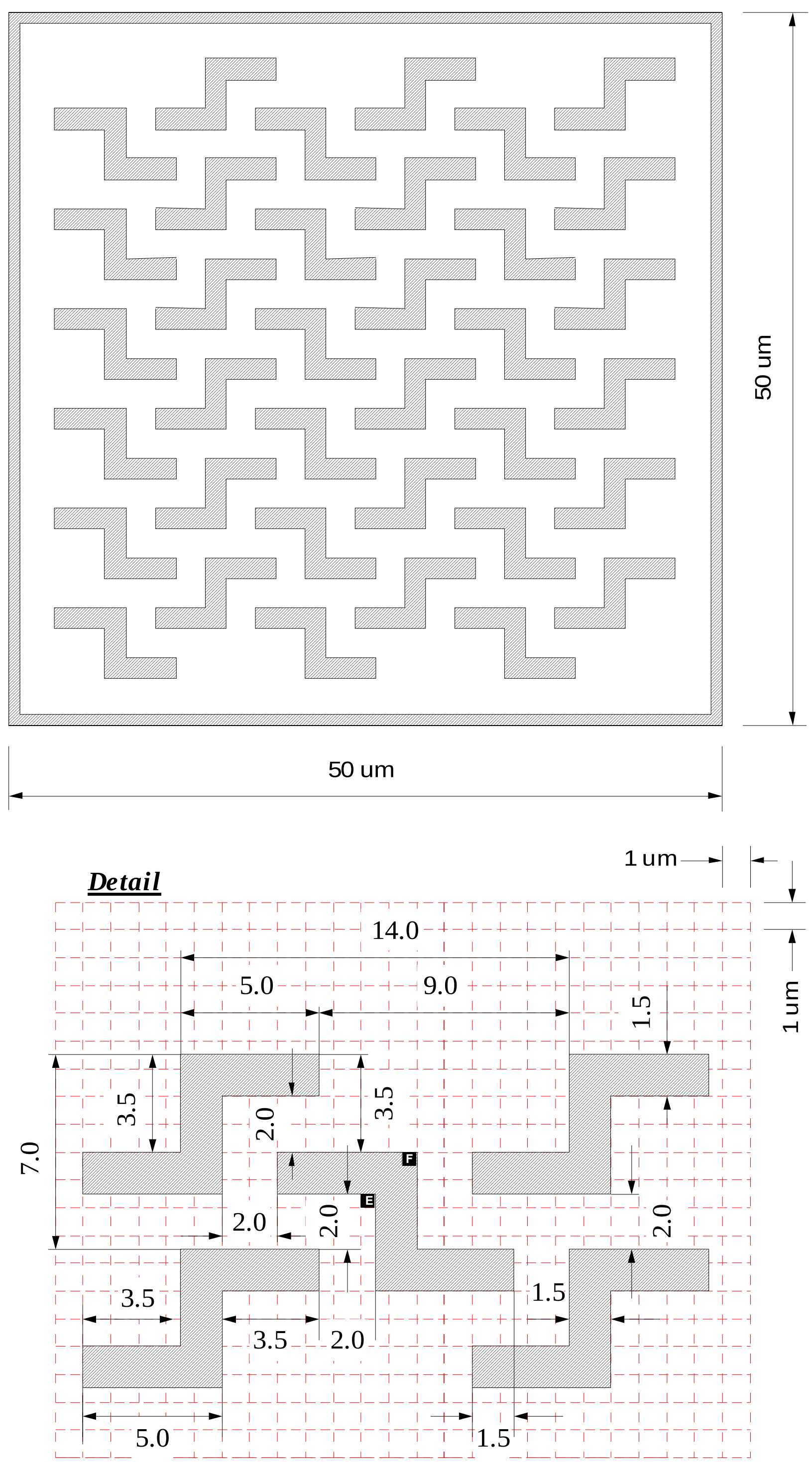


; Film Pattern

; Defect Position

Figure 19
Sub Cell
Wiring (Type E)

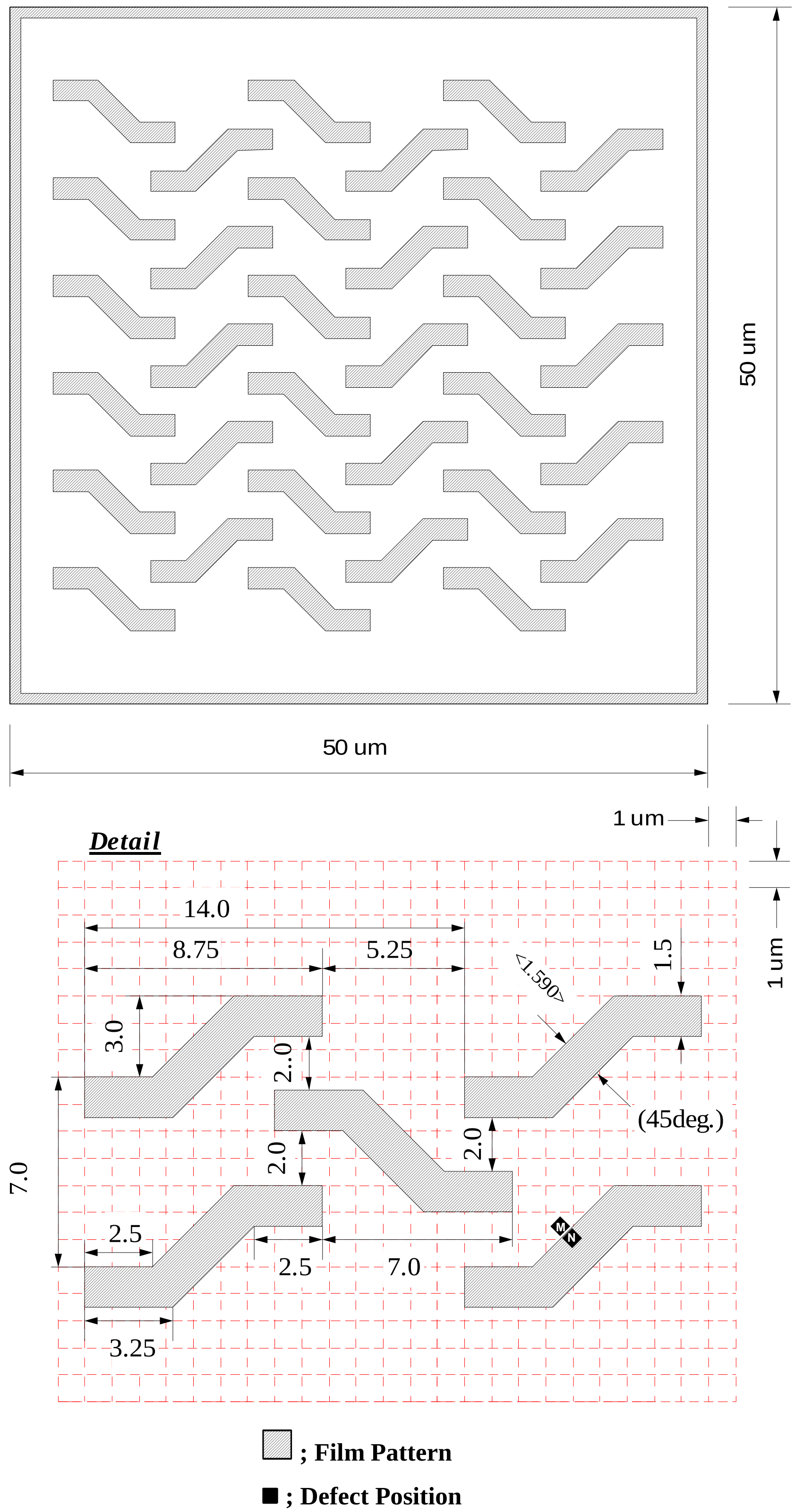
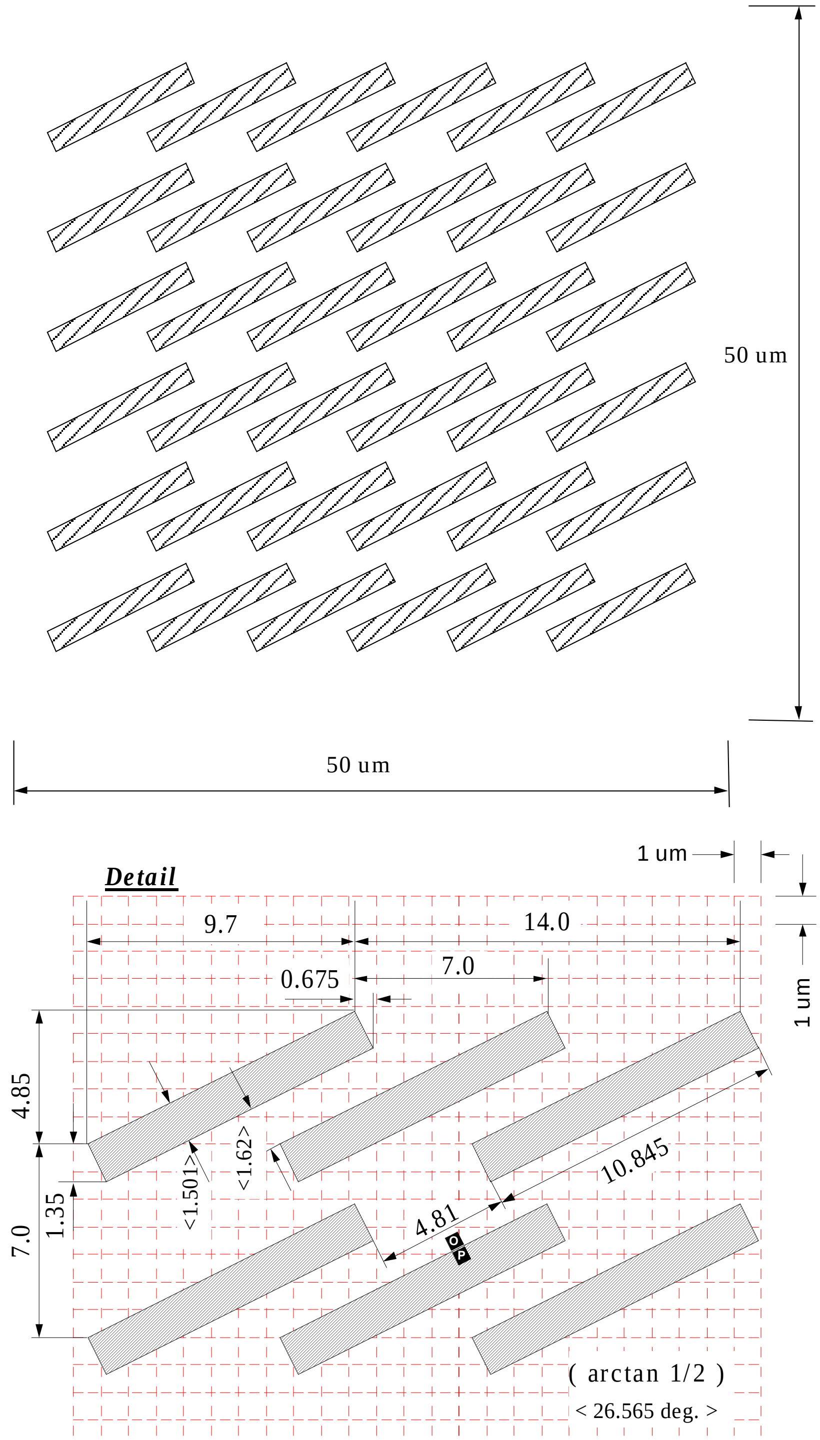


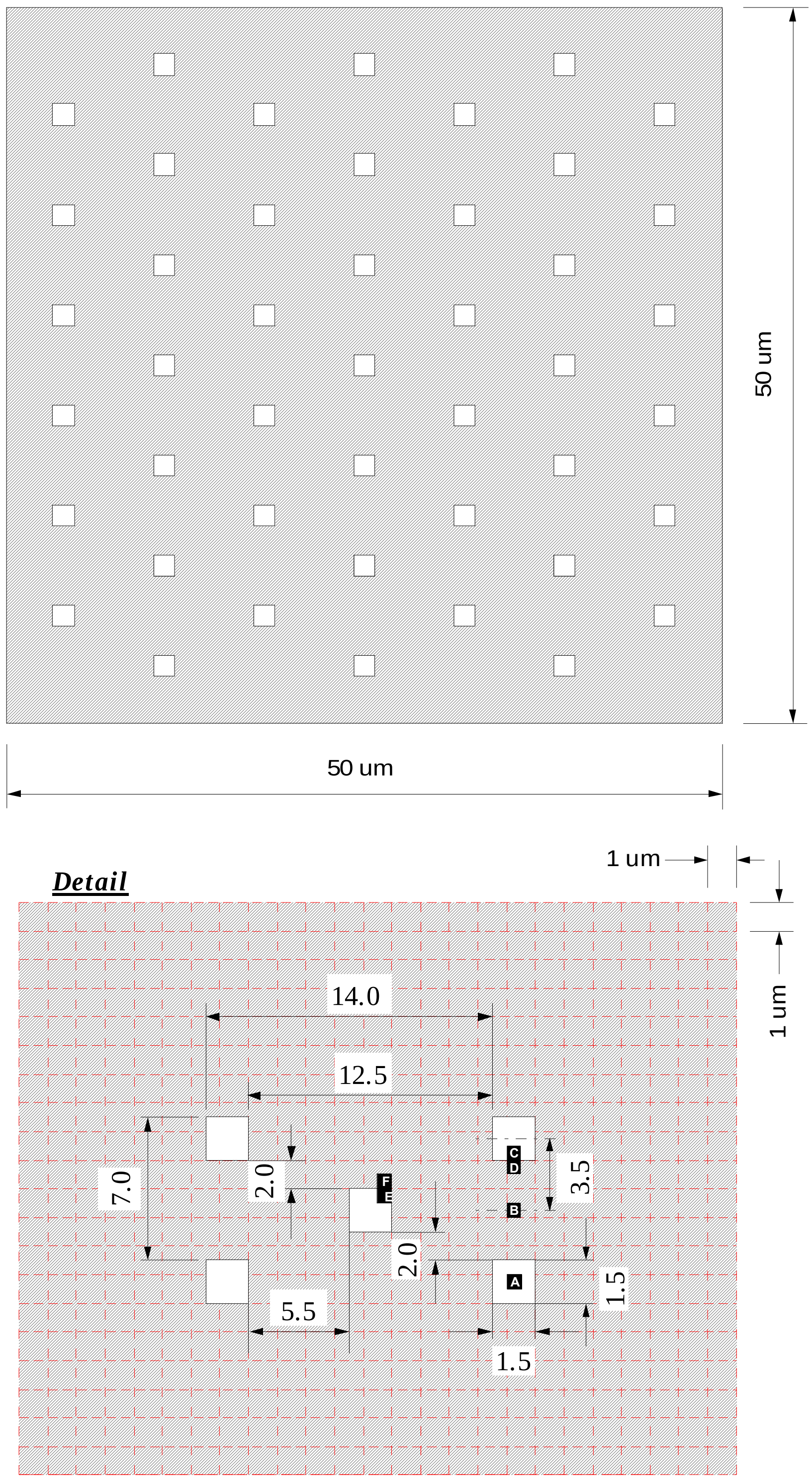
Figure 20
Sub Cell
Wiring (Type F)



; Film Pattern

■ ; Defect Position

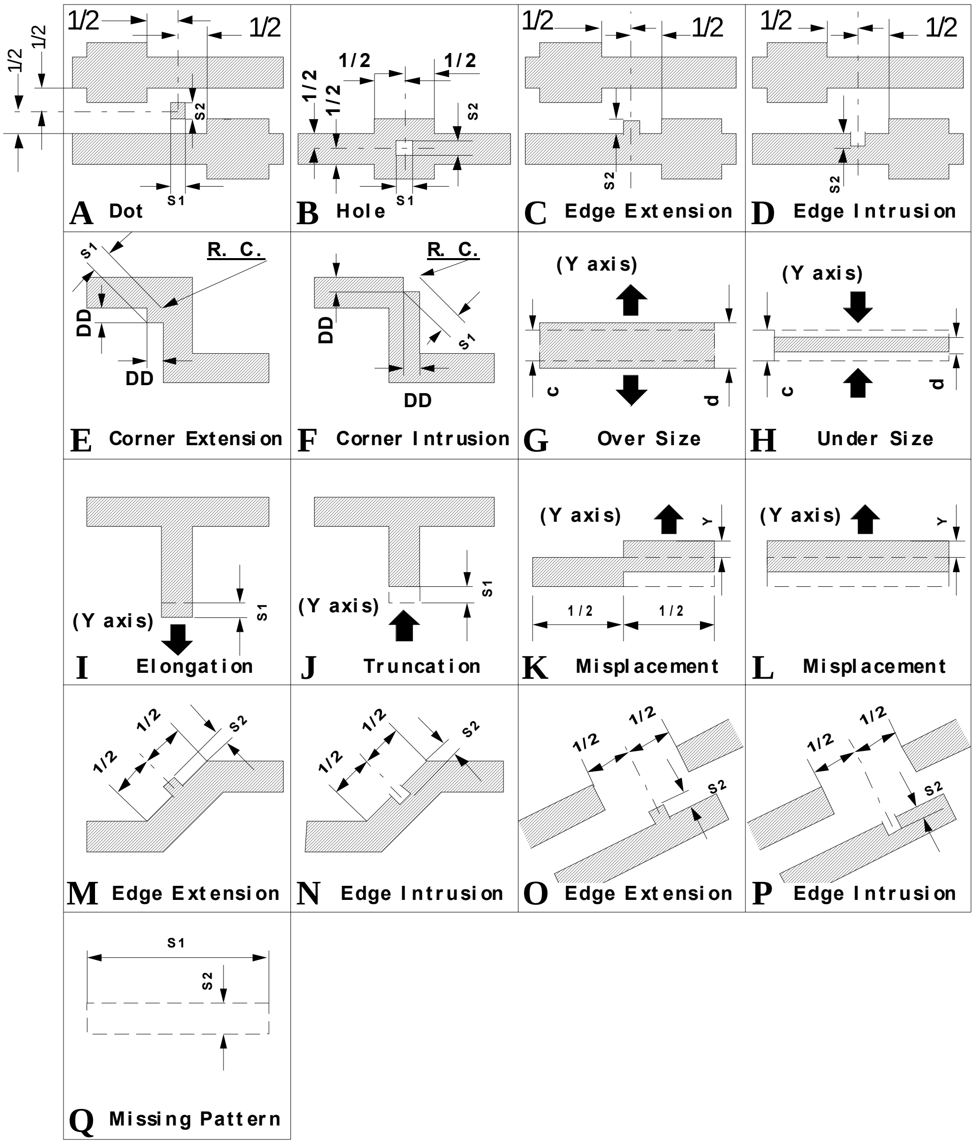
Figure 21
Sub Cell
Wiring (Type F)



; Film Pattern

■ ; Defect Position

Figure 22
Sub Cell
Contact Hole Pattern

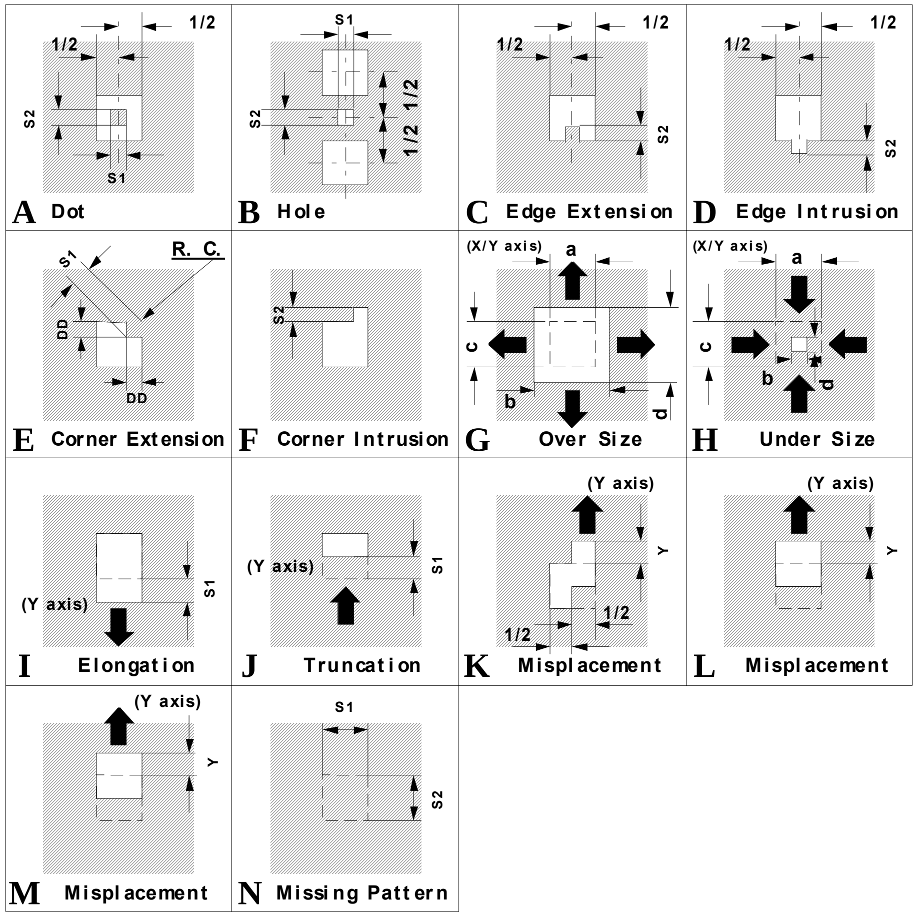


S1, S2 = Defect Size

DD = Defect Design Size

, R. C. = Reference Chip Pattern (or Design Pattern)

Figure 23
Defect
(Wiring Pattern)



S1, S2 = Defect Size

DD = Defect Design Size

, R. C. = Reference Chip Pattern (or Design Pattern)

Figure 24
Defect
(Contact Hole Pattern)

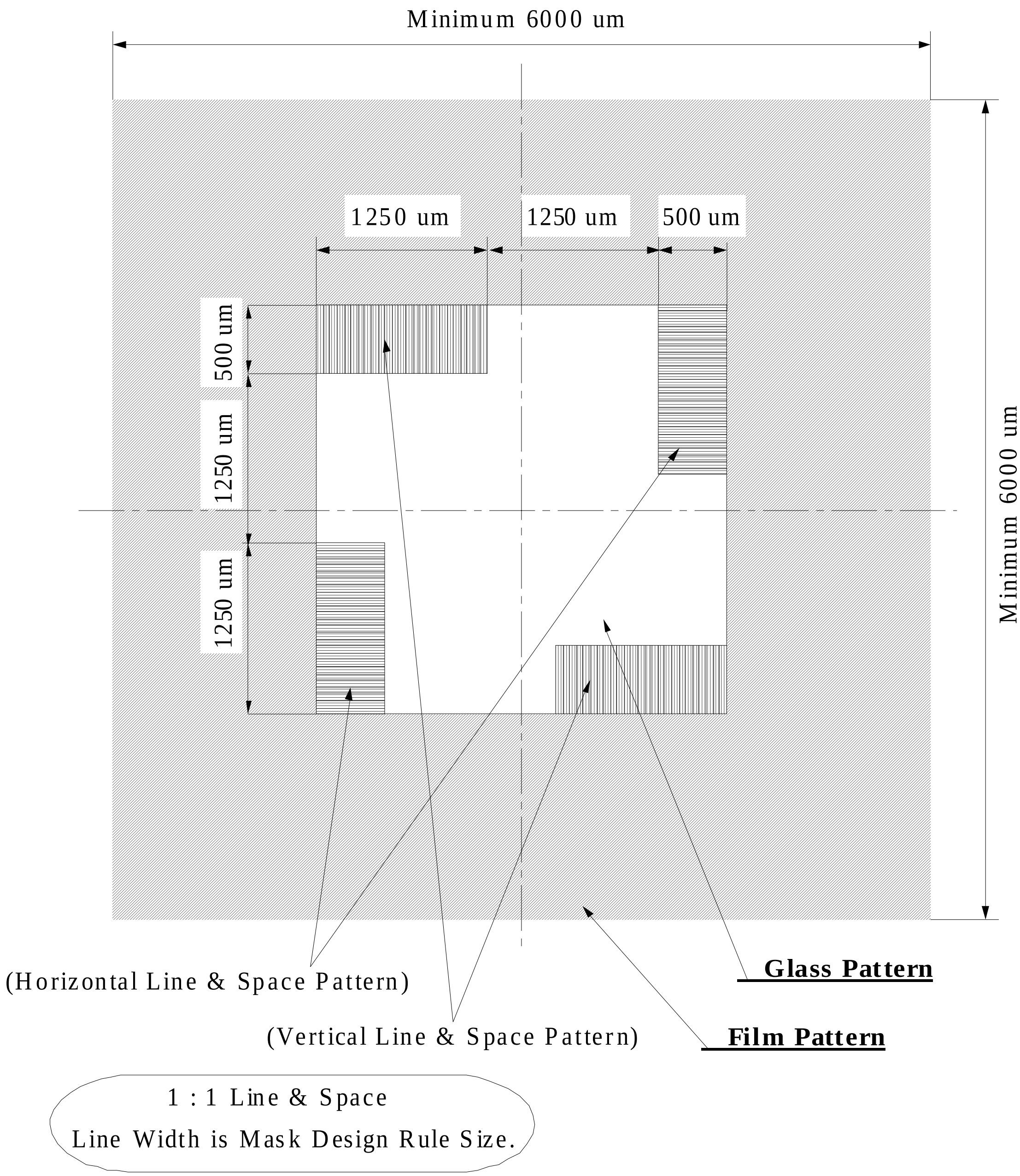
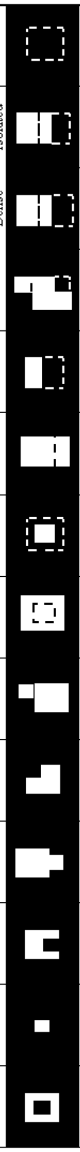


Figure 25
Light Intensity Adjustment Pattern

Defect Design Size		Isolated Defect		Edge Defect		Corner Defect		Size Defect				Misplacement Defect		Edge Defect				Missing
		Dot	Hole	Extension	Intrusion	Extension	Intrusion	Over size	Under size	Elongation	Truncation	Misplacement		Extension (45 degree)	Intrusion (45 degree)	Extension (arctan 1/2)	Intrusion (arctan 1/2)	
(micron)		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
0.05	1																	
0.10	2																	
0.15	3																	
0.20	4																	
0.25	5																	
0.30	6																	
0.35	7																	
0.40	8																	
0.45	9																	
0.50	10																	
0.55	11																	
0.60	12																	
0.65	13																	
0.70	14																	
0.75	15																	
0.80	16																	
0.85	17																	
0.90	18																	
0.95	19																	
1.00	20																	

Figure 26
Sensitivity Check Sheet – Wiring Pattern



Defect / Design Size (micron)		Isolated Defect		Edge Defect		Corner Defect		Size Defect				Misplacement Defect			Missing
		Dot	Hole	Extension	Intrusion	Extension	Intrusion	Over size	Under size	Elongation	Truncation	Misplacement	Dense	Isolated	
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
0.05	1														
0.10	2														
0.15	3														
0.20	4														
0.25	5														
0.30	6														
0.35	7														
0.40	8														
0.45	9														
0.50	10														
0.55	11														
0.60	12														
0.65	13														
0.70	14														
0.75	15														
0.80	16														
0.85	17														
0.90	18														
0.95	19														
1.00	20														

Figure 27
Sensitivity Check Sheet – Contact Hole Pattern

SEMI P24-94 (Reapproved 1104)
CD METROLOGY PROCEDURES

This standard 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 July 11, 2004. Initially available at www.semi.org September 2004; to be published November 2004. Originally published in 1994.

1 Purpose

1.1 The purpose of this document is to establish uniform procedures for metrology systems for the litho-metrology task. It does not address how these systems will be applied to solve problems, nor does it address other contributors to process variations such as thermal wafer processing, exposure tool focus control, materials, etc.

1.2 Background — Fundamental to manufacturing is the gauging or measurement process. It is required initially to develop a usable manufacturing capability and then to verify that what is being manufactured conforms to specification/expectation.

2 Scope

2.1 This document discusses determining the performance of gauging/measurement systems for a very specific application — the lithography section of integrated circuit wafer fabrication. This document in many cases, will be applicable to IC mask-making, in which case the word “mask” can be substituted for “wafer.”

2.2 It is acknowledged that the final measurement for a fabricated wafer is the electrical functionality. However, the intermediate lithographic measurements can be useful in prediction and control of final functionality. This document is intended to be useful for this litho-metrology application, irrespective of the technology employed.

2.3 Measurement results and system performance depend on the sample(s) used. Therefore, performance for different systems or the same system at different times can only be appropriately compared when the measurements are obtained with a sample of the same material composition.

2.4 The parameter addressed is precision. Additional important parameters are reliability and cleanliness, which have been addressed by other SEMI standards.

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 E10 — Standard for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM)

SEMI P19 — Specification for Metrology Pattern Cells for Integrated Circuit Manufacture

3.2 *ASTM Standards*[1]

ASTM D 1129 — Standard Terminology Relating to Water

ASTM C 609 — Standard Test Method for Measurement of Small Color Differences Between Ceramic Wall or Floor Tile

ASTM D 4790 — Standard Terminology of Aromatic Hydrocarbons and Related Chemicals

ASTM E 180 — Standard Practice for Determining the Precision of ASTM Methods for Analysis and Testing of Industrial and Specialty Chemicals

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

4 Applications

4.1 *linewidth measurement* — this task is to measure linewidths as defined by SEMI P19.

NOTE 1: Pitch is not addressed in this document.

4.2 *contact hole measurement* — contact and via hole area measurement is a different application which may use the same definitions and procedures as line-width measurement.

1 American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959, Phone: (610) 832-9585, Fax: (610) 832-9555, http://www.astm.org/

5 Terminology

5.1 *Definitions*

5.1.1 *precision* — the degree of agreement of repeated measurements of the same parameter expressed quantitatively as the standard deviation, computed from the results of a series of controlled determinations [ASTM D 1129, D-29].

5.1.2 A frequency plot of measurements taken with random error illustrates precision. The spread or variation of measurement in test A is smaller than that in test B. The results of test A are more precise than the results from test B. See Figure 1.

NOTE 2: Any test procedure used needs to differentiate between system and wafer contribution.

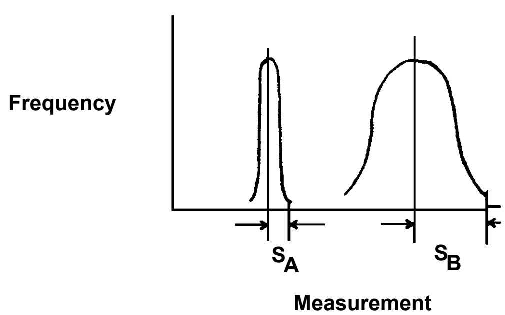


Figure 1
Generic Frequency Plot

5.1.3 *repeatability* — the standard deviation of results obtained by the same operator using the same instrument in successive measurements [ASTM C 609, C-21]. The same system parameters need to be used. The degree to which the individual operator affects the measured result is a critical parameter and must be identified and benchmarked.

NOTE 3: The degree to which the individual operator affects the measured result may be a critical parameter and must be identified.

5.1.4 *reproducibility* — the precision of a test method expressed in terms of agreement expected between measurements made in different laboratories using similar apparatus and the same procedure [ASTM D 4790, D-16].

5.1.5 *stability* — the standard deviation of means of groups of measurements taken at specified intervals over an extended period of time.

NOTE 4: The means are used to avoid including the measurement precision. Stability is a characterization of the system independent of precision. It is important to use a stable sample so that system stability, independent of the sample, is determined.

5.1.6 *standard deviation* — a measure of the dispersion of a series of results around their average, expressed as the square root of the quantity, obtained by adding the squares of the deviations from the average of the results and dividing by the number of observations minus one. It is also the square root of the variance and can be calculated as follows:

$$s = \sqrt{\frac{\sum (x_i = \bar{x})^2}{n-1}} \qquad (1)$$

Where:

s = estimated standard deviation of the series of results

X_i = each individual value

$\overline{X}$ = average (arithmetic mean) of all values, and

n = number of values

The following forms of this equation are more convenient for computation, especially when using a calculator:

$$s = \sqrt{\frac{\sum x^2 - \left(\sum x\right)^2 / n}{n-1}} \qquad (2)$$

or

$$s = \sqrt{\frac{n\sum x^2 - \left(\sum x\right)^2}{n(n-1)}} \qquad (3)$$

where:

s = estimated standard deviation

$\sum x^2$ = sum of the squares of all the individual values

$(\sum x)^2$ = square of the total of the individual values, and

n = number of values

NOTE 5: Care must be taken in using either of these equations that a sufficient number of decimal places is carried in the sum of the values and in the sum of their square so that serious rounding errors do not occur. For best results, all rounding should be postponed until after a value has been obtained for s [ASTM E 180, E 15].

6 Procedures to Benchmark Precision

6.1 *Precision Types*

6.1.1 *Static Precision* — A series of measurements made of a single feature where, for each measurement, the information is reacquired and reprocessed. The minimal intervention required to repeat the measurement will be used. The standard deviation will be calculated based on the sample data.

6.1.2 *Z (Axis Adjustment) Precision* — A series of measurements is made of a single feature where it is necessary to refocus before each measurement (without intentional movement in the x and y axes before each measurement). The standard deviation will be calculated based on the sample data.

6.1.2.1 *Dynamic Precision* — Make one measurement of grouped line and space features at n number of sites on a focus/exposure matrix wafer, which includes typical size and side wall angle variations. Remove the wafer from the system, then reload and remeasure. Compute the dynamic precision, 3s, by the double sample method (see Section 8.1.3).

6.1.2.1.1 A total of 1 size × *n* sites × 2 repeates = 2*n* measure-ments per wafer × 3 passes = 6*n* measurements required.

6.1.2.1.2 10 is a minimum recommended value for *n*.

6.1.2.1.3 This may also be redone for different thicknesses of lines to be measured and repeated for each of the wafer types in the process.

7 Precision Test

7.1 *Test Methods*

7.1.1 *Stability Test Method* — Makes a group of five measurements of a stable feature, such as etched polysilicon, at the same position, daily. Any system adjustment, maintenance, environment variation is allowed, but noted. Recalibration is optional, but is noted. Use a feature which doesn't change over time, or with repeated measurements. Plot the daily averages on an individual control chart with control limits based on the moving range of the daily averages.

7.1.2 *Sequence Test Method* — A series or sequence of measurements is taken of the same physical location. Any change between measurements determines the type of precision tested.

7.1.3 *Double Sample Test Method* — Two measurements are taken at separate times within the test run at a number of different physical locations. A series of sites is used which have: same nominal size, same proximity of other features, similar side wall angle, etc.

7.2 *Test Duration*

7.2.1 *Short Term* — No system calibration, adjustment, or maintenance will be done. The period should be short enough to minimize the effect of environmental variations. See R1-1.

7.2.2 *Long Term* — Any system adjustments, maintenance, environment variation is allowed. See R1-2. Recalibration is optional.

7.2.3 *Presentation of Results* — Some information, relative to the data, must be included to qualify the results. Graphical representation of the data is recommended.

7.2.3.1 The following must be included:

- The estimated (1, 2, or 3) standard deviation(s),
- Short or Long Term
- Confidence interval (see Application Note A.3)
- The number of measurements or sample size (*n*)
- Describe the feature film and substrate film
- Nominal or average measurement
- Feature Type: line or space or hole, grouped or isolated
- The frequency of recalibration
- Test identified as the type performed

7.2.3.1.1 Additional information which should also be included, particularly with unusual conditions, are:

- Metric units are recommended, such as nanometer [nm] or micrometer [µm]
- Feature characteristics, such as: sidewall angle, wall profile, corner radius, materials, thickness, index of refraction, edge waviness, edge roughness
- Duration of the test
- The sample frequency
- Significant parameters such as operator, system model, serial number, pertinent environmental conditions, etc.

8 Related Documents

"ASTM Compilation of ASTM Standard Definitions," American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohoken, PA 19428.

Nyyssonen, Dr. Robert D. Larrabee, "Submicrometer Linewidth Metrology for the Optical Microscope," (J. of Research of National Bureau of Standards, Vol. 92, No. 3, May/June 1987). National Institute of Standards and Technology (NIST), Bldg. 202, Room 204, Gaithersburg, MD 20899.

Dr. Robert D. Larrabee and Dr. Michael T. Postek, "Precision, Accuracy, Uncertainty and Traceability and Their Application to Submicrometer Dimensional Metrology" (Solid-State Electronics, Vol. 36, No 5, pp 673-684, 1993).

SEMASPEC #91090709A-ENG, "Introduction to Measurement Capabilities Studies," SEMATECH, Technology Transfer, 2706 Montopolis Drive, Austin, TX 78741.

RELATED INFORMATION 1

NOTICE: The material contained in this related information is not an official part of SEMI P24 and is not meant to modify or supersede the standard in any way. This information is provided as a source of information to aid in the application of the standard. As such, it is to be considered as reference material only. The standard should be referred to in all cases. This related information was approved for publication by full balloted procedures.

R1-1 Short Term Test Duration

R1-1.1 It is recommended the short term test duration be 30 measurements done in the shortest possible time under the most limited of conditions to eliminate extraneous sources of variation.

R1-2 Long Term Duration

R1-2.1 Common practice requires about 30 degrees of freedom in the highest level of sources of variation. For example, one should continue a long term study over 30 working days, if days is the highest level of variation.

R1-3 Confidence Interval

R1-3.1 This is one way in which confidence interval is calculated.

$$\sqrt{\left(\frac{vs^2}{x^2_{v.1-\alpha/2}}\right) \le \sigma^2 \le \left(\frac{vs^2}{x^2_{v.\alpha/2}}\right)}$$

where

v = df in the extimated standard deviation,

α/2 – the alpha risk accepted for the estimate (1-α) is the “confidence level”, and

X^2 refers to the “chi-square” distribution which fits variances. The equation is arranged such that the area under the chi-square distribution is to the right of the designated value.

R1-3.2 The reference distribution looks something like Figure R1-1 — its shape depends on the degrees of freedom in the estimate.

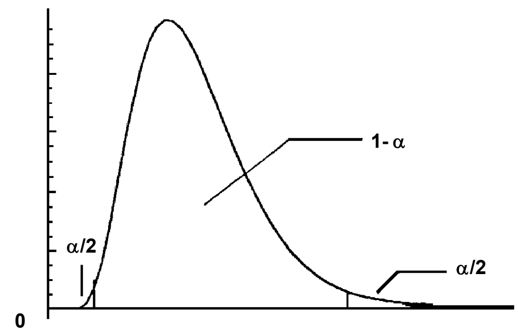


Figure R1-1
Example of a Chi-Square Distribution

NOTICE: SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature, respecting any materials or equipment mentioned herein. These standards are subject to change without notice.

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SEMI P25-94 (Reapproved 1104)
SPECIFICATION FOR MEASURING DEPTH OF FOCUS AND BEST FOCUS

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 August 16, 2004. Initially available at www.semi.org September 2004; to be published November 2004. Originally published in 1994.

1 Purpose

1.1 This document provides a common descriptive vocabulary and outline of basic technique for use by photolithographers in the IC industry to gauge and report the depth of focus, astigmatism, and field curvature of IC photolithographic instruments (e.g., scanners, steppers). [Hereafter referred to as "instrument" or "instruments."]

2 Scope

2.1 This specification is limited to the measurement of focus and depth of focus for photolithography as used in the manufacture of integrated circuits and closely allied technologies. Because of the wide variation in equipment techniques, it is not possible to provide a definitive measurement procedure for these parameters. Rather, in this document, a basic guideline is offered.

NOTE 1: This technique has value in determining the best focus setting for a given application, however the main concern will be the determination for the depth of focus, astigmatism and field curvature for the purpose of comparing different instruments and processes.

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 It must be emphasized that the values of depth of focus, astigmatism, and field curvature cannot be determined for a given instrument independent of the effects of the image geometries and the image transfer process. The values will have to be determined under the constraints of a practical application process, suitable for the instrument, illumination, process, object pattern, and environment. Thus, the process to be used for a fair measure of instrument performance must be one that is appropriate and has been optimized for the given instrument and application. Comparison of the performance of two different instruments will inherently be a comparison of the the total application, instrument specific processes included. A description of the process is a necessary part of the report of a depth of focus, astigmatism or field curvature measurement. Relying on values that were obtained under significantly different application conditions from the desired application will result in error and potential unexpected process failure.

4 Referenced Standards

4.1 *SEMI Standards*

SEMI P19 — Metrology Pattern Cells for Integrated Circuit Manufacture

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

5 Terminology

5.1 *Definitions*

NOTE 2: The scope of the following definitions does not necessarily cover application outside of the procedures discussed herein. For more universal definitions and discussion, the user is referred to any of the standard optical texts.

5.1.1 *image (micropatterning)* — any single geometric form appearing in a layout: (1) drafting — as a part of a master drawing or layout; (2) optical — as projected on a screen or viewed, usually at some magnification or reduction; (3) oxide — as etched in the silicon dioxide layer on an oxidized silicon wafer; (4) photographic — as in a photomask or in the emulsion of a photographic film or plate; (5) as a photoresist, an exposed and developed coating on a substrate.

5.1.2 *processed image (micropatterning)* — any single geometric form appearing in the realized pattern or topographical variation in a material surface or material constitution, obtained by a physical process of pattern transference from an optical image.

NOTE 3: This definition is intended to extend the discussion of depth of focus and focus to include both cases where the images are realized in photoresist films, per the image definition given above, and cases where there may not in fact be a photoresist film involved in the optical pattern transference process. Examples include photoactive chemical vapor deposition and photo ablation.

5.1.3 *standard coordinates* — a system of Cartesian coordinates with the z axis along the optical axis of the system and with the x and y axes in the flat plane perpendicular to the optical axis. The system user or the supplier will specify the x and y directions in this plane for any particular equipment studies.

NOTE 4: Upon occasion, cylindrical coordinates may be used for special discussions, for example, mapping astigmatism. The standard transform is used between the Cartesian (x,y) and the cylindrical (r,ø) is used.

NOTE 5: The x and y coordinates are taken as displacements from the optical axis along a flat plane. Thus, if the image plane is curved, the x and y coordinates are taken from the projection of the curved image plane onto a flat plane. Consistently, r is taken as the distance along a perpendicular to the optical axis.

NOTE 6: A displacement along the z axis (and hence the optical axis) from a reference position will be negative for displacements toward midpoint of the optical system and positive for displacements away from the midpoint of the optical system, regardless of whether the reference position is on the object side or on the image side or coincident with some portion of the optical system.

NOTE 7: For folded optical systems, the coordinate system is allowed to rotate with position along the optical axis so that the above definition holds at any given position along the axis. Alternately, it may be assumed that for purposes of using this coordinate system, all optical paths are represented as unfolded.

5.1.4 *image field* — the extent of the image along the x and y axes. It may be defined by the limits of image quality, as a practical matter, for the intended application.

NOTE 8: Definitions 5.1.1 and 5.1..2 in combination with 5.1.4 define the drafting image field, the optical image field, the processed image field, etc. The term “image” refers to a single geometrical form. The term “field” refers to the complete set of forms.

5.1.5 *practical use* — the conditions of photoprocess, image geometries, etc. that are required for the intended use of the instrument. The practical use is specified by the following:

- *process* — photoresist type and chemical processing, exposure conditions, and environmental conditions (temperature and humidty setpoints and stability).
- *pattern* — description or diagram of the test structures, including the choice geometrical dimensions, orientations, positions.
- *substrate* — the substrate quality and specifications, including all pre-existing structures and layers on the substrate.
- *leveling* — the leveling mechanism used to hold the substrate at the desired position and angle with respect to the optical image plane.
- *site* — list or map of the image sites in the processed image field used for the tests.
- *criteria* — the acceptance criteria used in the evaluation of the processed images.

NOTE 9: Typically, the instrument vendor will indicate a range of practical use parameters and the instrument user will select from this range the actual conditions, as is appropriate to the user’s needs.

5.1.6 *resolution, practical* — the minimum line width that reproduces the mask (or drafting) dimensions faithfully. [SEMI Micropatterning — Terms and Definitions Relating to the Microlithography Industry]

NOTE 10: The practical resolution is a number specified by the equipment vendor.

5.1.7 *point-like object* — A circular or square form in the image where the diameter or width is equal to the practical resolution.

5.1.8 *evaluative line pattern* — A pattern in the image constructed of 3 to 5 straight parallel lines where the lines are oriented at some specified angle with respect to the standard coordinates and where the width of the lines is equal to the practical resolution and the pitch of the lines is twice the practical resolution. (See SEMI P19.)

5.1.9 *saggital lines* — An evaluative line pattern where the lines lie along a radius to the optical axis. (See Figure 1.)

NOTE 11: Saggital lines are primarily formed from light rays that do not lie in planes containing the optical axis. For optical systems having cylindrical symmetry, such as some reduction steppers, the saggital lines will be radial lines from some particular point of the image field. For other systems the lines may not be radial. For example, the saggital direction for scanners is perpendicular to the direction of the scan throughout the image field.

5.1.10 *tangential lines* — An evaluative line pattern where the lines lie perpendicular to a radius to the optical axis. (See Figure 1.)

NOTE 12: Tangential lines are primarily formed from light rays that do lie in planes containing the optical axis. For systems having cylindrical symmetry, tangential lines lie upon circles about some particular point of the image field. For other systems, the lines may not be so arranged. For example, the tangential direction for scanners is parallel to the direction of the scan throughout the image field.

5.1.11 *focus* — a condition of geometric adjustment of the lens’s object, the optical system and the image plane such that the optical image rays originating from a given point in the object converge to the smallest possible area at the corresponding point in the optical image. It is always given as a numerical displacement of the optical image point along the optical axis from some arbitrary reference such as an optical exit surface, optical center, conjugate plane, etc. Focus may vary across the image field and is properly given as a z axis value for a specified image site in the image field. (See the definition for Focal Surface.)

NOTE 13: Point-like objects will have the sharpest optical image at this z-axis position. The z-axis position for the sharpest processed image of point-like objects will usually have a constant offset from the z-axis position for the sharpest optical image for point-like objects. (See “mean focus” and “best focus” definitions that follow in the text.)

NOTE 14: This is also the position which yields the highest contrast in the photon flux at the given point in the optical image.

5.1.12 *line focus* — the z axis position where for evaluative lines in the image, the optical image has the highest contrast and the evaluative line pattern will consequently appear with the correct width and pitch. Line focus may vary across the image field and is properly given as a z axis value for a specified image site in the image field. It also varies with the line angle, and the line focus must, therefore, include a specification of the angle (e.g., saggital, tangential, or some other angle).

5.1.13 *focal surface* — the surface determined by finding the focus for each point-like object in the optical image field, with the object fixed with respect to the lens. The focal surface is then the map of z axis displacements for the highest contrast at each point in the optical image field as a function of the (x,y) or (r,ø) coordinates.

NOTE 15: It is important to remember that the unqualified focal surface is determined using point-like objects, not lines or gratings. Separate determinations must be made for non-point-like objects.

5.1.14 *field flatness* — the difference between the maximum and the minimum z axis positions over the focal surface.

5.1.15 *saggital focal surface* — the focal surface determined by examining only saggital lines.

5.1.16 *tangential focal surface* — the focal surface determined by examining only the tangential lines.

5.1.17 *normal astigmatism* — the difference in z axis position at each image site between the saggital focal surface and the tangential focal surface. Astigmatism is a map of scalar values over the (x,y) coordinates of the image field.

5.1.18 *rotated astigmatism* — at each image site, the z axis difference for the line focus of two evaluative line sets, oriented at right angles to each other and at some specified angle to the coordinate system, where the specified angle is selected so that the z axis focus difference is a maximum at the given image site. The specified angle may vary from image site to image site.

NOTE 16: This is called “rotated” astigmatism because the specified angle is not necessarily the saggital or tangential direction.

5.1.19 *mean focus* — the z axis position representing the area average focal surface for point-like objects in the optical image.

5.1.20 *best focus* — a position of the processed image surface such that the best compromise of focus across the whole of the processed image is obtained, as defined by the application requirements upon the processed image. The best focus is a single numerical value for the processed image surface displacement. The best compromise may be such as to optimize the possible defocus range or may optimize the line width variations or may minimize the deviation from some target width or may relate to some other processed image parameter.

NOTE 17: Because of processing effects, this may or may not correspond to an optical conjugate plane coincident with the photoresist film or other processed layer — top, middle, or bottom.

NOTE 18: Because the processed image surface will generally have a curvature that is not adjustable, it is not usual for the processed image surface to fully correspond to any of the focal surfaces. Focal surfaces are defined by determining the z-axis position for a given focus condition, as a function of the image position. A processed image surface is therefore set at a z axis position that provides the best compliance to the focal surface.

5.1.21 *defocus* — the distance, perpendicular to the image plane, between the processed image plane and the plane of best focus.

NOTE 19: A defocus of zero is the best focus position, a positive defocus places the optical image plane further from the lens, a negative defocus places the optical image plane closer to the lens.

5.1.22 *focal range* — depth of focus — the total distance of defocus where over the whole of the processed image field, the processed image is sufficiently resolved for practical use.

5.1.23 *depth of focus map* — a plot, for each position in the image field, of the greatest defocus in the positive direction and the greatest defocus in the negative direction, where the processed image is sufficiently resolved for practical use.

NOTE 20: As stated previously, the focal range or the depth of focus are dependent on the process, upon the image geometries (especially the line width), and upon the permissible deviations. The depth of focus maps may be dependant, among other things, on the process, line width, and image geometry, especially the choice of point-like patterns or line-like patterns along the saggital, tangential, or other directions. Several maps may be produced as part of a test, covering these variations.

6 Procedure

6.1 *Pattern* — See SEMI P19. A pattern and pattern dimensions are to be selected in accordance with the most reasonable correspondence to the intended application of the equipment. Typically, the pattern will consist of two sets of evaluative lines. A sequence of patterns of varying line widths may also be employed, in which case the depth of focus may be reported as a function of the line width. The pattern selection and dimensions must be included as part of the report.

6.2 *Test Sites* — The pattern is to be repeated at least nine times over the image field. The minimum of nine sites will include the four corners of the image, the four edge midpoints of the image field and the center of the image field. Whichever many sites are used, the sites must be distributed symmetrical and uniformly over the image field, giving no special weight to any portion of the image field. For examples, see Figure 2.

6.3 *Process* — A test image will be printed under the same conditions and processes to be used in the practical application (see Section 2) of the instrument (stepper, scanner, etc.). The process description will be included in the depth of focus and best focus report.

6.4 *Focus Steps* — The image will be printed several times, varying the defocus by a fixed amount between each print. The amount of variation of defocus between steps and the limits of the defocus will be selected so as to bracket the expected best focus position and to reach beyond the depth of focus at the extremes of the image series, as best as can be determined. The number and size of the defocus steps must be specified in the report.

6.5 *Image Array* — These multiple images can be a row of separate exposure fields on one substrate, multiple stepped displaced exposures of the test geometry within one image field region, or even exposures on entirely separate substrates. The particular strategy is usually constrained by the functions of the instrument under test.

6.6 *Test Measurements* — For each image site for both test pattern orientations and at each value of defocus, the processed image geometries will be examined and either accepted or rejected on the basis of image sharpness, image size or some related image characteristic. Usually this examination will use the line width as the acceptance criteria. The total number of the measurements will be twice the number of sites times the number of defocus steps.

6.7 *Quantitative Image Evaluation* — The photoresist image patterns will be examined or measured for deviation from the target, in a manner specified by the vendor or user of the instrument. An acceptable image is where the variation of the pattern is not outside the permissible deviation under the conditions of the intended use of the equipment. The defocus values for which the image is usable will be determined at each image site within the image field.

6.8 *Depth of Focus and Best Focus Determination* — The defocus variation over which there are usable images at simultaneously every test site within the field, by the above criteria, will be reported as the practical focal range. In accordance with the definition, the best focus will be the z axis position where some target specification is met or the possible defocus is maximized or the line deviation minimized, etc. If there is no common range of usable defocus across the field, the depth of focus is zero and the best focus is undetermined. This can occur due to, among other things, a large plane tilt of substrate to the optical axis, high aerial image focus surface curvature, high astigmatism, and auto focus system instabilities.

6.9 *Focal Astigmatism Determination* — The test measurements are separated into two groups, one group for each of the two different orthogonal orientations of the test pattern. These groups are referred to as the “S” and “T” groups, however the saggital and tangential orientations have not necessarily been used in accordance with the definition of “rotated astigmatism.”

6.9.1 For each group separately, the focal surface is determined by using for each site the midpoint of the defocus values where the processed image is found to be acceptable, in accordance with Section 6.7.

6.9.2 The difference in z position between these surfaces for each image site is calculated. These differences are plotted as a function of image position. This map of values is the astigmatism.

6.9.3 The maximum of the absolute values is the maximum astigmatism.

6.9.4 The average of the absolute values is the mean astigmatism.

6.10 *Field Flatness Determination* — Two alternative but essentially equivalent methods of determining the focal surface are allowed:

a. The focal surface which is the midpoint of the S and T focal surfaces is calculated.

b. Alternatively, if point-like objects are available in the image for evaluation, the focal surface may be obtained by finding the z displacement for the best processed point image at each image site.

6.10.1 This focal surface is reported as a map of z displacements as a function of image position. This map is the curvature of field.

6.10.2 The difference between the minimum z displacement in the focal surface and the maximum z displacement in the focal surface is the maximum curvature of field.

NOTE 21: This includes optical image curvature, wafer curvature, fixture curvature, etc. This procedure for the sake of simplicity does not separate these effects. It is an error to consider this measure of field flatness equivalent to a measure of the optical image focal surface.

7 Report

7.1 The depth of focus, best focus, etc. reports will include a description of the practical use, per definition 5.1.5. In addition, the report should include mention of any special mechanical considerations — in particular, among others, mention should be made if a chip leveling scheme is used and whether this scheme is site by site or global.

7.2 List of report contents:

- Process: substrate and layer types and processing, exposure conditions
- Pattern: description or diagram of the test structures, including the choice of S and T or X and Y orientations
- Wafer: the wafer quality and specifications.
- Leveling: leveling mechanism.
- Sites: list or map of the image sites.
- Criteria: the acceptance criteria used in the evaluation of the test structures.
- Depth of Focus or Focal Range (single overall values)
- Best Focus (single overall value)
- Astigmatism map
- Maximum Astigmatism
- Mean Astigmatism
- Field Flatness map
- Maximum Curvature of Field

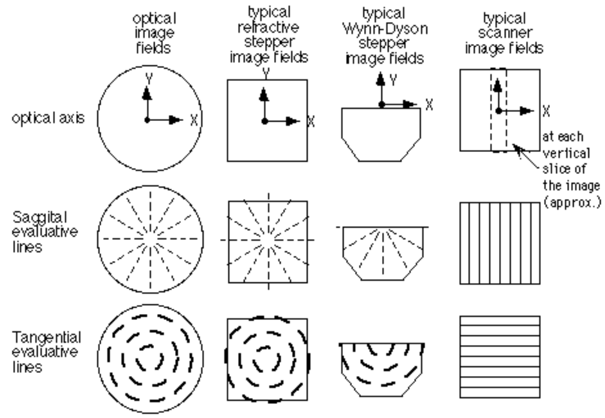

Figure 1
The Coordinate System and the Sagittal and Tangential Lines, Shown for the Optical Image Cylindrical Symmetry and for the Actual Processed Images of Steppers and Scanners

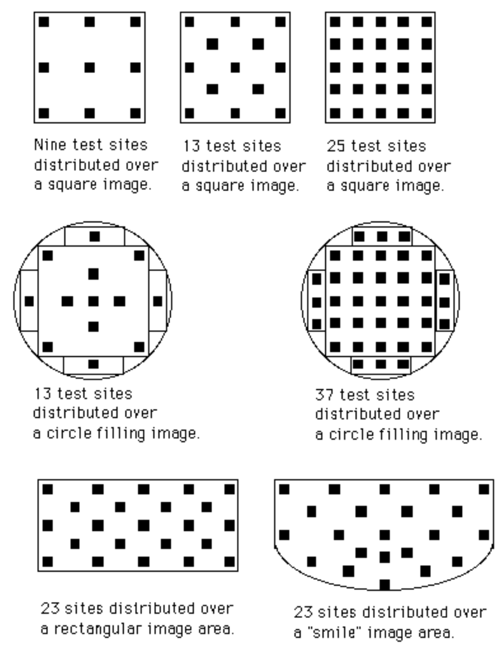

Figure 2
Typical Test Site Placements in Various Types of Image Fields

SEMI P26-0703
PARAMETER CHECKLIST FOR PHOTORESIST SENSITIVITY MEASUREMENT

This checklist was technically approved by the Global Micropatterning Committee and is the direct responsibility of the Japanese Micropatterning Committee. Current edition approved by the Japanese Regional Standards Committee on April 28, 2003. Initially available at www.semi.org June 2003; to be published July 2003. Originally published in 1996.

1 Purpose

1.1 This checklist identifies the parameters for the measurement of photoresist sensitivity in order to avoid the variations between the supplier and users of photoresist.

2 Scope

2.1 The resists for which this guideline is intended are positive photoresist.

2.2 In discussions between the supplier and the user of the resists, quantitative values should be provided for each parameter.

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 Standard*

SEMI P27 — Parameter Checklist for Resist Thickness Measurement on a Substrate

3.2 *ASTM*[1]

ASTM F1059 — Practice for Calculating the Contrast and Threshold Sensitivity of a Positive Photoresist

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

4 Terminology

4.1 *Definitions*

4.1.1 E_{op} *(optimum energy)* — the exposure energy where the mask dimensions can be reproduced faithfully.

4.1.2 E_{th} *(threshold energy)* — the exposure energy where the remained thickness ratio becomes zero on the sensitivity curve.

5 Parameters

5.1 *Substrate* — Silicon wafer

5.2 *Pre-Treatment of Substrate*

5.2.1 Removal of native oxide on silicon wafer is recommended.

5.2.2 Describe the process when the surface of silicon wafer has been treated with HMDS.

5.3 *Resist*

5.3.1 Trade-name of photoresist.

5.3.2 Film thickness after prebake. (Recommended thickness is 1.0–1.2 µ m.)

5.4 *Prebake Condition*

5.4.1 Type of equipment for prebake; contact or proximity-bake.

5.4.2 Measuring position of the temperature in baking equipment and equipment for temperature measuring.

5.4.3 Baking time (s).

5.4.4 Program sequence.

5.5 *Exposure*

5.5.1 Type of exposure machine; stepper or mirror projection.

5.5.2 Wavelength and half width (nm).

5.5.3 Light intensity of the exposed surface (mW/cm^2).

5.5.4 Numerical Aperture and sigma value.

5.6 *Post-Exposure Bake (if performed)*

5.6.1 Type of equipment for post-exposure bake; contact or proximity-bake.

5.6.2 Measuring position of the temperature in baking equipment and equipment for temperature measuring.

5.6.3 Baking time (s).

5.6.4 Program sequence.

1 American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, USA. Telephone: 610.832.9585, Fax: 610.832.9555, Website: www.astm.org

5.6.5 Film thickness after post-exposure bake.

5.7 *Development*

5.7.1 Type of developer; commercial name and chemical composition.

5.7.2 Concentration of developer (weight % or molar %).

5.7.3 Dilution factor.

5.7.4 Method; Spray (nozzle type, rotation speed, flow rate of developer), Puddle (program of sequence).

5.7.5 Temperature of developer, room temperature.

5.7.6 Development time (s).

5.8 *Postbake*

5.8.1 Type of equipment for postbake; contact or proximity-bake.

5.8.2 Measuring position of the temperature in baking equipment and equipment for temperature measuring.

5.8.3 Time (s).

5.8.4 Program sequence.

5.9 *Measuring Equipment*

5.9.1 Specify the measurement system for the film thickness measurement.

5.9.2 Specify the measurement system for the pattern width measurement.

5.10 *Other* — Line-width of pattern in the reticle affects to E_{op}. The use of reticle with the width accuracy of $\pm$ 5/100 μm to the pattern, or co-share of reticle for the crosscheck is recommended for the purpose of this guideline.

SEMI P27-96 (Reapproved 0703)
PARAMETER CHECKLIST FOR RESIST THICKNESS MEASUREMENT ON A SUBSTRATE

This checklist was technically approved by the Global Micropatterning Committee and is the direct responsibility of the Japanese Micropatterning Committee. Current edition approved by the Japanese Regional Standards Committee on April 28, 2003. Initially available at www.semi.org June 2003; to be published July 2003. Originally published in 1996.

1 Purpose

1.1 This checklist identifies the parameters for the thickness measurement of single layer resist on a substrate. Several methods are known for the thickness measurement of thin films, among them two methods are widely used for the thickness measurement of resist films.

1.2 They are the surface profilemeters which use mechanical contact method to detect the topology of a surface, and the light interference method which can be used only for transparent films.

1.3 The contacting method has more accuracy than light interference method, but the precision of the measurement is limited. The light interference method shows much more precision than the other but the results depend on measuring conditions.

2 Scope

2.1 This guideline describes on the parameters for the thickness measurement of single layer resist in lithography process.

2.2 For example, pre-expose resist thickness measurement on a bare silicon wafer for the QC of an optical resist, or the resist thickness measurement of partially exposed and fully exposed films after development for the determination of a characteristic curve of a resist.

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 *ASTM Standard*[1]

ASTM F804 — Standard Practice for Producing Spin Coating Resist Curves, 7.4 Thickness Measuring Instrument

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

4 Parameters for Contact Type Measuring Instruments (Surface Profilometer)

1. Name of the instrument used for the measurement
2. Pressure of the stylus
3. Radius of curvature of the stylus tip
4. Type of substrate
5. The method of making a scratch on the surface of the resist
6. Temperature and relative humidity of the room

NOTE 1: The stylus pressure should be so adjusted that it does not leave a visible indented track mark on the resist surface at × 50 optical microscope magnification.

5 Parameters for Light Interference Thickness Measurement Apparatus

1. Name of the apparatus used for the measurement
2. Refractive index or Cauchy indexes of the resist used as the parameter of the measurement

$$n = A + \frac{B}{Y^2} + \frac{C}{Y^4}$$

where

A, B, C = Cauchy indexes

n = refractive index

Y = wave length

1 American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, USA. Telephone: 610.832.9585, Fax: 610.832.9555, Website: www.astm.org

3. The range of wave length used for the measurement should be specified. Type of the substrate. Surface condition, cleaning method and the refractive index of the substrate if available.

4. Magnification setting

5. Type of optical filter

6. Temperature and relative humidity of the room

SEMI P28-96
SPECIFICATION FOR OVERLAY-METROLOGY TEST PATTERNS FOR INTEGRATED-CIRCUIT MANUFACTURE

1 Purpose

1.1 This document defines several standard overlay-metrology patterns that are used by metrology equipment users to evaluate and test micropatterning equipment and processes in integrated circuit (IC) manufacturing. These overlay cells may be placed by optional patterning methods onto substrates during the manufacturing process. Usage of the standard overlay patterns is an attempt to provide consistent industrywide use of automated metrology equipment.

2 Scope

2.1 This specification defines general designs that describe the shape, size, design rules, and placement considerations (where appropriate) of several basic patterns for overlay metrology. These standard test patterns can be used for optical, scanning electron beam, and other types of metrology.

3 Limitations

3.1 The patterns described in this document represent the first pass at an industrywide commonality for the purpose of compatibility among various types of automated metrology equipment. It is not suggested, however, that these test patterns are a full complement or are optimal for all overlay-metrology applications. This document does not attempt to specify how the patterns are to be imaged or measured on the substrate.

4 Referenced Documents

4.1 *SEMI Documents*

SEMI International Standards Handbook — Section E: Compilation of Terms

SEMI P6 — Specification for Registration Marks for Photomasks

SEMI P18 — Specification for Overlay Capabilities of Wafer Steppers

SEMI P19 — Specification for Metrology Pattern Cells for Integrated Circuit Manufacture

4.2 *ASTM Standard*[1]

F 127-84 — Definition of Terms Relating to Photomasking Technology for Microelectronics

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5 Terminology

5.1 *centerline* — a reference line that is equidistant from opposite edges of a feature.

5.2 *feature* — areas within a single continuous boundary (for example, an aggregate image) that have any physical property that is distinct from the background area outside the feature (e.g., the simplest element of a test pattern, such as a single line or bar). Some physical properties that may distinguish the feature are the refractive index, surface roughness, etc.

5.3 *feature dimension* — the dimension of interest; such as, the side of a box , bar width, and/or length.

5.4 *overlay (micropatterning)*

A vector quantity defined at every point on the wafer. It is the difference, O , between the vector position, P_1 , of a substrate geometry, and the vector position of the corresponding point, P_2 , in an overlaying pattern, which may consist of photoresist. [SEMI P18-92]

NOTE: All overlay test patterns are designed to provide both X and Y components of the vector overlay.

5.5 *pattern, overlay test* — a group of features for overlay metrology.

5.6 *pitch* — the distance between a point on an image and the corresponding point on the corresponding image in an adjacent functional pattern.

5.7 *substrate (materials)* — in semiconductor technology, a wafer that is the basis for subsequent processing operations in the fabrication of semiconductor devices or circuits. [ASTM F 1241-89] NOTE: The meaning of substrate is not limited to wafers.

6 General Specification

6.1 *Introduction*

6.1.1 This specification describes the overlay test patterns that are illustrated in the figures at the end of this document. The imaging means by which these test patterns are defined on the substrate may be selected by the user (see 6.2.1).

6.1.2 Characteristics of the overlay patterns, such as materials, topography, polarity, and method of pattern transfer will be defined by the user unless otherwise noted. When reporting measurements extracted from these overlay test patterns, the user should state the physical conditions (e.g., photoresist island on metal over an oxide window). The user should further state which features constitute the substrate geometry and which constitute the overlaying pattern (terms as used in the definition of overlay in 5.4). In general, the vectors P1 and P2 terminate at the geometrical centers of the substrate pattern and the overlaying pattern respectively.

6.2 *Applications*

6.2.1 The overlay test patterns are intended to be used in a variety of applications. The following applications list shows some uses for the overlay test patterns.

- Primary Pattern Generation
- Lithography & Metrology Equipment Characterization
- In-Line Process Overlay Monitoring
- Manufacturing Characterization
- Process Transfer Between Manufacturing Sites

6.3 *Guidelines*

6.3.1 The overlay test patterns described herein represent a basic metrology set from which composite patterns may be constructed.

6.3.2 Each overlay test pattern has a fundamental design. The user may adjust the dimensions appropriately as they apply to the user's specific processing/equipment situations.

6.3.3 It is required that labels, border lines, indicator marks, or any other adjacent features be avoided, or at least separated by a minimum of ten (10) micrometers from the overlay cell. This proximity guideline is defined to remind the user that patterns intended to be independent and symmetric be designed as circumstances permit. The user should determine actual spacing values, because spacing may be level-, process-, and/or tool-dependent.

6.3.4 It is recognized that there are design limitations dictated by the equipment and processes used to generate the pattern (e.g., computer aided graphics (CAD) grids, pattern generation (PG) rectangles, E-beam spot sizes). The user may modify the overlay test patterns in order to meet equipment limitations (e.g., stay on grid) provided that the resulting patterns or their representations retain the designed structures and symmetry.

7 Detailed Specification

7.1 *Introduction*

7.1.1 The figures provided within this document are intended to illustrate sample layouts of several overlay test patterns, and to define appropriate design elements used within each. The overlay test pattern dimensions are provided when appropriate. It is understood that, to optimize the test pattern's performance in a specific application, the user may deviate beyond this standard.

7.2 *Specific Overlay Patterns* — All patterns have 90° rotational symmetry.

7.2.1 *Box-in-Box (see Figure 1)*

7.2.1.1 The box-in-box test pattern is designed to be a test pattern for overlay measurement on metrology equipment. This is the simplest possible design presented.

7.2.1.2 The box-in-box test pattern consists of two square features. Each box is normally defined by a different imaging step; that is, one box corresponds to the substrate geometry and the other box corresponds to the overlaying pattern (5.4). The two boxes are designed to be concentric.

7.2.1.3 The design elements are the feature dimensions of the outer box, B_o, and of the inner box, B_i. The dimensions should follow these guidelines:

outer box: B_o = 12 – 30 micrometers (µm)

inner box: $B_i = B_o/2$

These specifications define a range of box sizes and their interfeature spacing. Users should modify the box-in-box dimensions as dictated by design rules, process, and/or measurement equipment requirements. The user should recognize that edges in close proximity may cause measurement errors.

7.2.2 *Frame-in-Frame (see Figure 2)*

7.2.2.1 The frame-in-frame test pattern is designed to be a test pattern for overlay measurement on metrology equipment. It has two designed edges per axis on each side of each imaged step. The additional information gained by having two features on each level, each with a centerline, may reduce the measurement uncertainty as compared to the box-in-box design.

7.2.2.2 The design elements are the pitch of opposite members of the outer frame (F_o), the pitch of opposite members of the inner frame (F_i), and the widths of the frames (W_o and/or W_i) as shown in Figure 2. Each frame is normally defined by a different imaging step; that is, one frame corresponds to the substrate geometry and the other box corresponds to the overlaying pattern (see 5.4). The frames are designed to be concentric.

7.2.2.3 The design elements are the outermost dimension of the outer frame (F_o), the outermost dimension for the inner frame (F_i), and the width(s) of the frames (W_o and/or W_i). The dimensions should follow these guidelines:

outer frame: F_o = 15–30 micrometers (µm)

inner frame: $F_i = F_o/2$

width: W = 1.0–1.5 µm for $F_o \leq 24$ µm, or 1.5–2.0 µm for $F_o \geq 24$ µm

NOTE: The width of the inner and outer bars may differ.

These specifications define a range of frame sizes and their interfeature spacing. Users may modify the frame-in-frame dimensions as dictated by design rules, process, and/or measurement equipment requirements.

7.2.3 *Bars-in-Bars (see Figure 3)*

7.2.3.1 The bars-in-bars test pattern is designed to be a test pattern for overlay measurement on metrology equipment. Each axis has two designed edges per axis on each side of each imaging step. The additional information gained by having two features on each level, each with a centerline, may reduce the measurement uncertainty as compared to the box-in-box design.

7.2.3.2 The overlay test pattern consists of two sets of bars, the outer set and the inner set. Each set of bars is arranged to form an overlay measurement frame as shown in Figure 3. Each bar-in-bar set is normally defined by a different imaging step; that is, the set of inner bars corresponds to the substrate geometry and the set of outer bars corresponds to the overlaying pattern (5.4), or vice versa. The two sets of bars are designed to be concentric.

7.2.3.3 The design elements are the pitch for the outer set of bars (B_o), the pitch for the inner set of bars (B_i), the length of the outer bars (L_o), the length of the inner bars (L_i), and the width(s) of the bars (W_o and/or W_i). The overlay test pattern dimensions should follow these guidelines:

outer bar set: B_o = 15–30 µm

inner bar set: $B_i = B_o/2$

outer bar length: L_o = 50%–70% B_o

inner bar length: L_I = 50%–70% B_i

width: W = 1.0–1.5 µm for $B_o \leq 24$ µm, or 1.5–2.0 µm for $B_o \geq 24$ µm

NOTE: The width of the inner and outer bars may differ.

These specifications define a range of box sizes and their interfeature spacing. Users may modify the box-in-box dimensions as dictated by design rules, process, and/or measurement equipment requirements. The user should recognize that edges in close proximity may cause measurement errors.

7.3 *User Considerations for Overlay-Metrology Equipment*

7.3.1 *Pattern Acquisition* — To ensure automatic acquisition of the desired overlay test pattern by an image-based automated overlay metrology equipment, one or more of the following may be required:

1. Separation of each overlay test pattern as required per metrology equipment specification.
2. Use of only one overlay test pattern in the measurement field-of-view.
3. Printing unique labels next to each overlay test pattern using the proximity guideline in Section 6.3.3.

7.3.2 *Feature Dimensions* — For each overlay test pattern, only a range of feature dimensions is defined (e.g., paragraph 7.2.2.3). The user and supplier together should determine that the dimensions of the overlay test patterns they select are those that consider design rules, the user's process capability, and limitations of the microlithography and measurement equipment.

7.3.2.1 *Width Dimensions* (frame-in-frame or bars-in-bars test patterns) — When all features of the overlay test pattern are imaged at the same process step, the widths of the inner and outer features are recommended to be equal, and of the same polarity, in order to minimize overlay-measurement errors.

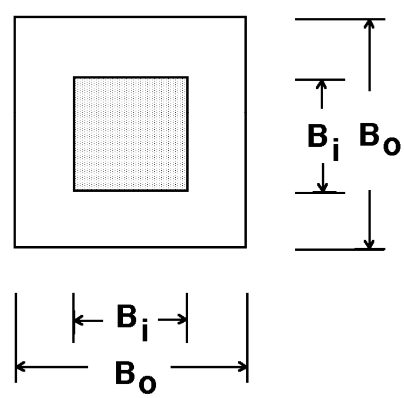


Figure 1
Box-in-Box

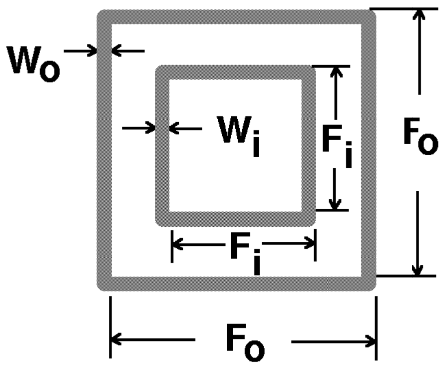


Figure 2
Frame-in-Frame

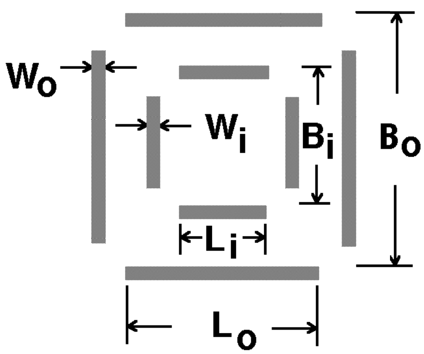


Figure 3
Bars-in-Bars

SEMI P29-0997

GUIDELINE FOR DESCRIPTION OF CHARACTERISTICS SPECIFIC TO HALFTONE/ATTENUATED PHASE SHIFT MASKS AND MASK BLANKS

1 Purpose

1.1 This guideline defines the characteristics specific to halftone/attenuated phase shift masks and mask blanks.

1.2 This guideline is intended to provide a baseline for specification of phase shift masks and mask blanks to be agreed between the supplier and user.

Because the phase shift mask is still under development, it may be needed to continue the research activity to standardize a final specification.

2 Scope

2.1 This guideline applies to halftone/attenuated phase shift masks and mask blanks for g-line, i-line, KrF, ArF, and/or DUV wavelengths.

2.2 These types of masks can be called either halftone or attenuated phase shift masks. This guideline uses "halftone phase shift masks" as the nomenclature.

2.3 Items not described in this guideline shall conform to SEMI P1.

3 Referenced Documents

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

3.1 *SEMI Documents*

SEMI P1 — Specification for Hard Surface Photomask Substrates

SEMI P22 — Guideline for Photomask Defect Classification and Size Definition

4 Terminology

4.1 *Terms for General Description*

4.1.1 *halftone phase shift mask* — a photomask designed to increase resolution through intentional control of light transmittance and phase against a transparent part by replacing a conventional opaque pattern with a thin, partially transmitting film (halftone shifter film) that controls light phase difference and transmittance.

4.1.2 *phase shift mask* — a photomask designed to increase resolution through intentional control of the exposure light phase.

4.2 *Terms for Structural Description*

4.2.1 *additional film type opaque ring* — an opaque ring composed of light shield materials other than the shifter.

4.2.2 *embedded shifter type opaque ring* — an opaque ring composed of small rectangles or line/space patterns in a shifter.

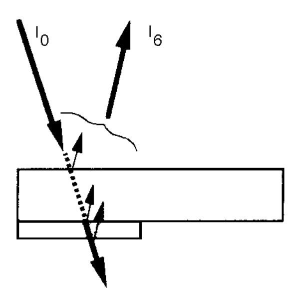
4.2.3 *multilayer halftone phase shift mask* — a halftone phase shift mask having multiple thin films of different material compositions to give a certain phase difference and transmittance. The layer that adjoins the substrate should be called the first layer.

4.2.4 *opaque ring* — an area of a certain width, adjacent to the periphery of the desired exposure area on a reticle, located in the non-exposure area of the reticle to obtain a dark portion required in a wafer lithography process.

4.2.5 *single-layer halftone phase shift mask* — halftone phase shift mask having a thin film of uniform material composition to give a certain phase difference and transmittance.

4.3 *Terms for Description of Optical Characteristics*

4.3.1 *glass side reflectivity* — a ratio of intensity of reflected light to intensity of incident light into the glass side that is the backside of the shifter film. The intensity of incident light is usually calculated by the intensity of reflected light measured using a reference mirror. (Figure 1 illustrates the glass side reflectivity.)

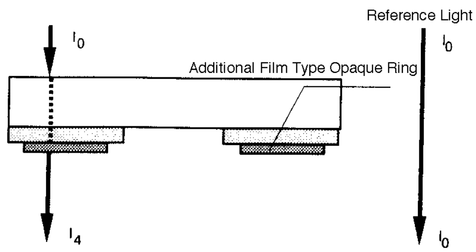


$$R_g = \frac{I_6}{I_0} \times 100 \quad (\%)$$

Figure 1
Glass Side Reflectivity

4.3.2 *opaque ring transmittance* — a ratio of intensity of light transmitted through the additional film type opaque ring area to intensity of incident light measured with air reference. (Figure 2 illustrates the opaque ring transmittance.)

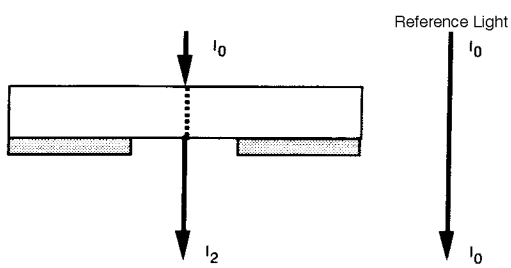
NOTE 1: For a halftone phase shift mask with embedded shifter type opaque ring, transmittance of the opaque ring area is not defined in this guideline because it depends heavily on the characteristics of the optical systems used.



$$T_4 = \frac{I_4}{I_0} \times 100 \quad (\%)$$

Figure 2
Opaque Ring Transmittance

4.3.3 *opening area transmittance* — a ratio of intensity of light transmitted through an opening area of a patterned halftone phase shift mask to intensity of vertical incident light measured with air reference. (Figure 3 illustrates the opening area transmittance.)

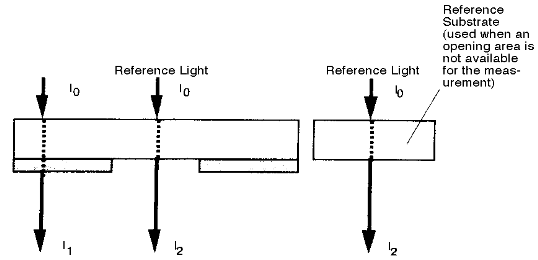


$$T_2 = \frac{I_2}{I_0} \times 100 \quad (\%)$$

Figure 3
Opening Area Transmittance

4.3.4 *phase difference* — a difference in phase of light generated by vertical transmission through a shifter area and an opening area with air equivalent to the shifter film in thickness.

4.3.5 *relative transmittance* — a ratio of intensity of light transmitted through a shifter area to intensity of light transmitted through an opening area. (Figure 4 illustrates the relative transmittance.)



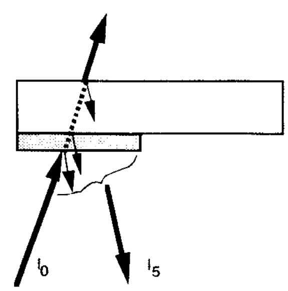
$$T_3 = \frac{T_1}{T_2} \times 100 \quad (\%)$$

$$= \frac{\left(\frac{I_1}{I_0}\right)}{\left(\frac{I_2}{I_0}\right)} \times 100$$

$$= \frac{I_1}{I_2} \times 100 \quad (\%)$$

Figure 4
Relative Transmittance

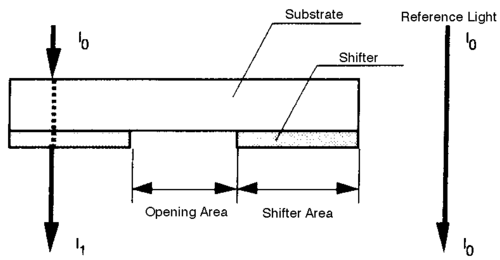
4.3.6 *shifter side reflectivity* — a ratio of intensity of reflected light to intensity of incident light onto the surface of a shifter film. The reflected light is the sum of the reflected light from the shifter surface and reflected light from the boundary between shifter and glass, and the boundary between glass and air. The reflectivity depends on the incident angle, the wavelength of the light, and the extent of polarization of the incident light. The intensity of incident light is usually calculated by the intensity of reflected light measured using reference mirror. (Figure 5 illustrates the shifter side reflectivity.)



$$R_s = \frac{I_5}{I_0} \times 100 \quad (\%)$$

Figure 5
Shifter Side Reflectivity

4.3.7 *shifter area transmittance* — ratio of intensity of light transmitted through a shifter area of a halftone phase shift mask (blank) to intensity of vertical incident light measured with air reference. (Figure 6 illustrates the shifter transmittance.)



$$T_1 = \frac{I_1}{I_0} \times 100 \quad (\%)$$

Figure 6
Shifter Area Transmittance

5 Mask Structure

5.1 Structure of a shifter shall be specified as single-layer type or multilayer type. A halftone shifter film whose components gradually change is classified into the multilayer type.

5.2 Structure of an opaque ring shall be specified as embedded shifter type or additional film type. In case of a mask blank, a light shield film may be added or not.

5.3 Addition of an electrically conductive layer, and/or a thin film for an etch-stop function shall be agreed upon by the supplier and user.

6 Film Thickness

6.1 For a mask blank, specifications such as film thickness of a shifter shall be agreed upon by the supplier and user. The film thickness may be described using a physical film thickness obtained from step height measurement, an optical film thickness obtained from ellipsometry or spectroscopy, and a controlled-film thickness obtained from rate method. Measuring method and measuring instrument shall be agreed upon by the supplier and user.

7 Film Materials

7.1 Specifications for materials and composition per layer in a shifter film and the opaque ring shall be agreed upon by the supplier and user.

8 Exposure Wavelength

8.1 As exposure wavelength, the center wavelength of g-line, i-line, KrF, ArF, and/or DUV shall be described in nm.

9 Transmittance

9.1 Specifications of transmittance shall be agreed upon by the supplier and user considering the selection of terms listed in Section 4.3 of this guideline.

9.2 A relative transmittance can also be obtained from the ratio of the shifter transmittance to the opening transmittance of a patterned halftone phase shift mask. In case the opening is not measurable, or it is a mask blank, a transmittance of a reference substrate should be used. The reference substrate shall be agreed upon by supplier and user beforehand.

9.3 Specifications of opening transmittance shall be agreed upon by the supplier and user considering its dependency to etching method.

9.4 Transmittance at the defect inspection wavelength, the dimension measurement wavelength, and/or the alignment wavelength shall be agreed upon by the supplier and user.

10 Phase Difference

10.1 Specifications of phase difference shall be agreed upon by the supplier and user giving attention to the measurement method. The unit should be degree. For a mask blank, the dependency of phase difference of a processed mask on the process method should be considered.

10.2 A measurement wavelength should be specified with its center value in nm. The measurement instrument and the bandwidth shall be agreed upon by the supplier and user.

11 Reflectivity

11.1 Shifter side reflectivity and glass side reflectivity should be described in percent, and its specification shall be agreed upon by the supplier and user. A measuring wavelength, a measuring instrument, a reference mirror, and an incident angle which are used for measurement shall be agreed upon by the supplier and user.

11.2 A defect inspection wavelength and an alignment wavelength shall be agreed upon by the supplier and user.

12 Opaque Ring Specification

12.1 Specification of an opaque ring shall be agreed upon by the supplier and user considering the type of opaque ring.

13 Etching Characteristics

13.1 Specifications of etching characteristics of a mask blank shall be agreed upon by the supplier and user.

14 Electrical Conductance

14.1 Electrical characteristics of a halftone phase shift mask blank should be represented by sheet resistance, and its specification and measuring method shall be agreed upon by the supplier and user.

15 Defects

15.1 Specific defects of a halftone phase shift mask and mask blank are phase defects and transmittance defects.

These defects are caused by halftone shifter dot, half-tone shifter hole, halftone shifter protrusion, halftone shifter intrusion, halftone shifter film thickness defect, halftone shifter film quality defect, and foreign materials.

15.2 Specifications for inspection and repair shall be agreed upon by the supplier and user.

15.3 Definition of defect sizes should conform to SEMI P22.

16 Ordering Information

16.1 It is recommended to agree mutually on the following items when ordering halftone phase shift masks. The other items should conform to SEMI P1.

Type of halftone structure	Single-layer type, or multilayer type
Type of opaque ring	Embedded shifter type, or additional film type
Film materials	To be agreed upon by the supplier and user
Exposure wavelength	To be agreed upon by the supplier and user
Transmittance	To be agreed upon by the supplier and user
Phase difference	To be agreed upon by the supplier and user
Reflectivity	To be agreed upon by the supplier and user
Defects, foreign materials, repair	To be agreed upon by the supplier and user

16.2 It is recommended to agree mutually on the following items when ordering halftone phase shift mask blanks. The other items should conform to SEMI P1.

Type of halftone structure	Single-layer type, or multilayer type
Light shield film	Added, or not
Film materials	To be agreed upon by the supplier and user
Exposure wavelength	To be agreed upon by the supplier and user
Transmittance	To be agreed upon by the supplier and user
Phase difference	To be agreed upon by the supplier and user
Reflectivity	To be agreed upon by the supplier and user
Etching characteristics	To be agreed upon by the supplier and user
Electrical conductivity	To be agreed upon by the supplier and user
Defects, foreign materials	To be agreed upon by the supplier and user

17 Sampling

17.1 Sampling should conform to SEMI P1.

18 Related Documents

SEMI P3 — Specification for Photoresist/E-Beam Resist for Hard Surface Photoplates

SEMI P30-0997 (Reapproved 1104)
PRACTICE FOR CATALOG PUBLICATION OF CRITICAL DIMENSION MEASUREMENT SCANNING ELECTRON MICROSCOPES (CD-SEM)

This standard was technically approved by the Global Micropatterning Committee and is the direct responsibility of the Japanese Micropatterning Committee. Current edition approved by the Japanese Regional Standards Committee on July 23, 2004. Initially available at www.semi.org September 2004; to be published November 2004. Originally published in 1997.

1 Purpose

1.1 The purpose of this practice is to define terms listed in Critical Dimension-Scanning Electron Microscopes (CD-SEM).

1.2 This document is designed to create a common understanding between suppliers and users.

2 Scope

2.1 This practice applies to terms listed in the CD-SEM catalog.

2.2 This practice also applies to terms listed in the estimate and purchasing specification.

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 None.

4 Terminology

4.1 *Definitions*

4.1.1 *accelerating voltage* — the mean kinetic energy of primary electrons converted into voltage.

4.1.2 *alignment* — corrects coordinates for positions and specimen stage. Matching the coordinates of a wafer and a specimen stage in order to address measured patterns formed on a wafer.

4.1.3 *alignment error* — distance from the pattern center to screen center after alignment. This is the maximum distance between the screen center and a target pattern after addressing by its coordinates and completing alignment.

4.1.3.1 *automatic pattern determination method* — the pattern selection method based on the automatic pattern recognition system.

4.1.4 *Critical Dimension Measurement SEM (CD-SEM)* — selects fine patterns on a wafer and measure dimensions. Here, wafers include SEMI standards (defined sizes) only. The operation is normally in the following "sequence": Transport -> Stage Travel -> Positioning -> Measuring -> Transport.

4.1.5 *image resolution* — resolution between two points. This is the minimum resolving distance between any two points in an image.

4.1.6 *magnification* — the ratio of a deflection width on a display to that on a measurement pattern. Compares the deflection width on the screen and on the pattern.

4.1.6.1 *manual pattern determination method* — operator uses cursors, etc. The pattern selection method is accomplished by the operator placing cursors on the measurement pattern.

4.1.7 *measurable range* — measurement range to guarantee static and dynamic repeatability as well as linearity. Measuring dimensions guaranteed to be within the specification of static repeatability, dynamic repeatability, and linearity.

4.1.8 *measurement pattern determination method* — identifies the pattern to be measured. This method is used to identify the pattern to be measured. It is performed by automatic pattern recognition, or instructions from the operator.

4.1.9 *measurement precision*

4.1.9.1 *dynamic repeatability* — variations between the nominal and measured dimensions. This is the maximum dispersion of measurements from the best approximate line defined between the nominal and measured dimensions.

4.1.9.2 *linearity* — variations in measurement values without changing device and wafer conditions. This is the closeness of agreement between the measured values obtained by measuring a pattern repeatedly without any changes of measurement conditions.

4.1.9.3 *reproducibility* — variations in average measurement values acquired in a sequence during a certain period. This is the closeness of agreement between the mean values obtained by measuring a pattern repeatedly at stated period with wafer loading, wafer alignment, stage traveling to a measurement site, positioning of a measured pattern, measuring, and wafer unloading.

4.1.9.4 *static repeatability* — variations in average measurement values acquired in a sequence for a pattern. This is the closeness of agreement between the measured values obtained by measuring a pattern with wafer loading, wafer alignment, stage traveling to a measurement site, positioning of a measured pattern, measuring, and wafer unloading.

4.1.10 *measurement target* — kind of measurement pattern. The measurement pattern, such as line, space, pitch, hole, box-in-box, etc.

4.1.11 *operation method* — the control method of operation sequence. There are three methods: auto, semi-auto, and manual.

4.1.11.1 *automatic operation method* — the operation method controlled by a computer automatically, after an operator sets a carrier on the equipment. The computer follows the commands written in a recipe. Uses a recipe on a computer.

4.1.11.2 *manual operation* — the operation method controlled by an operator without a recipe. Uses an operator.

4.1.11.3 *semi-auto operation* — the operating method controlled by a computer and an operator. The operator confirms the results of each command in a recipe using an automatic operation. Uses a recipe with an operator.

4.1.12 *pattern edge determination method* — uses a computer or an operator to look at the image. This is the method for determining the edge position of a given pattern, which is calculated by computer algorithm or by operator instructions.

4.1.12.1 *automatic pattern edge determination* — there are several methods, such as the threshold method, the linear approximation method, and the curve fitting method. This is the method used to determine the edge position automatically by calculating from the line profile signal of the secondary or back-scattered electrons. The calculations are performed using the aforementioned three algorithms.

4.1.12.2 *manual pattern edge determination method* — the operator measures the distance between cursors per image edge area. This method is used to determine the edge position manually by calculation based on the width between cursors, which are set to the measurement pattern edges by operator.

4.1.13 *pattern positioning error* — distance from the center of screen after positioning. This is the maximum distance between the screen center and a target pattern after pattern positioning.

4.1.14 *permissible air vibration* — the maximum air vibration that can provide the guaranteed resolution.

4.1.15 *permissible floor loading capability* — the minimum floor loading capability where the equipment can be settled.

4.1.16 *permissible stray magnetic field* — the maximum change in the stray magnetic field that can provide the guaranteed resolution.

4.1.17 *permissible floor vibration* — the maximum floor vibration that can provide the guaranteed resolution.

4.1.18 *positioning of measured patterns* — moving pattern to the center screen (center of image field).

4.1.19 *stage positioning error* — variations when moving stage to a selected location repeatedly without correction. This is the positioning error of stage, which occurs when traveling to the same site repeatedly without electron beam deflection.

4.1.20 *stage positioning range* — range on a wafer that can be measured by moving the wafer. This is the measurable range of a measured wafer placed on a specimen stage with stage moving.

4.1.21 *throughput* — the number of processed wafers (per unit time, which is calculated from the time required for processing under pre-scheduled measurement sequence and conditions).

4.1.22 *transport* — transferring wafer from a wafer carrier to a specimen stage, or the reverse process.

4.1.23 *wafer size* — wafer diameter.

5 Listed Items

The following are desirable items and examples for listing in the CD-SEM catalog.

5.1	Equipment name		
5.2	Model		
5.3	Performance		
5.3.1	Throughput	___________ wafers/h	(Example: 30 wafers / h)
5.3.2	Image resolution	___________ nm	(Example: 5 nm)
5.3.3	Measurement precision		
5.3.3.1	Static repeatability	___________ nm (3 σ_{n-1})	(Example: 5 nm (3 σ_{n-1}))
5.3.3.2	Dynamic repeatability	___________ nm (3 σ_{n-1})	(Example: 5 nm (3 σ_{n-1}))
5.3.3.3	Reproducibility	___________ nm (3 σ_{n-1})	(Example: 5 nm (3 σ_{n-1}))
5.3.3.4	Linearity	___________ nm (3 σ_{n-1})	(Example: 5 nm (3 σ_{n-1}))
5.3.3.5	Precision guaranteed range	___________ µm – ___________ µm	(Example: 0.2 µm ~ 10 µm, 5,000 ~ 200,000 x)
5.4	Function		
5.4.1	Wafer transport/Stage system		
5.4.1.1	Transport method	___________	(Example: double cassette support to C to C method)
5.4.1.2	Stage stopping error	___________µm	(Example: ± µm)
5.4.1.3	Wafer size	___________ mm	(Example: 100, 125, 150, 200 mm)
5.4.1.4	Positioning range	___________	(Example: whole wafer surface)
5.4.2	Alignment system		
5.4.2.1	Alignment method	___________	(Example: uses optical image)
5.4.2.2	Alignment precision	___________± µm	(Example: µm)
5.4.2.3	Pattern positioning method	___________	(Example: moving cursor)
5.4.2.4	Pattern positioning precision	___________	(Example: ± 0.1 µm)
5.4.3	Electro-optical system		
5.4.3.1	Electron gun type	___________	(Example: LaB6 / schottky / C-FE)
5.4.3.2	Accelerating voltage	___________	(Example: 0.5 − 1.5 kV, 0.1 kV step)
5.4.3.3	Probe current	___________	(Example: 0.2 − 10 pA)
5.4.3.4	Magnification	___________	(Example: 100 ≈ 200,000 times)
5.4.4	Measurement		
5.4.4.1	Measurement pattern	___________	(Example: line / hole / overlay)
5.4.4.2	Pattern determination method	___________	(Example: automatic (pattern recognition) / manual/cursor)
5.4.4.3	Pattern edge determination method	___________	(Example: automatic (line approximation) / threshold method)
5.4.4.4	Operation method	___________	(Example: auto / semiauto / manual)
5.4.4.5	Communication protocol	___________	(Example: SECS)
5.4.5	Vacuum exhaust system	___________	(Example: TMP (500 L / s) 1 unit, SIP (20 L / s) 2 units)
5.5	Installation conditions		
5.5.1	Dimensions	width______mm, depth______mm, height______mm	(May be included in the standard diagram.)
5.5.2	Standard layout diagram		
5.5.3	Mass	___________ kg	
5.5.4	Permissible environmental conditions		
5.5.4.1	Loading capability	___________ Kg / m^2	
5.5.4.2	Stray magnetic field,	___________ T p − p	

	maximum			
5.5.4.3	Floor vibration, maximum	___________	dB	
5.5.4.4	Air vibration, maximum	___________	dB	
5.5.5	Electric power supply	___________ ___________ ___________	V/, Φ/, kVA	
5.5.6	Water supply	___________	L/min.	
5.5.7	High-pressure gas supply	___________		(Example: Dry air, N_2)
5.5.8	Reference standard			(Example: SEMI PXX-XX)

6 Listed Items Guide (reference)

6.1 *Equipment Name — List*

6.2 *Model — List*

6.3 *Throughput* — To measure throughput, large-size wafers are generally used. List the number of processes per hour when 5-point measurement has been continuously processed. When wafers other than the maximum wafer sizes are used, list the wafer size. Also, list if the operator should intervene. The measurement position should be the center of wafer and the outside 4 points from 1/2 of the diameter on the diagonal line of the rectangle inscribing the wafer.

6.4 Please note that there are the following two methods:

6.4.1 The number of wafers that can be processed per hour for 1 wafer/lot processing.

6.4.2 The number of wafers that can be processed per hour for 25 wafers/lot continuous processing.

6.5 *Static Repeatability* — Use $3\sigma_{n-1}$ and nm as the unit of measurement. When not listed, the sample should be the photoresist pattern and the number of measurement cycles should be 10.

6.6 *Dynamic Repeatability* — Use $3\sigma_{n-1}$ and nm as the unit of measurement. When not listed, the sample should be the photoresist pattern, and the number of measurement cycles should be 10. In addition, one cycle of measurement should be just one cycle.

6.7 *Reproducibility* — Use $3\ \sigma_{n-1}$ and nm as the unit of measurement. When not listed, the sample should be the photoresist pattern.

6.8 *Image Resolution* — The resolution should be listed in nm. In addition, the accelerating voltage acquired should be listed. When not listed, the sample should use gold deposition, and the conversion should be done from the photo image.

6.9 *Measurement Precision Warranty Range* — Should be listed in µm. When the precision depends on magnification, the listing of magnification is desirable.

6.10 *Operation Method* — List methods that can be used in auto, semi-auto, and manual.

6.11 *Transport Method* — List double-cassette supporting C to C method and/or SMIF supporting C to C method.

6.12 *Wafer Size* — List dimensions defined in SEMI M1. When creating guidelines, the dimensions are as follows: 2 inch, 3 inch, 100 mm, 125 mm, 150 mm, 200 mm, 300 mm, and 400 mm.

6.13 *Measurable Range* — List ranges that can be observed and measured through normal use in mm.

6.14 *Stage Stopping Error* — List the stopping error in mm when moving the maximum distance in both X and Y directions.

6.15 *Alignment Method* — List methods using optical microscopes, SEM images, and other.

6.16 *Alignment Precision* — List in µm.

6.17 *Measuring Pattern Identification Method* — List manual and auto and the content thereof.

6.18 *Pattern Edge Determination* — List manual and auto and the content thereof.

6.19 *Measuring Pattern Positioning Method* — List manual and auto and the content thereof.

6.20 *Measuring Pattern Positioning Accuracy* — List in µm.

6.21 *Magnification* — List range.

6.22 *Accelerating Voltage* — List range in V or kV units.

6.23 *Electron Gun* — List electron gun type.

6.24 *Vacuum Exhaust System* — List pump type, exhaust volume, and number of units.

6.25 *Communication Protocol* — List external computer and method of communication.

6.26 *Dimensions* — List block width, depth, and height per equipment block in mm. This may be listed in the standard layout diagram.

6.27 *Standard Layout Diagram* — List the standard layout when installing equipment. Equipment installation conditions can be listed in the diagram.

6.28 *Mass* — List in kg.

6.29 Permissible Floor Weight — List in kg/m^2.

6.30 *Permissible Stray Magnetic Field* — List in T, and list effective values or peak values separately.

6.31 *Permissible Floor Vibration* — List the maximum vibration level in dB in the 1–80 Hz frequency range. The vibration acceleration level La is found from the following equation:

$La = 20 \log (a / a_o)$

Here,

a — Is the effective value of the vibration acceleration when the sensory vibration is not corrected:

a_o — (Standard vibration acceleration) (10^{-6} m / s^2)

6.32 *Permissible Air Vibration* — List the maximum sound level in dB in the 20 Hz – 8 kHz frequency range. The sound pressure level La is found from the following equation:

$La = 20 \log (a / a_o)$

Here, a is the effective value for sound pressure in Pa units.

a_o (Standard sound pressure) (20 Pa)

6.33 *Reference Specification* — List guideline as the reference specification.

SEMI P31-0304
PRACTICE FOR CATALOG PUBLICATION FOR CHEMICAL AMPLIFIED (CA) PHOTORESIST PARAMETER

This practice was technically approved by the Global Micropatterning Committee and is the direct responsibility of the Japanese Micropatterning Committee. Current edition approved by the Japanese Regional Standards Committee on January 9, 2004. Initially available at www.semi.org February 2004; to be published March 2004. Originally published September 1997.

1 Purpose

1.1 The purpose of this document is to provide a baseline for publication of chemical amplified (CA) photoresist parameters.

2 Scope

2.1 This document applies to CA photoresist used for semiconductor manufacturing.

2.2 This document is used as the guide to evaluate photoresist process parameters.

2.3 This document is not applicable for quality assurance.

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

None.

4 Terminology

4.1 *Abbreviations and Acronyms*

4.1.1 *PEB* — post exposure bake

5 Description

NOTE 1: The following parameters for CA photoresist publication and test conditions should be described in the catalog.

5.1 Resist, overcoat and developer commercial name

5.2 Temperature and humidity

5.3 Environmental conditions (see Section 6)

5.4 Ammonia concentration measurement method (see Section 7)

5.5 Delay time dependency (see Section 8)

5.6 PEB temperature dependency (see Section 9)

5.7 PEB time dependency (see Section 10)

5.8 Substrate dependency (see Section 11)

5.9 *Measurement Conditions*

5.9.1 *Resist Coating and Development*

5.9.1.1 Resist baking method (contact baking or proximity baking)

5.9.1.2 Resist pre-baking temperature and time

5.9.1.3 Resist PEB temperature and time

5.9.1.4 Development time

5.9.1.5 Resist thickness

5.9.2 *Exposure*

5.9.2.1 Illumination conditions (NA, σ, etc.)

5.10 *Equipment Name*

5.10.1 Exposure equipment

5.10.2 SEM equipment

5.10.3 Ammonia concentration measurement equipment

6 Environmental Conditions

6.1 *Ammonia Concentration* — It is recommended to measure all CA photoresist parameters under the condition that the ammonia concentration is less than 10 $\mu g/m^3$.

NOTE 2: CA photoresist is sensitive to the atmosphere, especially to ammonia. Acid from photoacid generator upon exposure is neutralized by the basic material in atmosphere like ammonia.

7 Ammonia Concentration Measurement Method

7.1 The ammonia concentration is measured by ion chromatography or another method which is capable to determine the ammonia concentration quantitatively less than 10 $\mu g/m^3$. The measurement equipment is calibrated with a standard ammonia solution.

8 Delay Time Dependency

NOTE 3: This section defines process conditions and procedures to obtain the delay time dependency.

8.1 *Resist Coating and Pre-baking* — Resist should be coated on a substrate. Suppliers should be notified of the kind of substrate and underlying film. After pre-baking, the resist thickness should be chosen the bottom of swing curve between 0.3–0.5 µm. Thickness could be changed in accordance with exposure wavelength. The actual thickness should be notified.

8.2 *Delay Time* — Delay time between resist coating and exposure, exposure and PEB, and PEB and development used for obtaining delay time dependency parameters are defined in Table 1.

Table 1 Delay Time Condition

Resist coating to exposure delay time						
0 min.			1 hour		6 hour	24 hour
NOTE: Normal sequential procedure without intentional delay between exposure and PEB as well as PEB and development.						
Exposure to PEB delay time						
0 min.	10 min.	30 min.	1 hour	2 hour		24 hour
NOTE: Normal sequential procedure without intentional delay between resist coating and exposure as well as PEB and development.						
PEB to development delay time						
0 min.	10 min.	30 min.	1 hour			24 hour
NOTE: Normal sequential procedure without intentional delay between resist coating and exposure time as well as exposure and PEB.						

NOTE: Zero minutes (0 min.) is defined as normal sequential procedure without intentional delay.

8.3 *Measurement*

8.3.1 After each time delay, fabricated 0.10 µm and 0.15 µm line and space patterns should be measured by SEM.

8.3.2 Record the measured pattern size.

8.3.3 Make the plotting of pattern size vs. delay time.

9 PEB Temperature Dependency

NOTE 4: This section defines process conditions and procedures to obtain the PEB temperature dependency.

9.1 *Resist Coating and Pre-baking* — Resist should be coated on a substrate. Suppliers should be notified of the kind of substrate and underlying film. After pre-baking, the resist thickness should be chose the bottom of the swing curve between 0.3–0.5 µm. Thickness could be changed in accordance with exposure wavelength. The actual thickness should be notified.

9.2 *Measurement*

9.2.1 Ten points of temperature should be selected within ± 20 °C from the optimized PEB temperature.

9.2.2 Record the measured pattern size.

9.2.3 Make the plotting of pattern width vs. PEB temperature. At least 6 to 8 points of pattern width should be plotted within the deviation of ± 10% from the optimized line width of 0.10 µm and 0.15 µm line and space patterns.

9.2.4 The cross section of resist patterns is observed and compared each other with standard sample. One should be selected from the optimized condition and the other one should be selected from the sample deviated around 10% from standard one.

10 PEB Time Dependency

NOTE 5: This section defines process conditions and procedures to obtain the PEB time dependency.

10.1 *Resist Coating and Pre-baking* — Resist should be coated on a substrate. Suppliers should be notified of the kind of substrate and underlying film. After pre-baking, the resist thickness should be chosen the bottom of swing curve between 0.3–0.5 µm. Thickness could be changed in accordance with exposure wavelength. The actual thickness should be notified.

10.2 *PEB Time* — PEB time should be selected from time 30 sec., 60 sec., 90 sec., 120 sec., 180 sec. on the optimized PEB temperature.

10.3 *Measurement*

10.3.1 Fabricated 0.10 µm and 0.15 µm line and space patterns should be measured by SEM.

10.3.2 Record the measured pattern size.

10.3.3 Make the plotting of pattern size vs. PEB time.

11 Substrate Dependency

11.1 *Resist Coating and Pre-baking* — Resist should be coated on a substrate. Suppliers should be notified of the kind of substrate and underlying film. After pre-baking, the resist thickness should be chose the bottom of swing curve between 0.3–0.5 µm. Thickness could be changed in accordance with exposure wavelength. The actual thickness should be notified.

11.2 *Observation* — Fabricated 0.10 µm and 0.15 µm line and space patterns and more than 1 µm isolated patterns should be observed by cross sectional SEM.

SEMI P32-1104
TEST METHOD FOR DETERMINATION OF TRACE METALS IN PHOTORESIST

This test method was technically approved by the Global Micropatterning Committee and is the direct responsibility of the Japanese Micropatterning Committee. Current edition approved by the Japanese Regional Standards Committee on July 23, 2004. Initially available at www.semi.org August 2004; to be published November 2004. Originally published September 1998.

1 Purpose

1.1 This document describes an outline of a quantitative analysis method on trace metal concentration. This standard is intended to promote communication between users and suppliers.

2 Scope

2.1 This document applies to a measurement of trace metal concentration in ppb level in photoresist by instrumental techniques, such as Atomic Absorption Spectrometry, Plasma Ion Source Mass Spectrometry, and Inductively Coupled Plasma Atomic Emission Spectrometry.

2.2 Object metals in this measurement are Al, Ca, Cr, Cu, Fe, Mg, Mn, Ni, K, and Na.

2.3 Either additional metals or fewer can be agreed upon between users and suppliers and are added to the measurement list.

2.4 The following method has given satisfactory results in determining trace metal impurities at the specified value for each of the target trace metals. Alternative methods or conditions may be used as long as appropriate studies demonstrate recovery between 75%–125% of a known sample spike for half the specification value. The results should be reported as within specification (below a certain value) or not in specification only (SEMI C1).

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 Standard*

SEMI C1 — Guide for the Analysis of Liquid Chemicals

3.2 *ASTM Standard*

ASTM D1193 — Standard Specification for Reagent Water

4 Summary of Method

4.1 Photoresist test solution is prepared by dry ashing method or direct method. Then trace metals in the test solution are measured by Atomic Absorption Spectrometry, Plasma Ion Source Mass Spectrometry, or Inductively Coupled Plasma Atomic Emission Spectrometry. The trace metal concentration is determined using a working curve, which is obtained by measuring a standard solution.

5 Terminology

5.1 *Definitions*

5.1.1 *blank test* — a measurement without the object photoresist, which is performed under the standard procedures.

5.1.2 *dilution factor* — numerical number that indicates final amount of solution divided by the initial amount of solution in the preparation of the photoresist process.

5.1.3 *direct method* — a sample preparation method for preparing samples for direct trace metal in photoresist. The materials are diluted with a solvent and then analyzed by the appropriate analytical instrument.

5.1.4 *dry ashing method* — a sample preparation method for preparing samples used in measuring trace metals in the photoresist. The photoresist is evaporated and decomposed to ash by heating. The ash is dissolved in a volumetric flask with acid and aqueous reagent, and then analyzed by the appropriate analytical instrument.

5.1.5 *plasma ion source mass spectrometry* — a method that isolates and measures quantitative metal element by mass spectrometer using plasma as excitation source. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Microwave Induced Plasma Mass Spectrometry (MIP-MS) belong to this category.

5.1.6 *working curve* — the relationship between known metal concentrations prepared by standard solutions and the observed values of instrumental analysis.

6 Apparatus

6.1 *Measurement Equipment*

6.1.1 Flame Atomic Absorption Spectrometer (F-AAS) and ICP-MS can be applied to the dry ashing method.

6.1.2 Graphite Furnace Atomic Absorption Spectrometer (GF-AAS), Electrothermal Atomization Atomic Absorption Spectrometer (ETA-AAS), ICP-MS, MIP-MS, and Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) can be applied to the direct method.

6.1.3 *Instrument Condition* — Recommended instrumental conditions are summarized in Table 1 for each target metal.

Table 1 Measurement Equipment and Metal Elements

Element	*Atomic Absorption Spectroscopy*	*Plasma Ion Source Mass Spectrometry*		*ICP-Atomic Emission Spectrometer*
		ICP-MS (Note 1)	*MIP-MS (Note 2)*	
Al	309.2 nm	^{27}Al	^{27}Al	396.2 nm
Ca	422.7 nm	^{40}Ca, ^{44}Ca (Note 3)	^{40}Ca	393.4 nm
Cr	357.9 nm 359.4 nm	^{52}Cr, ^{53}Cr (Note 3)	^{52}Cr	267.7 nm 283.6 nm
Cu	324.7 nm	^{63}Cu, ^{65}Cu	^{63}Cu, ^{65}Cu	324.8 nm
Fe	248.3 nm	^{56}Fe, ^{54}Fe (Note 3)	^{56}Fe, ^{54}Fe	259.9 nm
Mg	285.2 nm	^{24}Mg, ^{25}Mg, ^{26}Mg	^{24}Mg, ^{25}Mg, ^{26}Mg	279.6 nm
Mn	279.5 nm	^{55}Mn (Note 3)	^{55}Mn	257.6 nm
Ni	232.0 nm 341.4 nm	^{58}Ni, ^{60}Ni (Note 3)	^{58}Ni, ^{60}Ni	221.6 nm 231.6 nm
K	766.5 nm	^{39}K, ^{41}K (Note 3)	^{39}K, ^{41}K	766.5 nm
Na	589.0 nm	^{23}Na	^{23}Na	589.0 nm

NOTE 1: *ICP-MS* — Ar is used as the plasma generation gas.
NOTE 2: *MIP-MS* — N_2 is used as the plasma generation gas.
NOTE 3: Beware of interfering ion (see Table 2).

Table 2 Interfering Ions

Object Metal	*Interfering Ion*
^{39}K	$^{38}Ar^{1}H$
^{41}K	$^{40}Ar^{1}H$
^{40}Ca	^{40}Ar
^{52}Cr	$^{40}Ar^{12}C$, $^{36}Ar^{16}O$, $^{38}Ar^{14}N$
^{55}Mn	$^{40}Ar^{14}C^{1}H$, $^{40}Ar^{15}N$, $^{38}Ar^{16}O^{1}H$
^{56}Fe	$^{40}Ar^{16}O$, $^{38}Ar^{18}O$
^{58}Ni	$^{40}Ar^{18}O$

7 Vessels, Reagents, and Environment

7.1 *Vessel*

7.1.1 Quartz glass volumetric flask

7.1.2 Quartz glass measuring pipette

7.1.3 Quartz glass beaker

7.1.4 PTFE vessel

7.1.5 Platinum crucible

7.2 *Reagents*

7.2.1 *DI Water* — Resistivity ≥ 18.0 MΩ cm at 25°C per ASTM D 1193.

7.2.2 *Organic Reagent* — Use commercially guaranteed reagent for trace metal analysis.

7.2.3 *Inorganic Reagent* — Use commercially guaranteed reagent for trace metal analysis.

7.2.4 *Standard Reagent* — Use the commercially guaranteed reagents which have certified trace metals concentration.

7.3 *Environment*

7.3.1 The measurement is recommended to be performed in a clean room or clean zone at constant temperature. The stability of temperature should be better than ± 2°C. Dry ashing method should be performed in a draft chamber with HEPA filter, if possible.

7.3.2 In the case of volumetric analysis, the measurement environment is set to the standard temperature of measuring tools such as volumetric flask and measuring pipette.

8 Procedures

8.1 *Flow Chart of Measurement* — Refer to Figure 1 as suggested analysis process.

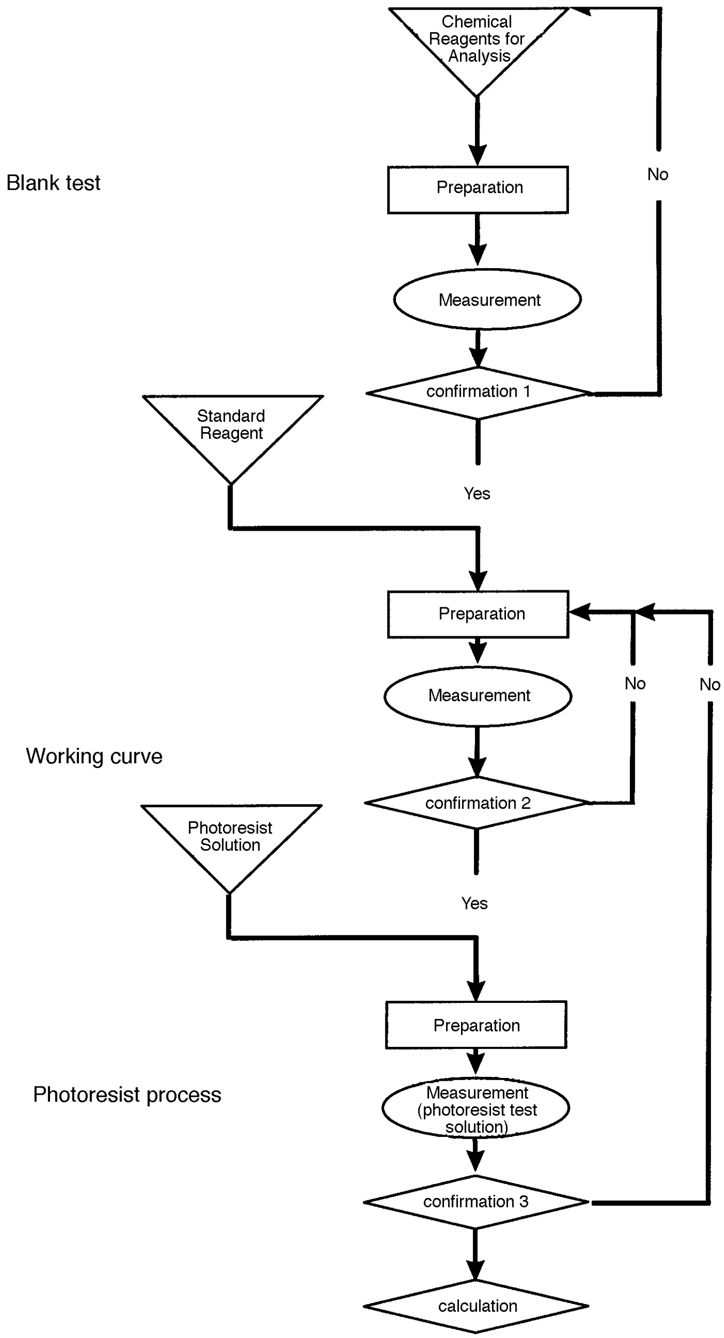


Figure 1
Flow Chart of Trace Metal Measurement

8.2 *Blank Test*

8.2.1 Prepare a blank test solution.

8.2.2 Measure each blank test solution.

8.2.3 The observed data should be adjusted for background correction, if necessary.

8.2.4 *Confirmation 1* — Blank level should be equal or less than half the specification level in the photoresist.

8.3 *Working Curve*

8.3.1 The concentration range in the working curve should cover the anticipated concentration in photoresist test solution.

8.3.2 Prepare a standard solution with a known metal concentration using the reagents that are used in preparing the photoresist test solution.

8.3.3 Measure each metal element in the standard solution.

8.3.4 The observed data should be adjusted for the blank level and background correction.

8.3.5 Prepare a working curve for each metal element.

8.3.6 *Confirmation 2* — Working curve should be linear in the concentration range of standard solution.

8.4 *Measurement of Photoresist Test Solution*

8.4.1 *Dry Ashing Method*

8.4.1.1 Remove the solvent of photoresist by evaporation using Platinum crucible.

8.4.1.2 Ash the matrix by heating using Platinum crucible. Ashing temperature should be referred to Table 3. Resist cannot be ashed without possible loss of some elements, so loss of each element should be investigated before trace metal analysis.

Table 3 Recommended Ashing Temperature

Element	*Ashing Temperature (°C)*	*Flame Component*
Al	1000	N_2O-C_2H_2
Ca	800	Air-C_2H_2 N_2O-C_2H_2
Cr	800	Air-C_2H_2 N_2O-C_2H_2
Cu	800	Air-C_2H_2
F3 (NOTE 4)	600 300 (if $FeCl_3$ presents)	Air-C_2H_2 N_2O-C_2H_2
Mg	600	Air-C_2H_2 N_2O-C_2H_2
Mn	800	Air-C_2H_2 N_2O-C_2H_2
Ni	800	Air-C_2H_2
K (NOTE 5)	< 500	Air-C_2H_2 H_2-O_2
Na (NOTE 5)	< 500	Air-C_2H_2 H_2-O_2

NOTE 4: Iron can be present as ferric chloride and ferric chloride boils at 310°C.

NOTE 5: These elements tend to volatilize over 500°C.

8.4.1.3 Dissolve the ash in platinum crucible with acid.

8.4.1.4 Prepare a photoresist test solution in a volumetric flask with a constant volume of solvent.

8.4.1.5 In F-AAS analysis, analytical wavelength should be determined referring to Table 1. In ICP-MS analysis, analytical mass number should be determined referring to Table 1.

8.4.1.6 Measure each metal element in the photoresist test solution.

8.4.1.7 The observed data should be adjusted for blank level and background corrections.

8.4.2 *Direct Method*

8.4.2.1 Prepare a photoresist test solution by diluting. Solvents such as PGMEA or EL are recommended.

8.4.2.2 Record the name of diluting solvent and dilution factor. Dilution factor is recommended to be in the range of 5 to 50.

8.4.2.3 In GF-AAS or ETA-AAS analysis, furnace program (step, temperature, ramp time, hold time) should be determined referring to Table 4 before trace metal analysis.

Table 4 Recommended Furnace Program for GF-AAS and ETA-AAS

Element	*Drying Temperature (°C)*	*Ashing Temperature (°C)*	*Atomization Temperature (°C)*
Al	130	1400	2700
Ca	130	1300	2600
Cr	130	1300	2700
Cu	130	900	1600
Fe	130	900	2500
Mg	130	900	2200
Mn	130	900	2600
Ni	130	1200	2700
K	130	800	2000
Na	130	800	2000

8.4.2.4 In GF-AAS, ETA-AAS, or ICP-AES analysis, analytical wavelength should be determined referring to Table 1. In ICP-MS or MIP-MS analysis, analytical mass number should be determined referring to Table 1.

8.4.2.5 Measure each metal element in the photoresist test solution.

8.4.2.6 The observed data should be adjusted for the blank level and background correction.

8.5 *Concentration of Trace Metal in Photoresist*

8.5.1 The concentration of trace metal in a photoresist test solution is determined from the working curve.

8.5.2 *Confirmation 3* — The observed concentration of photoresist test solution should be in the concentration range of working curve.

9 Suggested Reporting Information

9.1 Company

9.2 Test date

9.3 Photoresist

9.3.1 Commercial name

9.3.2 Tone

9.3.3 Lot No.

9.4 Results

9.4.1 Element

9.4.2 Concentration (ppb)

9.4.3 Method of chemical analysis

9.4.4 Other information on chemical analysis should be added to the reporting results by mutual agreement between users and suppliers.

10 Related Documents

10.1 *SEMI Standards*

SEMI P12 — Determination of Iron, Zinc, Calcium, Magnesium, Copper, Boron, Aluminum, Chromium, Manganese, and Nickel in Positive Photoresists by Inductively Coupled Plasma Emission Spectroscopy (ICP)

SEMI P13 — Determination of Sodium and Potassium in Positive Photoresists by Atomic Absorption Spectroscopy

SEMI P14 — Determination of Tin in Positive Photoresists by Graphite Furnace Atomic Absorption Spectroscopy

NOTICE: SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature respecting any materials mentioned herein. These standards are subject to change without notice.

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SEMI P33-0998
PROVISIONAL SPECIFICATION FOR DEVELOPMENTAL 230 mm SQUARE HARD SURFACE PHOTOMASK SUBSTRATES

1 Purpose

1.1 To define the dimensional requirements for nominally square hard surface photomask substrates of 230 mm nominal edge length for research on, and development of, process and manufacturing equipment, pellicles, carriers, other accessory materials, and any related mask designs.

2 Scope

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

3 Referenced Documents

3.1 *ANSI/ASQC Standard*[1]

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

3.2 *ASTM Standard*[2]

E 228 — Test for Linear Thermal Expansion of Rigid Solids with a Vitreous Silical Dilatometer

3.3 *Federal Standard*[3]

209E — Clean Room and Work Station Requirements, Controlled Environments

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 *critical side* — major side intended for patterning. The critical side has no chamfered corner(s) (see Section 9.2), and has flatness equal to or better than the non-critical side (see Section 8.1).

4.3 *non-critical side* — major side not intended for patterning. Any and all chamfered corners are on the non-critical side (see Section 9.2, Figures 5 and 6).

NOTE: Selected terms relating to photomasking are given for information only in Appendix 2, Related Information.

5 Ordering Information

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

5.1.1 Nominal edge length, nominal thickness dimension, edge criteria, and parallelism of major sides (see Section 6);

5.1.2 Material (see Section 7);

5.1.3 Flatness quality area and flatness Total Indicated Reading (TIR; see Section 8);

5.1.4 Visual quality area (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 beveled edges. 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 square substrates shall be parallel within 5.0 µm along both major axes. Measurements are taken within the quality flatness area, along both major axes. Calculation of parallelism is illustrated in Figure 7.

7 Material Specifications

7.1 Substrate materials shall be specified “ultra low thermal expansion” (ULTE). An example of ULTE material is fused silica (quartz).

7.2 Selected physical properties of ULTE materials are provided for information only in Appendix 1.

8 Flatness Specifications

8.1 Substrates shall be supplied with two major sides having flatness (TIR) of 1, 2, or 5 µm over a square quality flatness area as defined in Figure 4. Sides are not required to have equivalent flatness. (NOTE: 0.5 µm is not yet available but is widely expected in the

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

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

3 General Services Administrator, 4th and D Streets, SW, Room 6039, Washington D.C. 20407

near future. 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 area, shall be agreed upon between the user and supplier.

9.2 Fused silica (ULTE) 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.

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 E 228.

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

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

11.4 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. Substrates are to be handled with gloves approved for cleanroom use, when human handling is required.

13 Orientation

13.1 For ULTE substrates with a single corner chamfer (see Section 9.2), it is recommended that all orientation be performed referencing the corner of the substrate diagonally opposite the chamfer. 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 100 environment as defined by Federal Standard 209. Containers shall be designed to prevent glass-to-glass 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 container. Packaging shall comply with the applicable internal, 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, and Thickness for Square Substrates

Nominal Edge Length	*Edge Length Minimum*	*Edge Length Maximum*	*Squareness*	*Thickness Minimum*	*Thickness Maximum*	*Units*
230 mm	229.6	230.0	0.186/213	8.90	9.10	mm

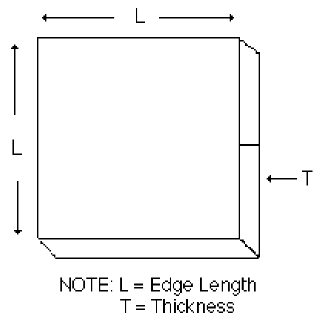

Figure 1
Square Hard Surface Photomask Substrate

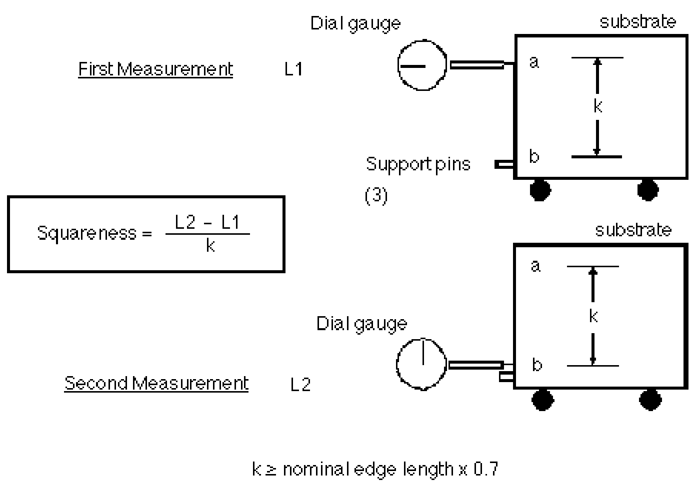

Figure 2
Measurement Fixture and Calculation to Determine Substrate Squareness

Table 2 Specifications for Beveled and Rounded Edge Dimensions

T	*A*	*A*	*B*	*B*	*C*	*C*	
Nominal	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Units*
9.00	0.20	0.60	0.20	0.60	2.00	3.00	mm

NOTE: “D” is radius of curvature of concerns.

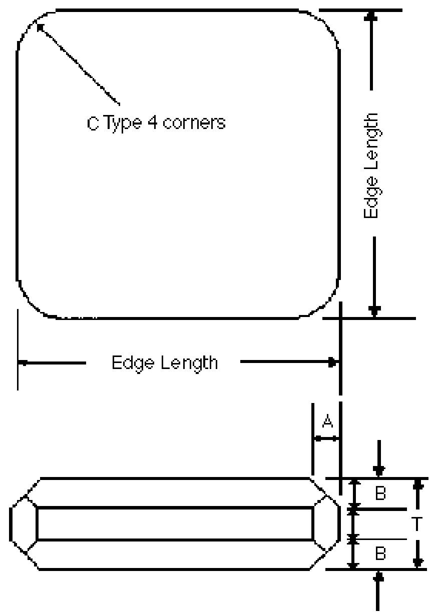

Figure 3
Beveled Edge Dimensions

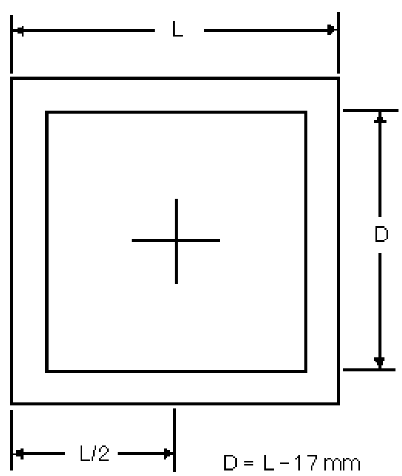

Figure 4
Square Quality Area