type of reference patterns: e.g., dense lines, etc.

6.5.4 Figures and/or pictures of the reference patterns with pattern dimensions which show top and/or cross sectional view.

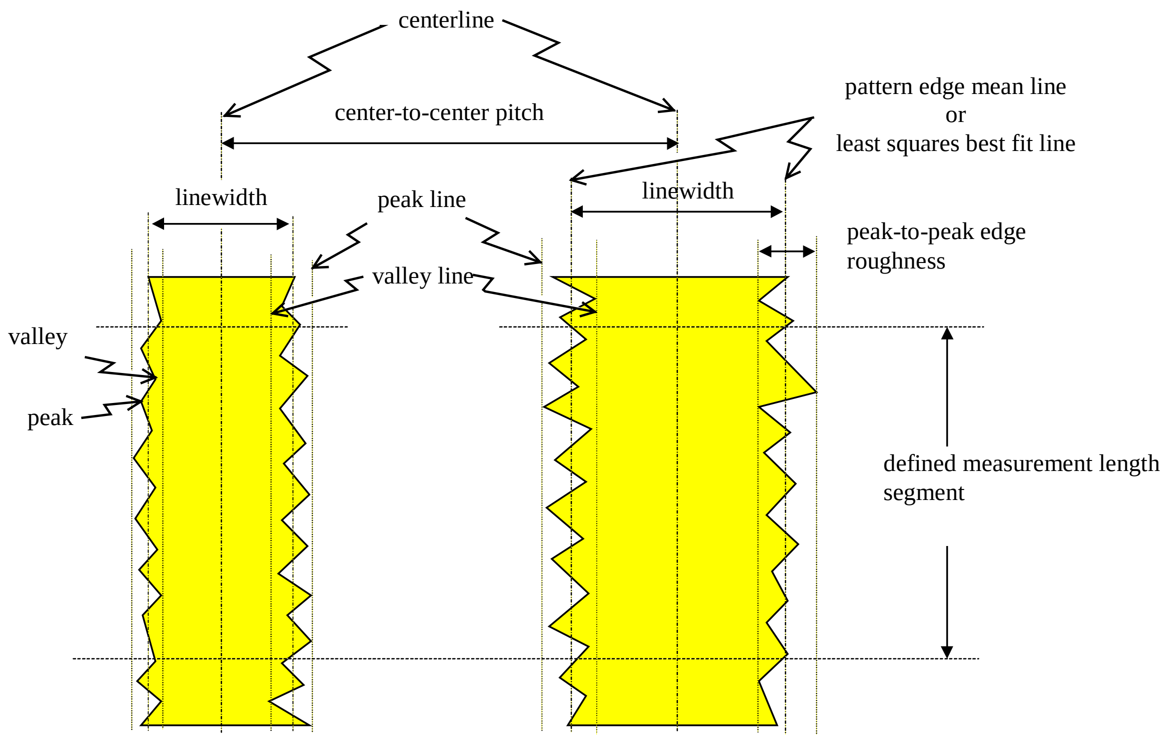
6.5.5 Calibration uncertainty of reference patterns: e.g., line pitch 180 ± 1 nm at 95% confidence level, etc.

6.5.6 Traceability and its certification organization, and measurement method used for deciding the calibration uncertainty of reference patterns: e.g., the uncertainty was decided in terms of mean value and variation obtained by means of a precise diffraction angle measurement using a He-Cd laser beam of a 2 mm spot diameter, and was certified by NMI (National Metrology Institute), etc.

NOTE 1: Traceability is the property of the calibration of the reference patterns whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparison of all having stated uncertainties. Refer to the international vocabulary of basic and general items in metrology, ISO, 1993, 60 p., ISEN 92-67 01075-1.

6.5.7 Applicable magnification range: e.g., 50k×–200k×, etc.

6.5.8 Notices of caution for cleaning and maintenance: e.g., whether cleaning is possible or not, and if possible, the process of cleaning, procedures for storage, etc.



NOTE 1: The figure ignores that fact that the SEM image is gray-scale and not black and white. Use the same intensity threshold setting for measuring pitch as for line width The center-to-center pitch averaged over the measurement length segment is to be certified and used for SEM magnification calibration

Figure 1
Definition of Edge Roughness

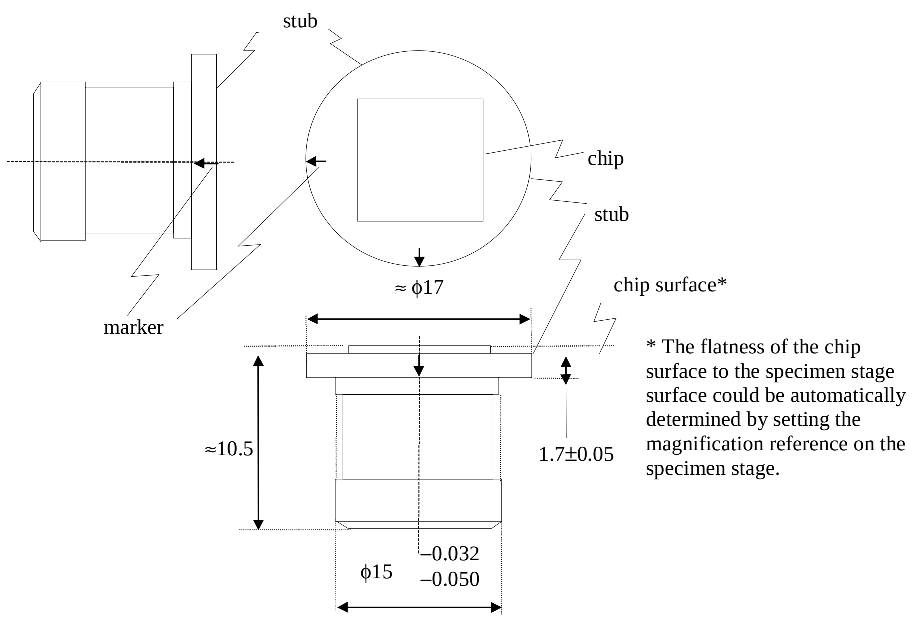


Figure 2
Shape and size of chip-type magnification reference: unit mm

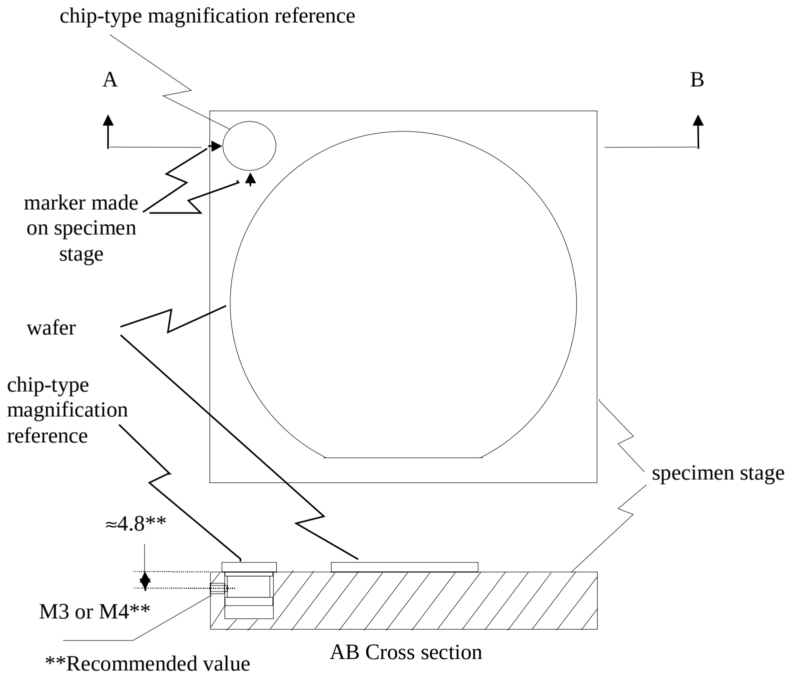


Figure 3
Chip-type magnification reference mounted on specimen stage: unit mm

APPENDIX 1
NOTES

NOTE: The material in this appendix is an official part of SEMI P36 and was approved by full letter ballot procedures on March 1, 2000 by the Japanese Regional Standards Committee.

A1-1 Reference patterns for adjusting CD-SEM magnification using their pitches and reference patterns for optimizing pattern-edge determination parameters using their widths

A1-2 The following procedures are generally applied to critical dimension measurements using CD-SEMs: an electron beam linearly scans across the measured pattern, secondary and/or reflected electrons emitted from every electron-beam incident point are collected to form its intensity profile, pattern edges are determined on the intensity profile using a designated pattern-edge determination method, and the measurement value of the width of the pattern is obtained from the distance between the two pattern edges.

A1-3 Therefore, measurement errors of CD-SEM measurements can be partitioned into two components: one is magnification error and another is pattern-edge determination error. Magnification error is caused by variation of the equipment conditions such as the sampling pitch and incident angle of electron beam. Pattern-edge determination error is affected by the manner of measurement such as pattern-edge determination algorithm used and pattern-edge determination parameters used, and the properties of the specimen such as pattern topography (e.g., pattern-edge slope) and pattern material.

A1-4 Magnification error, including inter-machine magnification error, can be detected and corrected through measuring pitches of reference patterns, and pattern-edge determination error could be detected and corrected through measuring widths of the reference patterns practical reference patterns are available for measuring their widths. However, it seems extremely difficult to produce practical reference patterns for measuring their widths; the source of the problem lies in the physics of electron beam image formation and not because the reference patterns are somehow inadequate because of the following reasons: (a) reference pattern can not be determined uniquely, since intensity profiles obtained are different from each other dependent on pattern topography and pattern materials even if the width of every reference pattern is the same, (b) it is technologically difficult to solve the problem of width change due to the contamination which changes the measurement value of pattern width dependent on measurement time.

SEMI P37-1102
SPECIFICATION FOR EXTREME ULTRAVIOLET LITHOGRAPHY MASK SUBSTRATES

This specification was technically approved by the Global Micropatterning Committee and is the direct responsibility of the North American Micropatterning Committee. Current edition approved by the North American Regional Standards Committee on August 29, 2002. Initially available at www.semi.org September 2002; to be published November 2002. Originally published November 2001.

1 Purpose

1.1 This specification covers the general requirements of the substrate for Extreme Ultraviolet Lithography (EUVL) masks.

2 Scope

2.1 This standard details the physical characteristics required for EUVL mask substrates. The specific material is not specified to allow for innovation in materials and substrates.

2.2 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 limitations prior to use.

3 Referenced Standards

3.1 *ISO Standard*[1]

ISO 14644-1 — Cleanrooms and Associated Controlled Environments Part 1: Classification of Air Cleanliness

3.2 *ANSI Standard*[2]

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

NOTE 1: Unless otherwise indicated, all documents cited shall be the latest published versions.

4 Terminology

4.1 None.

5 Ordering Information

5.1 Purchase orders for EUVL mask substrates furnished to this specification shall include the following:

5.1.1 Material coefficient of thermal expansion (see Section 7);

5.1.2 Defect quality area dimensions and defect limits (see Section 9); and

5.1.3 Lot acceptance criteria (see Section 10).

6 Dimensions and Permissible Variations

6.1 The square substrates shall conform to the dimensional tolerances appropriate to the nominal edge length and thickness as listed in Table 1. Dimensions are illustrated in Figure 1.

6.2 Substrates shall have chamfered or rounded edges. The edges shall conform to the dimensional tolerances appropriate to the nominal thickness listed in Table 2. Dimensions are illustrated in Figure 1.

6.3 Substrates shall be identified with notches at three corners on the backside of the substrate as shown in Figure 1. Dimensions of notches shall be as defined in Figure 1.

6.4 Figure 2 shows three datum points on the edges of the mask substrate. Three datum points are also shown on the back surface of the mask substrate. These datum points serve as reference locations for all dimensional measurements listed in Table 1.

7 Material Specifications

7.1 Substrate materials shall be identified as near zero thermal expansion (NZTE). Examples of NZTE materials are titania doped silica glass or two phase glass ceramics.

7.2 Substrate materials shall conform to thermal expansion characteristics defined in Table 3 over the entire range of temperature listed and at all spatial points within the substrate.

7.2.1 The thermal expansion properties of the substrate are defined in four classes. The particular class of thermal expansion material used shall be agreed upon between user and supplier. The thermal expansion properties of the substrate are defined over the entire temperature range shown in Table 3.

1 International Organization for Standardization, ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30 Website: www.iso.ch

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

7.2.2 Table 3 defines the permissible range of the mean and the permissible range of the coefficient of thermal expansion.

7.3 The substrate material shall have specific stiffness as defined in Table 3.

7.4 Selected physical properties of NZTE materials are provided for information only in Appendix 1.

7.5 The front, sides, and or back surfaces of the substrate may be coated with layers that are agreed upon between user and supplier. The substrate including these optional additional layers must meet all requirements outlined in this standard.

8 Flatness Specifications

8.1 The flatness requirements for the substrate are defined in four classes. The particular class of flatness shall be agreed upon between user and supplier. Substrates shall be supplied with front and back sides having flatness as listed in Table 4 over a flatness quality area as defined in Figure 3. The flatness error is defined as the deviation of the surface from the plane that minimizes the maximum deviation, which is illustrated in Figure 4.

8.2 The global flatness requirement for the front and back sides, which includes the region excluded from the flatness quality area (defined in Figure 3), is shown in Table 4.

8.3 Substrates shall be supplied with wedge angle defined in Table 4 and defined in Figure 5.

8.4 Substrates shall be supplied with local slope angle as defined in Table 4 and defined in Figure 4.

8.5 A low order thickness variation (LOTV) requirement is defined over a range of spatial periods (shown in Table 4) composing the surface profile power spectral density. This thickness variation may be determined from the residual flatness error of the front and back surfaces after removing the wedge angle from the data.

8.6 The surface roughness requirements for the front and backside are listed in Table 4, and they are defined over a range of spatial periods.

9 Visual Criteria

9.1 A defect quality area, which may or may not correspond with the flatness area, shall be agreed upon between the user and supplier. Figure 6 shows the labeling of the dimensions of the defect quality area.

9.2 Each plate shall not have more defects than listed in Table 5 inside the defect quality area defined in Figure 6 on the front side. Dimensions of the quality area shall be agreed upon between user and supplier. Each plate shall not have more defects than listed in Table 5 outside the defect quality area defined in Figure 6 on the front side.

9.3 Each plate shall not have more defects than listed in Table 5 on the back side within the flatness quality area defined in Figure 3.

10 Sampling

10.1 Unless otherwise specified, appropriate sample sizes shall be selected from each lot in accordance with ASQC-Z1.4. Each quality characteristic shall be assigned an acceptable quality level (AQL) in accordance with 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 values. Inspection levels shall be agreed upon between user and supplier.

11 Test Methods

11.1 *Thermal Expansion* — to be agreed upon between user and supplier.

11.2 *Flatness and Wedge Angle* — to be agreed upon between user and supplier.

11.3 *Visual* — to be agreed upon between user and supplier.

11.4 *Surface Roughness* — to be agreed upon between user and supplier.

12 Certification

12.1 Upon request of the purchaser in the contract or order, a manufacturer's or supplier's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

13 Packing and Marking

13.1 Substrates shall be packed in a class 1 environment as defined by ISO 14644-1. Containers shall be designed to protect the substrates from contamination in handling and transit. Substrates shall be shipped with the acceptable flatness side toward the front of the box. This orientation shall be indicated on each container. Packaging shall comply with the applicable internal, national, state, and local laws and regulations required for shipping.

13.2 Containers shall be labeled "Warning: Open and Handle Under Cleanroom Conditions Only" as well as identified by user purchase order number (if applicable), drawing number (if applicable), quantity, supplier lot number, and material identification.

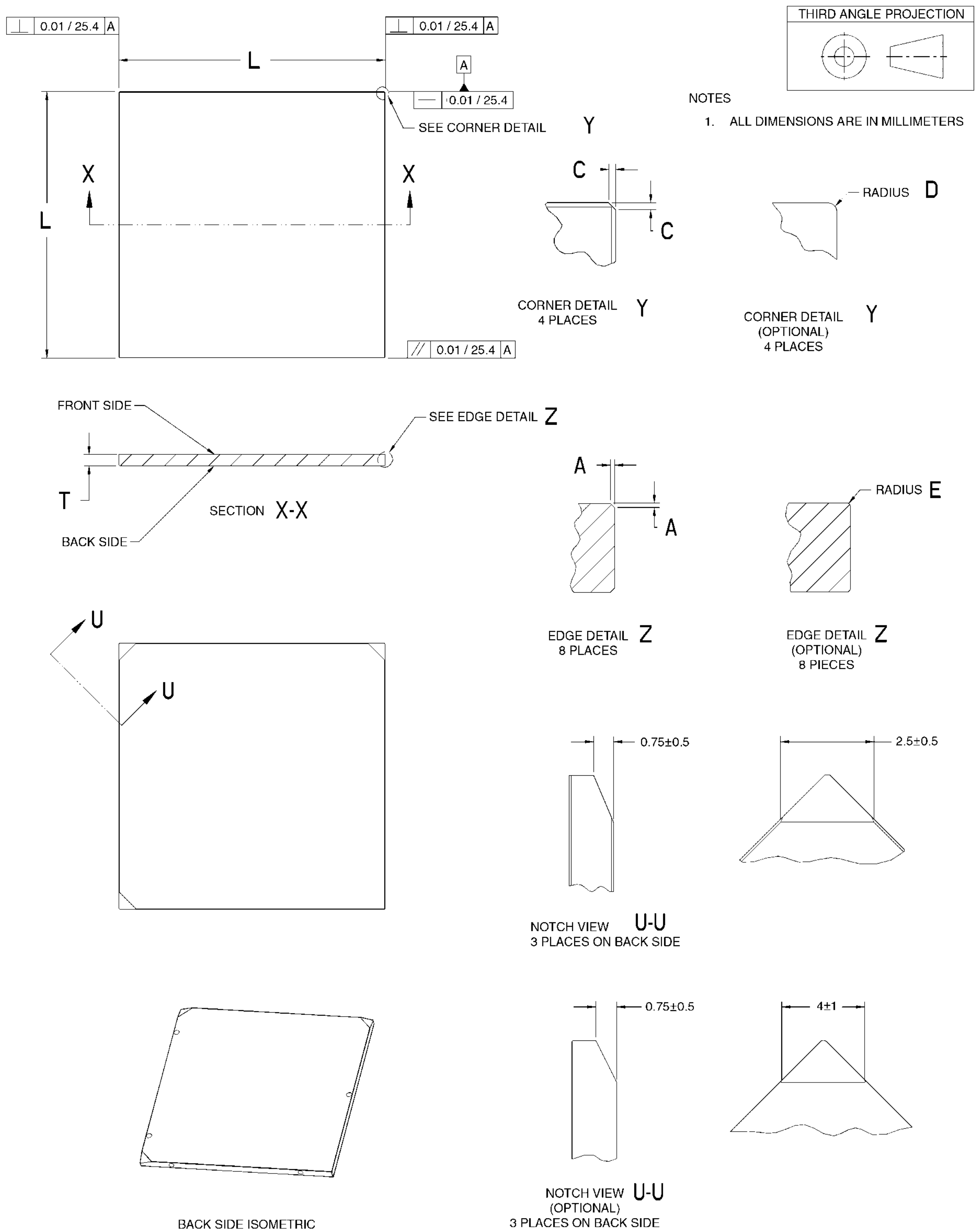


Figure 1
Dimensions of EUVL mask substrate

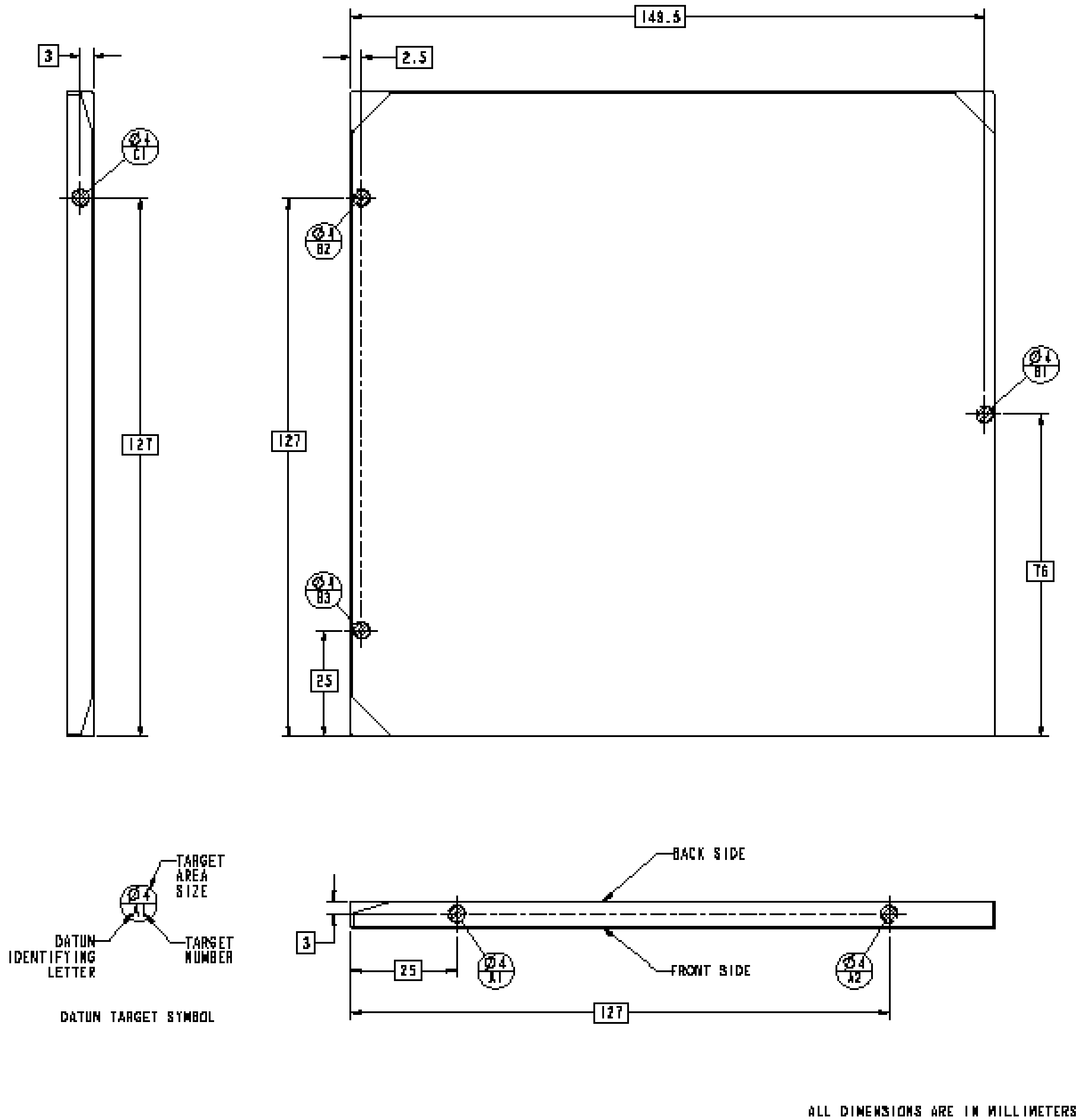


Figure 2
Datum locations on the EUVL mask substrate

Table 1 Specifications for Edge Length, Squareness, and Thickness for Square Substrates

Edge Length Min. L	*Edge Length Max.* L	*Squareness*	*Minimum Mean Thickness* T	*Maximum Mean Thickness* T	*Units*
151.9	152.1	0.01/25.40	6.25	6.45	mm

Table 2 Specifications for Chamfered and Rounded Edge Dimensions

T	*A*	*A*	*C*	*C*	*D*	*D*	*E*	*E*	
Nominal	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Units*
6.35	0.20	0.30	0.30	0.70	0.50	1.00	0.25	0.30	mm

Table 3 Substrate Material Characteristics

Property	*Symbol*	*Characteristic*
Temperature range for CTE requirement		19 to 25°C
Coefficient of Thermal Expansion	CTE (ppb/°C)	Class A: mean: 0 ± 5 ppb/°C 6 ppb/°C total spatial variation Class B: mean: 0 ± 10 ppb/°C 10 ppb/°C total spatial variation Class C: mean: 0 ± 20 ppb/°C 10 ppb/°C total spatial variation Class D: mean: 0 ± 30 ppb/°C 10 ppb/°C total spatial variation
Specific Stiffness (Young's elastic modulus divided by density)	E/ρ (m^2s^{-2})	$\geq 3 \times 10^7$

Note: ppb stands for parts per billion.

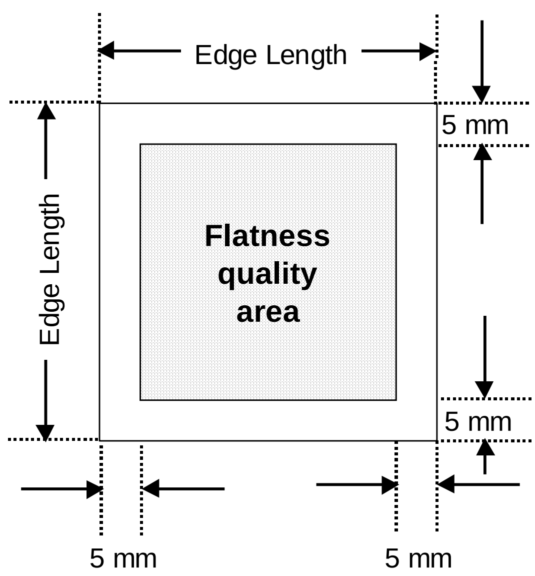


Figure 3
Front and Back Side Flatness Quality Area

Table 4 Flatness, Wedge and Surface Roughness

FLATNESS ERROR IN FLATNESS QUALITY AREA

Class	*Frontside Flatness, within Flatness Quality Area*	*Backside Flatness, within Flatness Quality Area*	*Low Order Thickness Variation (LOTV), within Flatness Quality Area (See Note 2.)* $\lambda_{spatial} >$ *(edge length)*	*Units*
A	100 peak-to-valley	100 peak-to-valley	100	nm
B	75 peak-to-valley	75 peak-to-valley	75	nm
C	50 peak-to-valley	50 peak-to-valley	50	nm
D	30 peak-to-valley	30 peak-to-valley	30	nm

NOTE 1: $\lambda_{spatial}$ is the spatial period of the flatness error.
NOTE 2: Evaluated after removing wedge angle.

FLATNESS OVER ENTIRE SURFACE

Frontside Flatness $\lambda_{spatial} \leq$ *(edge length)*	*Backside Flatness* $\lambda_{spatial} \leq$ *(edge length)*	*Units*
1000 peak-to-valley	1000 peak-to-valley	nm

NOTE 1: $\lambda_{spatial}$ is the spatial period of the flatness error.

WEDGE

Wedge angle	*Units*
≤ 100	microradians

LOCAL SLOPE OF FRONT SURFACE

Local slope angle *400 nm* $\leq \lambda_{spatial} \leq$ *100 mm*	*Units*
≤ 1.0	milliradians

FRONT SIDE SURFACE ROUGHNESS

Surface Roughness in Quality Area (Figure 6), $\lambda_{spatial} \leq 10\ \mu m$	*Units*
≤ 0.15 rms	nm

BACK SIDE SURFACE ROUGHNESS

Surface Roughness over entire back surface, $50\ nm \leq \lambda_{spatial} \leq 10\ \mu m$	*Units*
≤ 0.5 rms	nm

NOTE 1: rms is root mean square error. $\lambda_{spatial}$ is the spatial wavelength of the roughness.

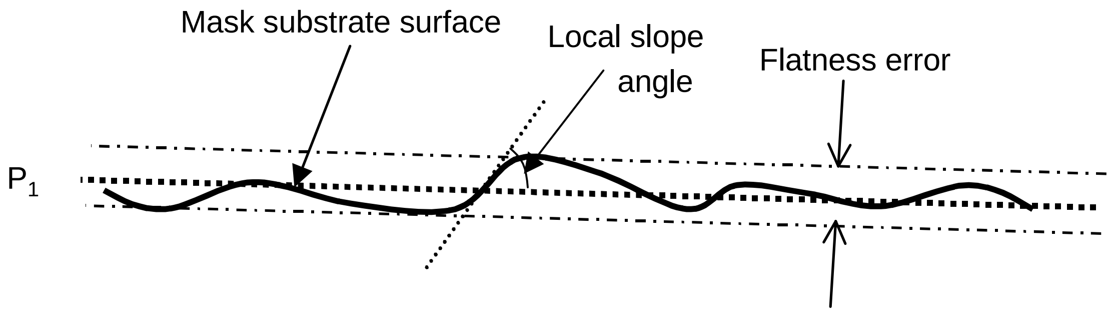


Figure 4
Definition of Flatness Error and Local Slope Angle
P1 is the plane that minimizes maximum deviation of the surface.

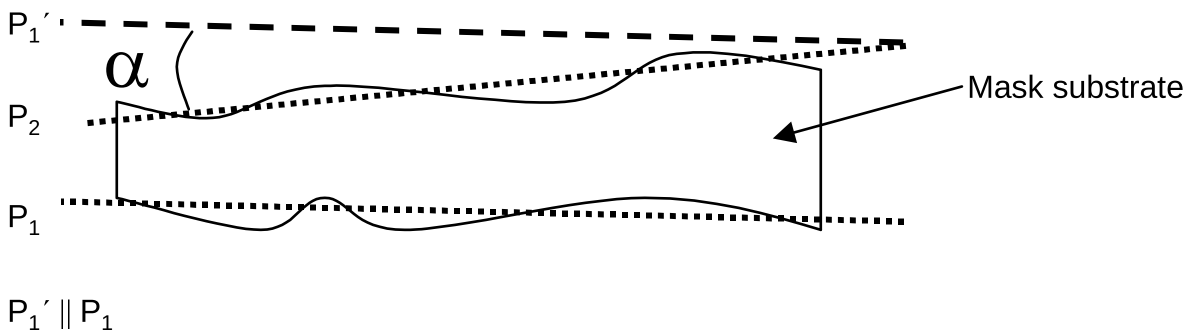


Figure 5
Definition of Wedge Angle, α
P_1 and P_2 are the planes that minimize the maximum deviation of the front and back surfaces, respectively.

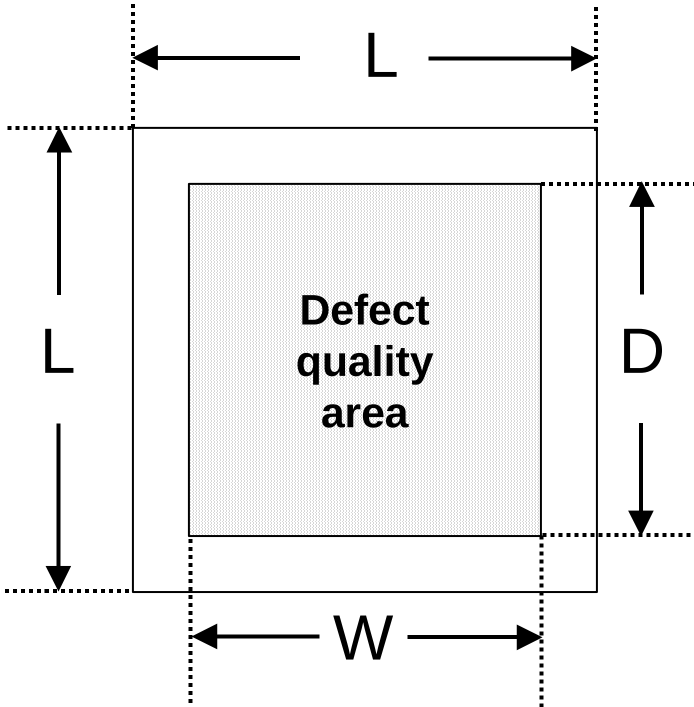


Figure 6
Definition of defect quality area on front side

Table 5 Substrate Defect Limits per Plate

FRONTSIDE SURFACE DEFECTS IN THE DEFECT QUALITY AREA

Frontside	*Residue*	*Total Scratch and Sleek Defects > 1 nm in depth (See Note 1.)*	*Total Localized Light Scatterers > 50 nm PSL equivalent size (per cm^2) (See Note 2.)*	*Total Localized Light Scatterers < 50 nm PSL equivalent size (per cm^2) (See Note 2.)*
NZTE	None	0	0	To be agreed upon between user and supplier

NOTE 1: The maximum size for scratches and sleeks will be agreed upon between user and supplier.
NOTE 2: Localized light scatterers are any isolated features, such as particles or pits, on or in the substrate surface, resulting in increased light scattering intensity relative to that of the surrounding substrate surface. PSL equivalent size means the detected defect appears to be the same size as a polystyrene latex sphere examined under the same inspection conditions.

FRONTSIDE DEFECTS OUTSIDE THE DEFECT QUALITY AREA

Edge Chips	*Defect Limit*	*Total Number*
Radial Depth	≥ 0.76 mm	None
Peripheral Cord	≥ 0.76 mm	None
Other	Shall be negotiated between vendor and supplier	Shall be negotiated between vendor and supplier

BACKSIDE DEFECTS IN FLATNESS QUALITY AREA

Localized Light Scatterer Size (PSL equivalent) (See Note 2.)	*Total*	*Total Number of Backside Scratches (See Note 1.)*
> 1.0 µm	0	0
≤ 1.0 µm	no limit	

NOTE 1: The maximum size for scratches and sleeks will be agreed upon between user and supplier.
NOTE 2: Localized light scatterers are any isolated features, such as particles or pits, on or in the substrate surface, resulting in increased light scattering intensity relative to that of the surrounding substrate surface. PSL equivalent size means the detected defect appears to be the same size as a polystyrene latex sphere examined under the same inspection conditions.

RELATED INFORMATION 1
MATERIAL PROPERTIES

NOTE: This related information is not an official part of SEMI P37 and was derived from the work of the originating committee. This related information was approved for publication by full letter ballot procedures on August 27, 2001.

Table A1-1 Typical EUVL Mask Substrate Bulk Material Properties (for information only)

Property	*Symbol*	*NZTE*
Mean Specific Heat	C_p (J/kg-°C)	750–820
Thermal Conductivity	K (W/m-°C)	1.3–1.6
Density	ρ (g/cm^3)	2.1–2.6
Elastic Modulus	E (GPa)	65–91
Poisson's Ratio	ν	0.17–0.25
Index of refraction	n	1.4–1.6
Electrical conductivity at 20°C	σ (Siemens/m)	10^{-14}–10^{-18}
Dielectric constant	ε at 1 KHz	3.5–9.0

SEMI P38-1103
SPECIFICATION FOR ABSORBING FILM STACKS AND MULTILAYERS ON EXTREME ULTRAVIOLET LITHOGRAPHY MASK BLANKS

This specification was technically approved by the Global Micropatterning Committee and is the direct responsibility of the North American Microlithography Committee. Current edition approved by the North American Regional Standards Committee on September 3, 2003. Initially available at www.semi.org October 2003; to be published November 2003. Originally published November 2002.

1 Purpose

1.1 This specification covers the requirements of the multilayer coating and of the absorbing film stack on Extreme Ultraviolet Lithography (EUVL) masks.

2 Scope

2.1 This standard details the physical characteristics and tolerances required for EUVL mask multilayer coatings. Material composition is not specified to allow for innovation in materials.

2.2 This standard details the physical characteristics and tolerances required for EUVL mask absorbing film stacks. The absorbing film stack comprises two or more layers. Material composition is not specified to allow for innovation in materials.

2.3 For purposes of this standard, the supplier fabricates the mask blank and provides it to the user. In most cases, the user patterns some of the layers on the front side of the mask blank.

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 Referenced Standards

3.1 *SEMI Standards*

SEMI P37 — Specification For Extreme Ultraviolet Lithography Mask Substrates

3.2 *ANSI/ASQC Standards*[1]

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

3.3 *ISO Standard*[2]

ISO 14644-1 — Cleanrooms and Associated Controlled Environments Part 1: Classification of Air Cleanliness

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

4 Terminology

4.1 *Definitions*

4.1.1 *absorber layers* — one or more layers of material that absorb EUV radiation and are patterned in the mask fabrication process. These layers are deposited on top of the buffer layer (see Figure 1).

4.1.2 *absorber stack* — stack of film layers that includes the absorber layer or layers and the buffer layer. (See Figure 1.)

4.1.3 *buffer layer* — layer of material beneath the absorber layer or layers. See Figure 1. This layer is patterned on the final mask.

4.1.4 *capping layer* — layer or layers on top of the multilayers are not patterned. (See Figure 1.)

4.1.5 *conductive layer* — layer deposited on the backside of the EUV mask substrate that is electrically conductive. (See Figure 1.)

4.1.6 *defect* — any flaw or imperfection in the opaque coating, reflective multilayer coating, or functional pattern of a mask that will reproduce itself in a photoresist film and impair the proper functioning of the microelectronic device being fabricated.

4.1.7 *EUV* — extreme ultraviolet radiation with wavelength in the range of 4 to 20 nm.

4.1.8 *multilayer stack* — stack of film layers that includes layers deposited on the mask blank to provide high EUV reflectivity, any capping layers and any underlayers. (See Figure 1.)

1 American National Standards Institute, Headquarters: 1819 L Street, NW, Washington, DC 20036, USA. Telephone: 202.293.8020; Fax: 202.293.9287, New York Office: 11 West 42nd Street, New York, NY 10036, USA. Telephone: 212.642.4900; Fax: 212.398.0023, Website: www.ansi.org

2 International Organization for Standardization, ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30, Website: www.iso.ch

4.1.9 *multilayers* —film stack with layer materials and thickness values selected to produce high reflectivity of incident EUV radiation. (See Figure 1.)

4.1.10 *resist* — layer of radiation-sensitive material patterned in the lithography process for fabricating the mask. See Figure 1.

4.1.11 *underlayers* — layer or layers between the multilayers and the EUV mask substrate, which is described by SEMI P37-1101. (See Figure 1.)

5 Ordering Information

5.1 Purchase orders must include the type of mask blank. Table 1 shows the layers that are included in each mask type.

5.2 Purchase orders for EUVL masks furnished to this specification shall include the items listed in Table 2.

6 Area covered by requirements

6.1 *Layer Quality Area* — A layer quality area with width, W_L, and height, D_L, shall be agreed upon between user and supplier. Figure 2 shows the labeling of the dimensions of the layer quality area. The layer quality area may be smaller than the edge length, L, of the mask substrate, which is defined in SEMI P37. The layer quality area is the region where the multilayer stack and absorber stack properties are specified in Section 7. The multilayer, capping, absorber layer(s) and buffer layer properties are also specified only in the layer quality area.

6.1.1 Specifications for the layers and layer stacks outside the layer quality area are agreed upon between user and supplier.

6.2 *Defect Quality Area* — A defect quality area, with width, W_d, and height, D_d, shall be agreed upon between the user and supplier. Figure 3 shows the labeling of the dimensions of the defect quality area. The defect quality area may or may not be identical to the area described in Section 9.1 of SEMI P37. The defect quality area may be smaller than the edge length, L, of the mask substrate, which is defined in SEMI P37. The defect quality area is not necessarily the same as the layer quality area described in Section 6.1.

6.2.1 Specifications for defects outside the defect quality area are agreed upon between user and supplier.

7 Layer properties

7.1 The multilayer stack attributes and properties are defined in Table 3. The EUV reflectivity requirements are defined in Tables 4 and 5, and the EUV reflectivity uniformity requirements are defined in Table 6. Figure 4 illustrates the EUV reflectivity parameters. The median wavelength is defined as shown, and the peak reflectivity might not occur at the median wavelength. The optical properties of the multilayer stack at wavelengths besides EUV wavelengths are defined in Table 10.

7.2 The buffer layer requirements are shown in Table 7. The optical properties of the buffer layer at wavelengths besides EUV wavelengths are defined in Table 10. The reflectivity requirements in Table 10 apply to the buffer layer as deposited on top of the multilayer stack. By mutual agreement between the user and supplier, the range of wavelengths for mean reflectivity requirement may be reduced to a subset of the range shown in Table 10.

7.3 The absorber layer requirements are defined in Table 8.

7.4 The requirements for the absorber stack are defined in Table 9. The optical properties of the absorber stack at wavelengths besides EUV wavelengths are shown in Table 11. The reflectivity requirements in Tables 9 and 11 apply to the absorber stack as deposited on top of the multilayer stack. By mutual agreement between the user and supplier, the range of wavelengths for mean reflectivity requirement may be reduced to a subset of the range shown in Table 11.

7.5 At all points on the backside of the mask blank, the sheet resistance should be $\leq$ 100 Ohms/square. The requirements for the conductive layer on the backside of the substrate are shown in Table 12.

8 Defects

8.1 The multilayer stack must be inspected for defects before deposition of the buffer layer and absorber layer(s). The multilayer stack must meet the defect requirements shown in Table 13.

8.2 The absorber stack must meet the defect requirements shown in Table 14. For Type 3 mask blanks, the resist and absorber stack must meet the defect requirements shown in Table 14.

8.3 The location and size of all defects in the mulitlayer or absorber stacks that were located by the supplier will be provided to the user. The required accuracy and reference point(s) for these locations will be negotiated between user and supplier.

8.4 Mask blanks must meet the backside defect requirements in Section 9.3 of SEMI P37.

9 Flatness Specifications

9.1 The flatness of the mask blank shall be agreed upon between user and supplier.

10 Sampling

10.1 Unless otherwise 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) 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 values. The method of certification shall be agreed upon between user and supplier.

11 Test Methods

11.1 *Thickness* — Method of measuring layer thickness values to be agreed upon between user and supplier.

11.2 *Reflectivity* — Method of measuring reflectivity at specified wavelengths to be agreed upon between user and supplier with these exceptions:

11.2.1 Each individual reflectivity measurement should represent reflectivity over an area having rectangular dimensions < 1 mm.

11.2.2 EUV reflectivity must be measured at 6 degrees with respect to the normal to the plane of the mask blank surface.

11.3 *Stress* — Method of measuring stress is to be agreed upon between user and supplier.

11.4 *Outgassing* — Method of measuring outgassing rate is to be agreed upon between user and supplier.

11.5 *Etch Rates* — Method of measuring etch rates and etch selectivity is to be agreed upon between user and supplier.

11.6 *Defects* — Method of inspection for defects is to be agreed upon between user and supplier.

11.7 *Flatness* — Method of measuring flatness is to be agreed upon between user and supplier.

11.8 *Backside Sheet Resistance* — Method of measuring sheet resistance is to be agreed upon between user and supplier.

11.9 *Electrical Resistance* — method of measuring electrical resistance is to be agreed upon between user and supplier.

12 Certification

12.1 Upon request of the purchaser in the contract or order, a manufacturer's or supplier's certification that the material was manufactured and tested shall be provided in accordance with this specification.

13 Packing and Labeling

13.1 Mask blanks shall be packed in a Class 1 environment. Containers shall be designed to prevent blank-to-blank contact and to protect the substrates from contamination in handling and transit. Substrates shall be shipped with the coated side facing toward the same end of the box. This orientation shall be indicated on each container. Packaging shall comply with the applicable international, national, state laws, and local regulations required for shipping.

13.2 Containers shall be labeled, "Warning: Open and Handle Under Clean Room Conditions Only." Each shipment shall be identified by user purchase order number, drawing number (if applicable), quantity, supplier lot number, and material identification. Material identification methodology to be agreed upon between user and supplier.

13.3 Each mask blank shall be labeled with an alphanumeric sequence that contains the items listed in Table 15 in sequential order. No spaces will be included, and each item listed in Table 15 shall be separated by a dash in the text of the label. Note that the class values for different properties of a mask blank are determined individually.

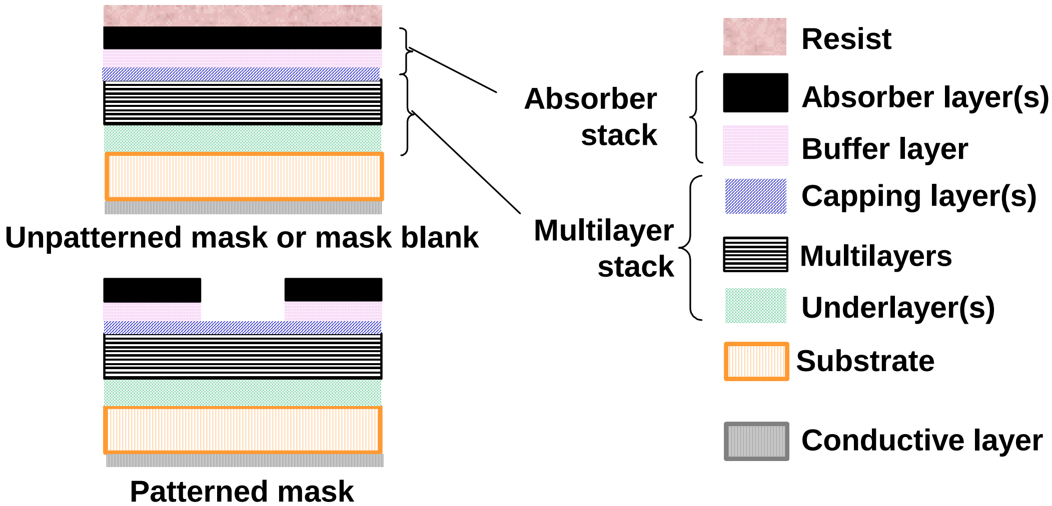


Figure 1
Definition of Absorber, Buffer, Capping Layer, Multilayers, Absorber Stack, and Multilayer Stack

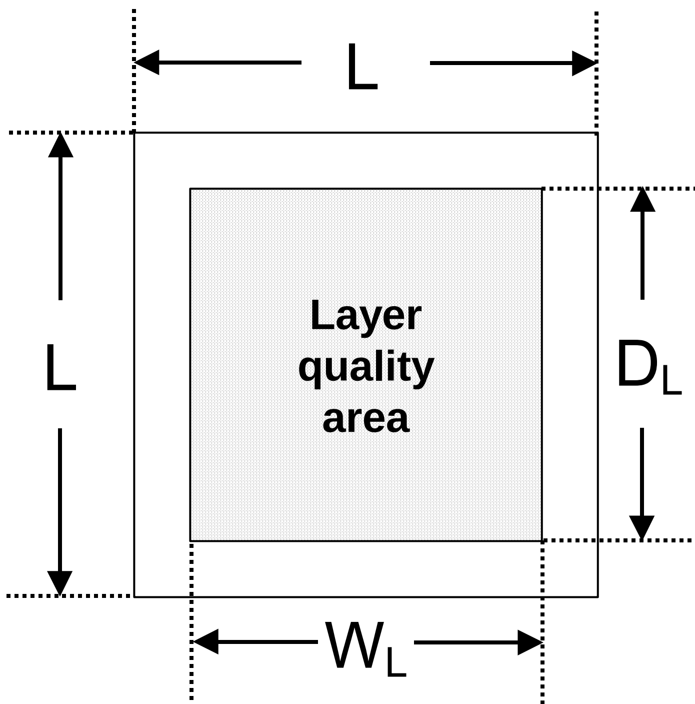


Figure 2
Dimensions of Layer Quality Area

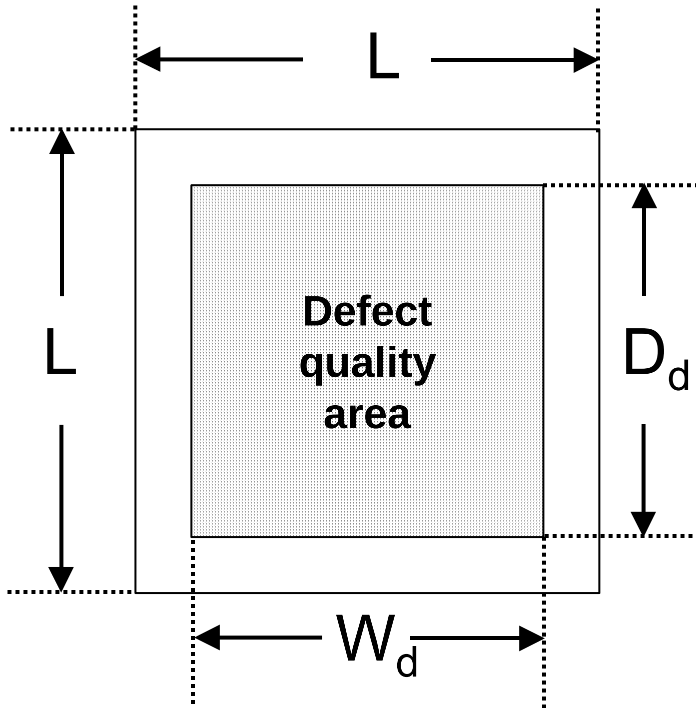


Figure 3
Dimensions of Defect Quality Area

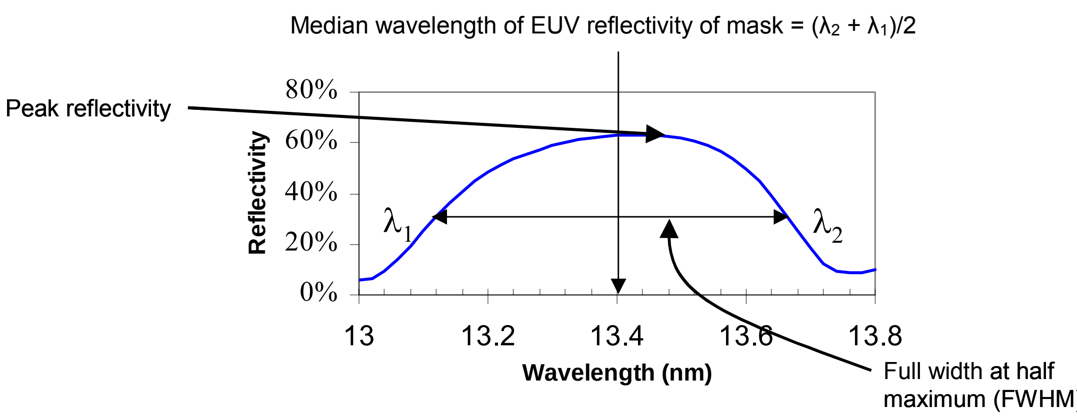


Figure 4
EUV Reflectivity of Multilayer Stack

Table 1 Mask Blank Type

Type	*Layers or groups of layers included in addition to the substrate*
1	Conductive layer and multilayer stack
2	Conductive layer, multilayer stack, and absorber stack
3	Conductive layer, multilayer stack, absorber stack and resist

Table 2 Ordering Information For Multilayer And Absorber Stacks On EUVL Mask Blanks

Property	*Requirement*	*Included in order for Type 1 (See Note 1.)*
Type	Specified type from Table 1	Yes
Defect quality area	Agreed upon between user and supplier	Yes
Flatness	Agreed upon between user and supplier	Yes
Layer quality area	Agreed upon between user and supplier	Yes
Material composition of multilayers	Agreed upon between user and supplier	Yes
Composition of capping layers on the multilayer stack	Agreed upon between user and supplier	Yes
Multilayer stack mean median reflected wavelength	Agreed upon between user and supplier	Yes
Multilayer stack mean peak reflectivity	Specified class from Table 5	Yes
Multilayer stack peak reflectivity uniformity	Specified class from Table 6	Yes
Multilayer stack defects	Specified class from Table 13	Yes
Absorber stack defects	Specified class from Table 14	No
Absorber stack material composition	Agreed upon between user and supplier	No
Optical properties of absorber stack	Specified class from Table 11	No
Electrical resistance measured between the surface of the absorber stack and the backside of the mask blank	Agreed upon between user and supplier	No

Note 1: All items in Table 2 are included in the label for mask blank types 2 and 3.

Table 3 Properties of Multilayer Stack

Multilayer stack property	*Value*
Material composition of layers	Agreed upon between user and supplier
Stress	Agreed upon between user and supplier
Capping layer thickness	Agreed upon between user and supplier
Capping layer composition	Agreed upon between user and supplier
Peak reflectivity change after 50 billion pulses in EUV exposure tool (See Note 1.)	Agreed upon between user and supplier

Note 1: $\geq$ 1 mJ/cm^2/pulse in a bandwidth that equals 2% of the nominal wavelength full width at half maximum (FWHM).

Table 4 Median Wavelength And Bandwidth Of EUV Reflectivity Of Multilayer Stack

Mean FWHM of reflectivity versus wavelength	> 0.50 nm
Mean median reflected wavelength	Agreed upon between user and supplier

Note 1: Mean is determined from measurements made at different spatial locations on the mask blank surface. Sample size and measurement locations for determining mean are to be agreed upon between user and supplier.

Table 5 Peak EUV Reflectivity Of Multilayer Stack

Class	*Mean peak reflectivity*
A	> 67%
B	65–67%
C	63–65%
D	60–63%

Note 1: Mean is determined from measurements made at different spatial locations on the mask blank surface. Sample size and measurement locations for determining mean are to be agreed upon between user and supplier.

Table 6 Uniformity Of EUV Reflectivity Of Multilayer Stack

Class	*Maximum range of peak reflectivity(absolute)*	*Maximum range of bandwidth(nm at FWHM)*	*Maximum range of centroid wavelength (nm)*
A	0.50%	0.005	0.06
B	0.70%	0.005	0.08
C	0.80%	0.01	0.1
D	1.20%	0.01	0.12

Note 1: Mean is determined from measurements made at different spatial locations on the mask blank surface. Sample size and measurement locations for determining range are to be agreed upon between user and supplier.

Table 7 Properties of Buffer Layer

Buffer layer properties	*Requirement*
Buffer layer etch selectivity to multilayer	Agreed upon between user and supplier
Buffer layer material composition	Agreed upon between user and supplier
Focused ion beam etch selectivity between buffer layer and absorber	Agreed upon between user and supplier
Focused ion beam etch selectivity between buffer layer and multilayer	Agreed upon between user and supplier
Secondary electron contrast of the buffer layer surface with respect to the surface of the absorber layer(s) for between 0.5 and 2 kV primary electrons	Agreed upon between user and supplier
Secondary electron contrast of the buffer layer surface with respect to the surface of the capping layer(s) for between 0.5 and 2 kV primary electrons	Agreed upon between user and supplier
Buffer etch selectivity to absorber stack	Agreed upon between user and supplier
Buffer layer thickness	Agreed upon between user and supplier

Table 8 Properties Of Absorber Layer or Layers

Absorber layer properties	*Requirement*
Material composition of absorber layer(s)	Agreed upon between user and supplier
Thickness of absorber layer(s)	Agreed upon between user and supplier

Table 9 Properties Of Absorber Stack

Attribute	*Requirement*
Stress	−200 to 200 MPa
Mean reflectivity at EUV wavelength (See Note 1 and 2.)	< 0.5%
Uniformity of EUV reflectivity	< 0.1% TIR
Thickness uniformity	Agreed upon between user and supplier
Etch rate in cleaning solutions (See Note 3.)	Agreed upon between user and supplier
Thickness change after 50 billion pulses in EUV exposure tool (See Note 4.)	< 1 nm
Stress change after 50 billion pulses in EUV exposure tool (See Note 4.)	< 50 MPa
Absorber stack outgassing during EUV radiation (See Note 4.)	Agreed upon between user and supplier

Note 1: Mean is determined from measurements made at different spatial locations on the mask blank surface. Sample size and measurement locations for determining range are to be agreed upon between user and supplier.

Note 2: Reflectivity at 6 degrees angle of incidence with respect to the normal to the absorber surface at the mean median reflected wavelength specified in Table 4 and integrated over the bandwidth equal to the FWHM of the reflectivity versus EUV wavelength.

Note 3: Cleaning solutions to be agreed upon between user and supplier.

Note 4: ≥ 1 mJ/cm^2/pulse in a bandwidth that equals 2% of the nominal wavelength full width at half maximum (FWHM).

Table 10 Optical Properties of Buffer Layer and Multilayer Stack

Minimum multilayer stack reflectivity at 150 < λ< 257 nm (See Note 2.)	55%
Mean buffer layer reflectivity at 190<λ<257 nm (See Notes 1 and 2.)	Agreed upon between user and supplier
Uniformity of buffer layer reflectivity (absolute) (See Note 1.)	Agreed upon between user and supplier

Note 1: Mean is determined from measurements made at different spatial locations on the buffer layer or multilayer stack surface. Sample size and measurement locations for determining range are to be agreed upon between user and supplier.

Note 2: λ is the inspection wavelength. Reflectivity is specified for < 1% fractional bandwidth at normal incidence

Table 11 Optical Properties of Absorber Stack Surface

Class	*Mean absorber stack reflectivity at 190<λ<257 nm (See Notes 1 and 2.)*	*Uniformity of reflectivity (absolute) (See Notes 1 and 2.)*
A	5%	± 2%
B	10%	± 1.5%
C	15%	± 1.5%
D	20%	± 1.5%

Note 1: Mean is determined from measurements made at different spatial locations on the absorber stack surface. Sample size and measurement locations for determining range are to be agreed upon between user and supplier.

Note 2: λ is the inspection wavelength. Reflectivity is specified for < 1% fractional bandwidth and at normal incidence.

Table 12 Properties of the Conductive Layer on the Back Side of the Mask Substrate

Conductive layer properties	*Requirement*
Thickness	Agreed upon between user and supplier
Stress	Agreed upon between user and supplier
Mechanical durability	Agreed upon between user and supplier

Table 13 Defect Requirements for Multilayer Stack

Class	*PSL equivalent size range (nm) (See Note 1.)*	*Maximum defect count*
A	> 25	0
B	> 30	0
C	> 40	0
D (Test)	> 60	Agreed upon between user and supplier
E (Test)	> 90	Agreed upon between user and supplier

Note 1: PSL equivalent size means the detected defect appears to be the same size as a polystyrene latex sphere examined under the same inspection conditions. Defect count for defects with size smaller than that shown is not specified.

Table 14 Defect Requirements for Absorber Stack

Class	*Defect size range (nm) (See Note 1.)*	*Maximum count*	*Defect size range (nm) (See Note 1)*	*Maximum count*
A1	15–180	0	> 180	0
A2	15–180	10	> 180	0
B1	25–265	0	> 265	0
B2	25–265	10	> 265	0
C1	35–360	0	> 360	0
C2	35–360	10	> 360	0
D1	50–520	0	> 520	0
D2	50–520	10	> 520	0
E (Test)	< 1000	1500	> 1000	0

Note 1: PSL equivalent size means the detected defect appears to be the same size as a polystyrene latex sphere examined under the same inspection conditions. Defect count for defects with size smaller than that shown is not specified.

Table 15 Items Included In Mask Blank Label

Item in label	*Corresponding Table or Figure*	*Included in label for Type 1 (See Note 1)*
Type	Table 1	Yes
Layer quality area dimensions, W_L followed by D_L (to nearest 0.1 mm)	Figure 2	Yes
Mean median wavelength (to nearest 0.01 nm)	Table 4	Yes
Peak reflectivity class of multilayer stack	Table 5	Yes
Multilayer stack reflectivity uniformity class	Table 6	Yes
Defect quality area dimensions, W_L followed by D_L (to nearest 0.1 mm)	Figure 3	Yes
Multilayer stack defect class	Table 13	Yes
Class for absorber optical properties	Table 11	No
Absorber defect class	Table 14	No

Note 1: All items in Table 15 are included in the label for mask blank types 2 and 3.

SEMI

SEMI P39-0304E2
OASIS™ – OPEN ARTWORK SYSTEM INTERCHANGE STANDARD

This standard was technically approved by the Global Micropatterning Committee and is the direct responsibility of the North American Microlithography Committee. Current edition approved by the North American Regional Standards Committee on July 12, 2003. Initially available at www.semi.org December 2003; to be published March 2004.

E This document was modified in April 2004 to correct editorial errors. Changes were made to Sections 29.8 and 36.2. This document was also editorially modified in July 2004 to correct editorial errors. Changes were made to Section 36.

1 Purpose

1.1 The purpose of this specification is to define an interchange and encapsulation format for hierarchical integrated circuit mask layout information.

1.2 *Background* — In the fall of 2001, SEMI's Data Path Task Force formed a working group to define a successor to the venerable GDSII Stream format, which had served the I.C. industry as a *de facto* standard for layout interchange for more than two decades. The old format, limited by 16-bit and 32-bit internal integer fields, by its inefficient representation of cell-native geometric figures, and by high structural overhead, was becoming difficult to use for leading-edge designs, and file sizes were becoming unwieldy, in some cases growing to many tens of gigabytes. The successor format was chartered with several overall goals:

- Achieve at least an order-of-magnitude file size improvement compared to GDSII Stream.
- Remove all 16-bit and 32-bit integer width restrictions—make the new format fully 64-bit capable.
- Efficiently represent cells with large payloads of flat native geometric figures.
- Provide a richer information palette to facilitate interchange of layout-related information between design and manufacturing.

1.2.1 In the months leading up to the formation of the SEMI Data Path Task Force, International Sematech sponsored a series of meetings focusing on Mask EDA issues. Many of the Task Force participants were also involved in these Sematech meetings, and carried forward much useful information from those sessions into the definition of this specification.

2 Scope

2.1 This format is designed primarily to encapsulate hierarchical mask layout for interchange between systems such as EDA software, mask writing tools, and mask inspection/repair tools.

2.2 This format is designed to be both hardware- and software-independent.

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 Use of extension records such as XNAME, XELEMENT, and XGEOMETRY may impair interoperability between tools. It is recommended that these extensions be used primarily for prototyping, and that interoperability be maintained through the formal inclusion of extensions to this specification.

4 Referenced Standards

4.1 *IEEE Standards*[1]

IEEE 754-1985 — IEEE Standard for Binary Floating-Point Arithmetic

4.2 *ISO Standards*[2]

ISO-646-IRV — "US-ASCII" Character Set

ISO-3309 — Information technology — Telecommunications and information exchange between systems — High-level data link control (HDLC) procedures — Frame structure

4.3 *IETF Standards*[3]

RFC 1951 — DEFLATE Compressed Data Format Specification version 1.3

1 Institute of Electrical and Electronics Engineers, IEEE Operations Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, New Jersey 08855-1331, USA. Telephone: 732.981.0060; Fax: 732.981.1721, Website: www.ieee.org

2 International Organization for Standardization, ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30, Website: www.iso.ch

3 Internet Engineering Task Force, Website: www.ietf.org

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *BNF*—Backus-Naur Form

5.1.2 *EDA*—Electronic Design Automation

5.1.3 [4]*OASIS*™—Open Artwork System Interchange Standard

5.2 *Definitions*

5.2.1 Most definitions of terminology specific to OASIS are found within the text of the paragraphs that contain them.

5.2.2 *cell* — a named object in a layout hierarchy, containing native geometric information, annotation information, and/or placements of other cells.

5.2.3 *geometry* — a two-dimensional geometric figure such as a polygon, rectangle, trapezoid, path, circle, etc. with inherent attributes of *layer* and *datatype*.

5.2.4 *placement* — a specification by reference that a copy of a cell is to be placed within the coordinate space of another cell at a particular location, orientation, and scale. Cell placement is the fundamental mechanism which makes hierarchy within the OASIS file possible.

5.2.5 *property* — an annotation element consisting of a name plus an optional list of values, supplying descriptive information about the characteristics of the file or one of its components.

5.2.6 *record* — the principal data division in an OASIS file.

5.2.7 *text element* — an annotation element consisting of an (x,y) coordinate point and an associated string.

5.3 *Symbols*

5.3.1 **"->"** — indicates a mapping of an argument to its contents or its meaning.

4 Used with consent by the owner.

6 OASIS Basics

6.1 An OASIS file is a sequence of **bytes** divided into **records**. The length of a record is discernible from its structure and is not explicit (in contrast to GDSII Stream, where all record lengths are explicit).

6.2 An OASIS file has the following overall syntax (using the modified BNF notation described in Section 36 on page 27). Individual record types appear in bold uppercase and are described in more detail in following sections.

<oasis-file> -> <magic-bytes> **START** { **CBLOCK** | **PAD** | **PROPERTY** | <cell> | <name> }* **END**
<name> -> { **CELLNAME** | **TEXTSTRING** | **LAYERNAME** | **PROPNAME** | **PROPSTRING** | **XNAME** }
<cell> -> { **CELL** { **CBLOCK** | **PAD** | **PROPERTY** | **XYRELATIVE** | **XYABSOLUTE** | <element> }* }
<element> -> { <geometry> | **PLACEMENT** | **TEXT** | **XELEMENT** }
<geometry> -> { **RECTANGLE** | **POLYGON** | **PATH** | **TRAPEZOID** | **CTRAPEZOID** | **CIRCLE** | **XGEOMETRY** }

6.3 An OASIS file may represent a complete layout hierarchy, a portion of a layout hierarchy, or multiple layout hierarchies. These interpretations are not intrinsic to the format and are governed by application semantics only. Each OASIS file must be syntactically complete—it must begin with <magic-bytes> and contain at least a **START** and **END** record.

6.4 The <magic-bytes> element is a sequence of 13 ASCII characters: "`%SEMI-OASIS<CR><NL>`" where `<CR><NL>` represents the ASCII hexadecimal sequence `0D 0A`. It is provided as a recognition signature to make OASIS files easily identifiable to the UNIX *file* utility. (The intent of the carriage return and newline is to help detect corruption by FTP programs operating in non-binary mode.)

6.5 <u>*EXCEPTION HANDLING*</u> — OASIS processors should treat any deviation from the syntax presented in this document as a fatal error. OASIS readers are not required to implement syntax-check preprocessing in order to be considered compliant with this specification. The sequence in which exceptions are detected and reported is entirely application-dependent. In addition, for access requests which do not require the interpretation of the entire file (such as retrieval of a single cell or a subset of the cells within the file), this specification does not require OASIS readers to exhaustively check the validity of the entire file.

7 Data Constructs

7.1 *Bytes*

7.1.1 A byte is a fixed-length 8-bit value. Bit patterns for bytes are shown with the least significant bit (bit 0) on the right.

7.2 *Integers*

7.2.1 An ***unsigned-integer*** is an N-byte (N > 0) integer value. The low-order byte appears <u>first</u> in the OASIS format. Integer byte length is variable and integers are represented as *byte-continuations* where the most significant bit of each byte except the last in the chain is a 1; the remaining seven bits in each byte are concatenated to form the actual integer value itself. There are no restrictions on integer byte length (and hence, magnitude).

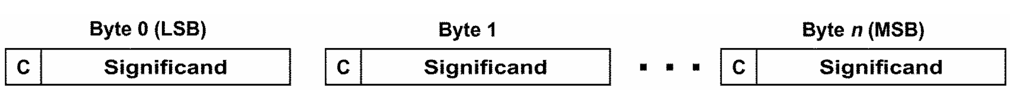


Figure 1
Unsigned-Integer Representation