

# 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](http://www.semi.org) September 2004; to be published November 2004. Originally published in 1994.

**NOTICE:** This Standard or Safety Guideline has an Inactive Status because the conditions to maintain Current Status have not been met. Inactive Standards or Safety Guidelines are available from SEMI and continue to be valid for use.

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

## 3 Limitations

3.1 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 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 and Documents

### 4.1 SEMI Standards and Safety Guidelines

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 ( $r,\theta$ ) 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 humidity 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, $\theta$ ) 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