

SEMI P43-0304 (Reapproved 0611) PHOTOMASK QUALIFICATION TERMINOLOGY

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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.

NOTICE: This document was reapproved with minor editorial changes.

1 Purpose

1.1 This standard defines a unique language in the field of specification for, and qualification of, photomasks for use in optical lithography within the semiconductor industry.

2 Scope

2.1 At present only the International Technology Roadmap for Semiconductors (ITRS) serves as a universally accepted working document on how to specify photomasks, however the definitions used are subject to interpretation. Different tool makers, mask makers and mask users are hindered in the communication with each other, as they first need to know and understand each other's terminology. The lack of a common terminology complicates comparison of tools. A uniformly used, and universally accepted terminology, with a minimum of ambiguity, is required.

2.2 The definitions listed are for mask qualification, incorporating 3 possible types of value for a given qualification parameter:

- **<(true) qualification parameter>**, which would be the result of an ideal measurement of the total population of features of interest¹.
- **<measured qualification parameter>**, the result of a given population of measurements. It is hereby mentioned that a measured value (for example the mean, the standard deviation, the range) is always subject to the sample size of the measured population and the measurement method. Therefore, both the sample size and the measurement method are mandatory information.
- **<qualification parameter spec(ification)>**, the maximum or minimum value that may not be exceeded for the selected population of measurements which must be defined as mandatory information.

2.2.1 The first two types of value for a given parameter, the true and measured qualification parameters, will be defined in the present document.

2.2.2 The third parameter type, the parameter specification, will not be discussed here, since it is subject to the agreement between the individual parties of the mask qualification process.

2.3 In order to assist users, the major differences in recommended default values between this standard and the ITRS mask table definitions are noted where applicable.

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 This document is restricted to dimensional metrology aspects. Other conventional mask qualification aspects, including those related to materials, overlay and defectivity, are not considered within the scope of this version.

3.2 The definitions listed are specific to state-of-the-art photomasks, with a focus on reduction reticles. They may therefore overrule any related terminology in other standards, with a more general scope. Application to other types

¹ See reference document in ¶ 4.2.

of masks, for example, for next generation lithography, may be feasible, but is not within the scope of the present document.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI P10 — Specification of Data Structures for Photomask Orders

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

SEMI P21 — Guidelines for Precision and Accuracy Expression for Mask Writing Equipment

SEMI P22 — Guideline for Photomask Defect Classification and Size Definition

SEMI P24 — CD Metrology Procedures

SEMI P35 — Terminology for Microlithography Metrology

4.2 ISO Standard²

ISO Guide 99 — International Vocabulary of Basic and General Terms in Metrology (VIM)

4.3 Other Documents

International Technology Roadmap for Semiconductors (ITRS)³

SEMI International Standards: Compilation of Terms

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

5 Interpretation of Related General Terminology

NOTE 1: This paragraph includes general terms, as a basis for the specific mask related terminology, which is the main subject of this document.

5.1 *feature* — as defined in SEMI P35.

5.2 *proximity range* — distance over which a feature influences another significantly (criterion to be stated). This term applies to mask fabrication, mask metrology and/or printed wafer image, defining 3 types of proximity range (for example *mask fabrication proximity range*). It is mandatory to state which of the 3 types is referred to.

NOTE 2: Within this document *proximity range* will refer by DEFAULT to the first type mentioned.

5.3 *line* — a clear field, dark feature of quasi-infinite length ($\gg$ *proximity range*) determined by its width. A *line* is an example of a 1D feature (see Figure 1).

5.4 *space* — in analogy to line, but a clear feature in a dark field (see Figure 1).

5.5 *contact* — a clear feature in a dark field with length:width ratio ranging from 0.5 (1 is default) to 2 maximum (see Figure 1). The width of such feature may be measured as if it were a 1D feature, but for enhanced relevance it requires 2D assessment such as an area measurement. A large contact can be called a *window*.

5.6 *dot* — in analogy to contact, but a dark feature in a clear field (see Figure 1). A large dot can be called a *pad*.

5.7 *isolated feature* — feature that has no neighbors that are within a distance smaller than the proximity range to any edge of the feature.

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

³ International Technology Roadmap for Semiconductors, organized by International SEMATECH, 2706 Montopolis Drive, Austin, Texas 78741, see <http://www.itrs.org>

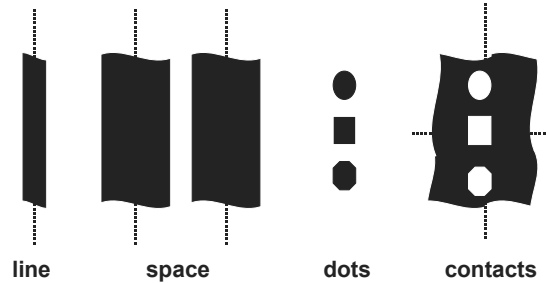


Figure 1
Nomenclature for Feature Types (as designed) Default Contact (dot) is Square

5.8 *dense features* — features that influence each other (i.e., features that are not isolated). Clarification is required to describe the proximity, either by detailing the feature pitch and number of lines, for regular arrays (pitch = design values of line width and space width added), or by describing the surrounding area (see § 7). In absence of such clarification dense is regarded by default as equal lines and spaces in a semi-infinite array size, insofar that the feature width does not exceed the proximity range.

5.9 *nominal feature* — feature as it is intended. This usually corresponds to the data used for mask making, including any pre-compensation to overcome process biases of the wafer process (e.g., subresolution features such as hammerheads and serifs), but excluding any precompensation that is purely done to deal with mask process limitations (e.g., chrome etch bias). In the simplest case it corresponds to the original design itself.

5.10 *actual feature* — feature as it is on the mask. In practical cases this will include deviations in feature widths, lengths, shape and position from the nominal feature.

NOTE 3: A feature, whether actual or nominal, may contain holes, as shown in Figure 2.



Figure 2
Example of Features Containing Holes (left: nominal; right: actual)

5.11 *pattern* — subset of a layout containing one or more features.

NOTE 4: It is possible that some features are only included in part, see *clipped feature*.

5.12 *region of interest (ROI)* — circumscribed section of a pattern that contains (parts of) the features considered for measurement.

NOTE 5: It is recommended to make the ROI as small as possible without affecting the obtained result.

5.13 *clipped (nominal/actual) feature* — the part of the (nominal/actual) feature lying within the region of interest (Figure 7).

5.14 *feature (or Pattern) alignment* — positioning of nominal and actual feature (or pattern) relative to each-other (see ¶ 8.4).

6 Coordinate System

6.1 The coordinate system XYZ for this document is defined in Figure 3. It is defined with patterned mask side upwards and mask orientation as it was patterned. XY determines the mask plane. Z is the direction perpendicular to it. $z = 0$ at the absorber-substrate interface and $z < 0$ to the substrate side. Absorber is for example chrome or embedded material. $(x,y) = (0,0)$ is tool or application specific.

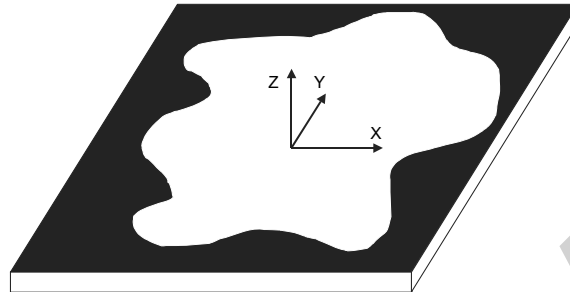


Figure 3
Mask Coordinate System

6.2 Features are called vertical when their length is along Y. Feature width is then measured in X. This corresponds to Figure 2 of SEMI P35. Horizontal features have their length along X. Feature width is then measured in Y. See Figure 4.

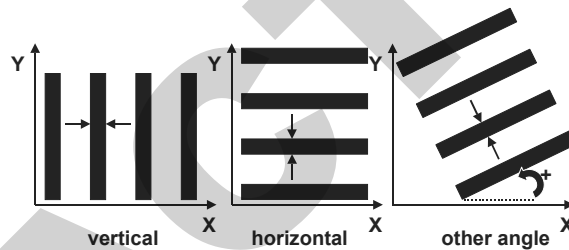


Figure 4
Orientation of Mask Features

7 1D Mask Qualification Terminology

7.1 *feature width* — width of a cross section of a mask feature at a certain height defined by an appropriate bounding box model as described in SEMI P35 (see Figure 5). The bounding box model must be stated as mandatory information, as well as the z height of the measurement. DEFAULT is at $z = 0$.

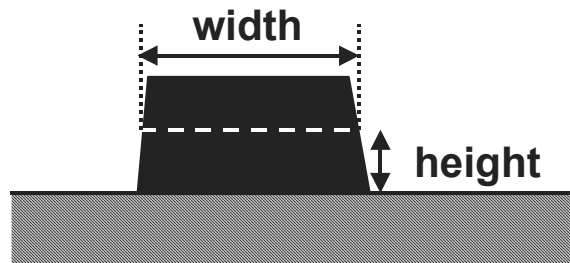


Figure 5
Cross Section of a Mask Feature

7.2 *measured feature width* — width determined from the measured signal obtained on the mask feature. For example, the width may be determined at a certain level of the measured signal. To be stated as mandatory information:

- region of interest. For 1D features this corresponds to the specified line segment (SEMI P35),
- measurement method used (SEM, optical reflection, optical transmission, AFM, etc.),
- calibration and/or correlation used,
- precision (SEMI P24),

and as optional information:

- measurement tool (vendor, model or any tool specific options), and
- measurement algorithm used.

NOTE 6: The bounding box could be infinitely short as in the special situation of a measurement of a *feature* using a cross-section.

7.3 *feature width deviation (from target)* — difference between actual and nominal feature width.

7.4 *measured feature width deviation (from target)* — difference between measured and nominal feature width.

7.5 *feature edge* — position of the material boundary of a mask feature at a certain height of the physical cross section (see Figure 2 of SEMI P35), to be stated as mandatory information. DEFAULT is feature/substrate interface.

7.6 *measured feature edge* — position determined from the measured signal obtained on the mask feature edge. For example, position determined at a certain level of the signal, as defined by the bounding box model of SEMI P35. The same mandatory/optional information must be stated as for *measured feature width*.

7.7 *critical dimension (CD)* — a user defined feature width of interest, mainly used for further qualification. The critical dimension can be plural. DEFAULT CD is one width and one pitch. Mandatory information is the nominal feature width and pitch.

NOTE 7: The ITRS mask table assumes multiple pitches.

7.8 *feature width uniformity* — the spread of the distribution of the width of all mask features of a given design size, selected as detailed hereafter. To be stated as mandatory information:

- its targeted feature width,
- the criterion used (range, 3-sigma, maximum deviation, etc.), where sigma stands for standard deviation. Recommendation: before 3-sigma is relevant, the distribution needs to be “normal” or “near normal”, and the number of measurements should be >30,
- type and tone of features considered (line, contact, space, etc. as defined in SEMI P19),

NOTE 8: Several types and/or tones of features could be combined, but the recommendation is one tone and one type, DEFAULT is lines for clearfield, spaces for darkfield).

- all orientations considered (adopting a pre-determined mask orientation, based on the coordinate system in § 6), for example horizontal and vertical together, horizontal only, vertical only, including other angles, horizontal-and-vertical separately, etc. DEFAULT is horizontal and vertical together,
- the pitch of the feature (or in general: a description of the surrounding area, see further), for example, equal lines and spaces, isolated line, etc., or (if wished, but not recommended) an interval of pitches, and

NOTE 9: In case of multiple pitches the defined *feature width uniformity* would not be proximity free. DEFAULT is one fixed pitch, to be mentioned. (The ITRS mask table assumes multiple pitches.)

- The considered area of interest on the mask.

7.9 *measured feature width uniformity* — measured value of feature width uniformity, stating as mandatory information in addition to that of measured feature width and feature width uniformity:

- the number of measurement points used,
- the measured area on the mask,

and as optional information:

- the spatial distribution of measurement locations, for example, by their coordinates. DEFAULT is spread evenly over the measurement area.

7.10 *(measured) CD uniformity* — the special case of feature width uniformity where the selected feature is the critical dimension.

7.11 *feature mean-to-target* — the difference between the mean width of features, selected as detailed, and the targeted feature width, stating the same information as for *feature width uniformity*. (DEFAULT: selecting the same information and values as for *feature width uniformity*.)

7.12 *measured feature mean-to-target* — the difference between the mean of measured feature widths and the targeted feature width, stating the same information as for *measured feature width uniformity*. (DEFAULT: selecting the same values as selected for *measured feature width uniformity*.)

7.13 *(measured) CD mean-to-target* — the special case of (measured) feature mean-to-target where the selected feature is the critical dimension.

7.14 *maximum feature width deviation from target* — maximum deviation of the width of a *feature* from its target width in the total population of features considered, stating the same information as in *feature width uniformity*. (DEFAULT: selecting the same information and values as used for *feature width uniformity*.)

7.15 *measured maximum feature width deviation from target* — maximum deviation of the measured width of a *feature* from its target width in the population of measurements, stating the same information as in *measured feature width uniformity*. (DEFAULT: selecting the same values as used for *measured feature width uniformity*.)

NOTE 10: (Measured) maximum feature width deviation from target combines (measured) feature width uniformity and (measured) mean-to-target.

7.16 *mean X-Y deviation* — the difference between the mean of considered feature widths in X and Y directions (horizontal and vertical direction), stating the same information as *feature width uniformity*. (DEFAULT: selecting the same values as used for *feature width uniformity*.)

7.17 *measured mean X-Y deviation* — the difference between the mean values of measured feature widths in X and Y directions, stating the same information as for *measured feature width uniformity*. (DEFAULT: selecting the same values as used for *measured feature width uniformity*.)

7.18 *X-Y deviation uniformity* — the spread of the distribution of the difference between the width of all considered feature widths in X and Y directions (horizontal and vertical direction), stating the same information as *feature width uniformity*. (DEFAULT: selecting the same values as used for *feature width uniformity*.)

NOTE 11: For such purpose X and Y feature width measurement locations should be as close as practically possible.

7.19 *measured X-Y deviation uniformity* — the spread of the distribution of the difference between the width of the measured feature widths in X and Y directions (horizontal and vertical direction), including/stating the same information as *measured feature width uniformity*. (DEFAULT: selecting the same values as used for *measured feature width uniformity*.)

7.20 *feature linearity error* — total range of the deviations between the mask feature width and the respective target width on a range of feature widths (see Figure 6a), stating as mandatory information:

- the range of feature widths used (at mask level). (DEFAULT is the interval from the critical dimension to 5 times this value.)

NOTE 12: The ITRS uses a wider interval.

- all types and tones of features considered, for example, line, contact, space, etc. (see in § 5 for definitions of these terms). It is a strong recommendation to fix on 1 tone and 1 type to reach a useful number. DEFAULT is on lines (“*line linearity error*”). Contacts may be more challenging (“*contact linearity error*”).
- all orientations considered, for example, horizontal and vertical together, horizontal only, vertical only, including other angles, horizontal-and-vertical separately, etc.

- the pitch of the feature (or in general: a description of the surrounding mask area, (see further), for example, equal lines and spaces, isolated line, etc., or (if wished, but not recommended) an interval of pitches. DEFAULT is isolated features only, which is defined as *feature intra-proximity error*.

NOTE 13: If a range of pitches is included, the resulting definition will include (inter)proximity effects. (The ITRS mask table assumes multiple pitches.)

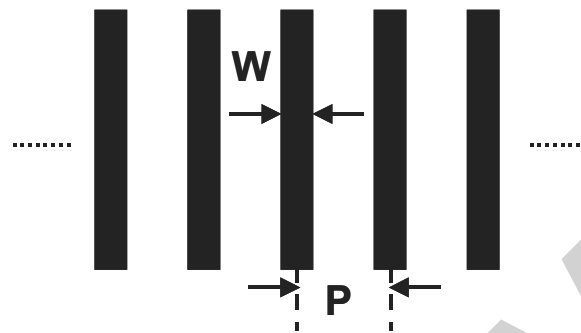


Figure 6

Choice of Width (W) and Pitch (P) in an Array of Features (here shown for lines) for the Determination of:

- Feature Linearity: Varying W and P Fixed;**
- Feature Interproximity: Fixed W and Varying P;**
- Feature Proximity: W and P BOTH Varying**

7.21 *measured feature linearity error* — measured value of feature linearity error, stating as mandatory information in addition to that of measured feature width and feature linearity error:

- the number of measurement points per feature width (which is recommended to be more than one measurement per feature width). If more than one measurement per feature is taken, then the mean value for each feature width is used.

and as optional information:

- the measured area.
- the spatial distribution of measurement locations.

7.22 *feature inter-proximity error* — range of the deviations between the mask feature width of a given size and the respective target width, on a variation of local pattern density and configuration (i.e., of the surround) (see Figure 6b), stating as mandatory info:

- the nominal feature width at mask level.
- all types and tones of features considered, for example, line, contact, space, etc. (see in § 5 for definitions of these terms). It is a strong recommendation to fix on 1 tone/1 type to reach a useful number. DEFAULT is on lines (*line inter-proximity error*).
- all orientations considered, for example, horizontal and vertical together, horizontal only, vertical only, including other angles, horizontal-and-vertical separately, etc.
- range of feature pitches. DEFAULT is equal lines-and-spaces to isolated features. If only equal lines-and-spaces and isolated features themselves (and nothing in-between) are used, the term *iso-dense deviation* can also be used. In more general cases an alternative detailed description of the surrounding mask area, preferably clarified with a drawing, will replace the pitch information.

7.23 *measured feature inter-proximity error* — measured value of feature inter-proximity error, stating as mandatory information in addition to that of measured feature width and feature inter-proximity error:

- the number of measurement points used per pitch or surrounding mask area (to be more than one measurement per pitch). If more than one measurement per pitch is taken, then the mean value for each pitch is used.