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TECHNICAL SPECIFICATION

Nanotechnologies – Description, measurement and dimensional quality parameters of artificial gratings

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NANOTECHNOLOGIES – DESCRIPTION, MEASUREMENT AND DIMENSIONAL QUALITY PARAMETERS OF ARTIFICIAL GRATINGS

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62622, which is a technical specification, has been prepared within the joint working group 2 of IEC technical committee 113 and ISO technical committee 229.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
113/133/DTS	113/143/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table. In ISO, the standard has been approved by 16 member bodies out of 16 having cast a vote.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Artificial gratings play an important role in the manufacturing processes of small structures at the nanoscale as well as characterization of nano-objects.

For example, in high volume manufacturing of semiconductor integrated circuits by means of lithography techniques, grating patterns on the photomask and the silicon wafer are optically probed and the resulting optical signal is analyzed and used for relative alignment purposes of mask to wafer in the different lithographic production steps in the wafer-scanner production tools. In semiconductor manufacturing as well as in other manufacturing processes requiring high positioning accuracy at the nanoscale, often length or angular encoder systems based on artificial gratings are used to provide position feedback of moving axes. Another area of application for artificial gratings in nanotechnology is their use as calibration standards for high resolution microscopes, like scanning probe microscopes, scanning electron microscopes or transmission electron microscopes which are necessary tools for the characterization of nanoscale structures.

The quality of the artificial gratings used for position feedback generally influences the achievable accuracy of alignment systems or positioning systems in manufacturing tools. This also holds for the application of artificial gratings as standards for calibration of image magnification of high resolution microscopes, where the quality of the grating plays an important role in the achievable calibration uncertainty of the standard and thus for the attainable measurement uncertainty of the microscope.

This technical specification concentrates on specifying quality parameters, expressed in terms of deviations from nominal positions of grating features, and provides guidance on the application of different categories of measurement and evaluation methods to be used for calibration and characterization of artificial gratings

NANOTECHNOLOGIES – DESCRIPTION, MEASUREMENT AND DIMENSIONAL QUALITY PARAMETERS OF ARTIFICIAL GRATINGS

1 Scope

This technical specification specifies the generic terminology for the global and local quality parameters of artificial gratings, interpreted in terms of deviations from nominal positions of grating features, and provides guidance on the categorization of measurement and evaluation methods for their determination.

This specification is intended to facilitate communication among manufacturers, users and calibration laboratories dealing with the characterization of the dimensional quality parameters of artificial gratings used in nanotechnology.

This specification supports quality assurance in the production and use of artificial gratings in different areas of application in nanotechnology. Whilst the definitions and described methods are universal to a large variety of different gratings, the focus is on one-dimensional (1D) and two-dimensional (2D) gratings.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO/TS 80004-1:2010, *Nanotechnologies – Vocabulary – Part 1: Core terms*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 Basic terms

3.1.1
feature
region within a single continuous boundary, and referred to a reference plane, that has a defining physical property (parameter) that is distinct from the region outside the boundary

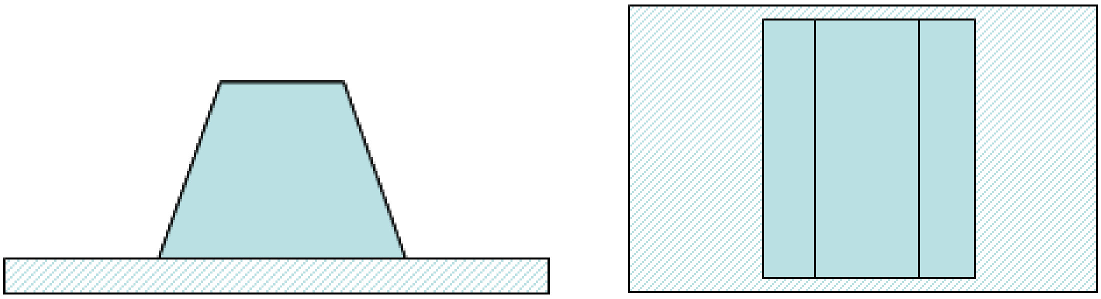

Figure 1 – Example of a trapezoidal line feature on a substrate

EXAMPLE In Figure 1 a feature with a trapezoidal cross-section on a substrate is shown.

Note 1 to entry: This definition is adapted from [1][1] (SEMI P35 (5.1.5 feature (lithographic)).

Note 2 to entry: In general, a feature is a three-dimensional object. It can also be a nano-object (defined in ISO/TS 80004-1:2010, 2.5). It can have different shape, e.g. it can be a dot, a line, a groove, etc. It might be symmetric or non–symmetric. It can have the same material properties as the substrate or different ones. It can be located on the surface of a substrate or within the substrate (sometimes called “buried feature”).

Note 3 to entry: In [2] the term ‘geometrical feature’ is generally defined as point, line or surface.

3.1.2
reference plane
user-defined plane approximating the surface of a substrate and containing a feature coordinate system

Note 1 to entry: This definition is adapted from [1].

3.1.3
feature coordinate system
coordinate system
Cartesian coordinate system defined by the reference plane as x-y plane, the x-axis defined by the main grating direction and the origin defined by a suitable, specified reference position

Note 1 to entry: Often, the position of a particular feature is chosen as the origin of the coordinate system, e.g. the first feature in a 1D grating, or the lower left feature in a 2D grating.

Note 2 to entry: In other cases, the origin can also be defined from an analysis of the positions of all features of interest, e.g. the mean value of all positions in the x-direction for a 1D grating. In the case of a 2D grating the origin can also be defined by a least squares regression fit over all measured x- and y-positions of all features of the 2D grating allowing translation of the origin and rotation of the whole 2D grating (so-called multi-point alignment). In these cases the origin of the feature coordinate system no longer corresponds to a particular feature.

Note 3 to entry: The origin can also be chosen as the position of a specified alignment feature or auxiliary feature within the reference plane.

Note 4 to entry: In case of angular gratings the feature coordinate system can favorably be defined as a polar coordinate system: r, φ or a cylindrical coordinate system: r, φ, z.

3.1.4
feature pattern
set of features, specified by number, type, and positions of features

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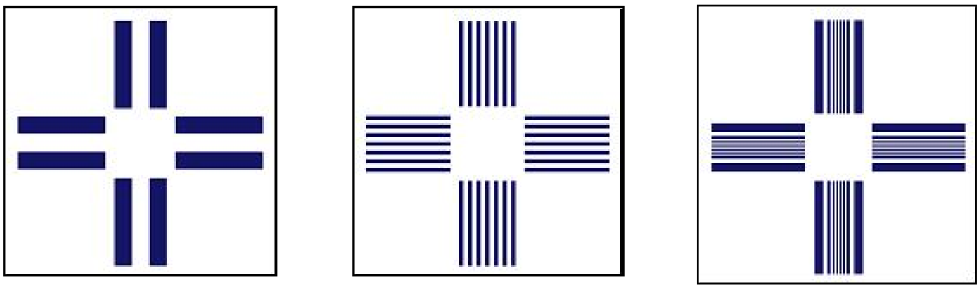
1 Numbers in square brackets refer to the Bibliography.



Double cross   Cross of line arrays   So-called Braker structure pattern

IEC 1792/12

Figure 2 – Examples of feature patterns

EXAMPLE Figure 2 shows examples of different types of feature patterns.

Note 1 to entry: Different kinds of features can be arranged differently in a set to form feature patterns. These can be rather simple e.g. a single cross structure as a combination of two orthogonal line features, complex like, e.g. a double cross-structure or a line array or even more complex, e.g. irregularly spaced line features.

3.1.5
feature position
x_i, y_i, z_i
coordinates describing the position of a prescribed point of the i^{th} feature of a number N of features projected onto the reference plane relative to a specified coordinate system

Note 1 to entry: For 1D gratings the x-positions of the features are primarily of interest assuming the direction of the grating, i.e. the direction in which the number of grating features per unit length is maximal, is the x-direction, whereas for 2D gratings their x- and y-positions are of interest. In both cases, their z-positions are usually of minor interest, assuming the *reference plane* is already well aligned to the axes of the measurement instrument.

Note 2 to entry: Depending on the chosen criterion for the feature position evaluation (see Note 3), the measured feature position is dependent on the interaction of the measurement instrument used with the feature characteristics, like its shape, size and material properties.

Note 3 to entry: The determination of the feature position is often based on the analysis of a microscopic image of the feature. The microscope image signals can be analyzed in different ways to determine the feature position. Mostly the centre position of the feature is of interest which can be determined, e.g. by calculation of the centroid or by determination of the mean value between the position of the left and the right edge of the feature.

Note 4 to entry: If only parts of the feature are of interest, e.g. the edge position of a line feature, the determination of the position of the respective edge(s) should be based only on the parts of the feature that are of interest.

Note 5 to entry: The above definition for the feature position can also be applied to a feature pattern.

Note 6 to entry: If angular gratings are analyzed, it is favorable to express the feature position in polar coordinates r, φ or in cylindrical ones r, φ, z.

3.1.6
distance between features
d
difference of the feature positions determined on equivalent or homologous feature characteristics in the direction of interest

Note 1 to entry: The distance d between two consecutive features, i and i-1, in the x-direction is:

$$d = \text{abs}\ (x_i - x_{i-1})$$

Note 2 to entry: The distance d between two consecutive features in the reference x,y plane generally is:

$$d = [(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2]^{0,5}$$

Note 3 to entry: The distance d between two consecutive features at the positions x_i, y_i, z_i and x_{i-1}, y_{i-1} z_{i-1} in the general case is:

$$d = [(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2 + (z_i - z_{i-1})^2]^{0,5}$$

Note 4 to entry: Usually the distance between features is of interest for the centre positions of the features. In some cases however the distance can also be of interest for positions on the feature edges.

3.2 Grating terms

3.2.1
grating
periodically spaced collection of identical features

Note 1 to entry: In [3], which provides a vocabulary of diffractive optics, a grating is defined as a "periodic spatial structure for optical use" (3.3.1.2). In this technical specification, gratings are not restricted to optical use only.

Note 2 to entry: Often gratings show a ratio of the distance between neighboring identical features to their size that is close to one. However, the definition is not restricted to these cases and also includes so-called sparse gratings and thus in principle line scales, too.

Note 3 to entry: Although this technical specification is primarily addressing periodic gratings, the definition of grating quality parameters should also be applicable to non-periodic gratings, like chirped gratings (3.3.5.2) as far as possible. Limitations might occur in particular for spatial filtering approaches of feature position data.

Note 4 to entry: Sometimes a grating can be divided into several sub-gratings having different features.

3.2.2
pitch
p
distance between neighboring features of a grating

Note 1 to entry: Often, the feature centre positions are used to determine the pitch. In some cases, however, also the distance between equivalent edges of a pair of features is used to determine the pitch values.

Note 2 to entry: This definition is in alignment with the definition for pitch as specified in [1] (5.1.14).

3.2.3
nominal pitch
p_{nom}
intended pitch value, indicated in the specification of a grating

3.2.4
number of grating features
N_f
result of a summation over all identical features of the grating in the direction of interest

Note 1 to entry: The number of grating features can be different in the different directions for 2D and three-dimensional (3D) gratings. The total number of features in 2D and 3D gratings is the product of the number of grating features along the 2 or 3 different directions (e.g. dots in the case of 1D features).

3.2.5
mean pitch
p_m
average pitch value determined over all identical features of the grating

Note 1 to entry: The mean pitch is not necessarily the arithmetic mean pitch, but any statistically characteristic pitch.

Note 2 to entry: If all feature positions of the grating are known, the mean pitch of a grating can be determined by a linear least squares regression fit of all measured feature positions $x_{i,\,m}$ to the nominal feature positions $x_{i,\,nom}$. If the uncertainties of the measured feature positions are equal, a standard linear regression fit can be applied. In case of a variation of the uncertainties u_{xi} of the measured feature positions $x_{i,\,m}$, a weighted linear regression fit should be applied, using the inverse variances as weights ($w_i = 1/(u_{xi})^2$). The resulting slope m of the regression line (yielding values for slope m and intercept b) can be used to calculate the mean pitch value $p_m = m \cdot p_{nom}$ taking into account the position information of all features of the grating.

Note 3 to entry: The mean pitch of a grating is often also called the period length or grating constant Λ of the grating.

Note 4 to entry: For an ideal grating, the values for the mean pitch, the local pitch and the pitch for all neighboring features are identical. For real gratings, however, the values would be different, depending on the quality of the grating and the different length ranges over which the local pitch value will be evaluated. In addition, the capability of measurement methods to determine the different pitch values on non-ideal gratings is different. The measurement methods, therefore, can be classified in different groups, see 3.5.

Note 5 to entry: If the boundary length of a grating L_b (3.2.8) and the number of grating features N_f (3.2.4) are known, an approximation to the mean pitch can be determined by the equation: $p_m = L_b / (N_f - 1)$; $N_f \geq 2$. The same pitch value results if the arithmetic mean value of all pitch values over all neighboring features is calculated. In the sum $\Sigma^{N_f-1}_{i=1} (x_{i+1} - x_i) / (N_f - 1)$ for calculation of the arithmetic mean value of all pitch values of a grating all feature position values x_i cancel out except for the first and last feature. In both cases the resulting approximation of the mean pitch value is based on the positions of the first and the last feature in the grating only and thus less representative of the whole grating than the mean pitch determined by a linear regression fit [4].

3.2.6
local pitch
p_{loc} (x_c, l_r)
average pitch value determined over a defined length range l_r of a grating centered around a defined feature position x_c

EXAMPLE If a local pitch p_{loc} of a nominally 1 mm long 1D grating with 100 nm nominal pitch is evaluated around a central position at x_c = 400 µm over a length range l_r of 20 µm, the resulting local pitch should be expressed as: p_{loc} (400 µm, 20 µm) or p_{loc} (4001, 201) if expressed in number of features of the grating.

Note 1 to entry: The local pitch can also be defined over a specified number of features N_r centered around a specified feature with index N_c. In this case the notation for the local pitch is: p_{loc} (N_c, N_r).

3.2.7
nominal length of grating
L_{nom}
intended length of a grating, indicated in the specification of the grating

Note 1 to entry: The length of a grating is defined in the direction of the grating, i.e. the direction in which the number of grating features per unit length is maximal.

3.2.8
boundary length of grating
L_b
distance between the first and the last feature of a grating

Note 1 to entry: The center to center distance is the default case.

3.2.9
characteristic length of grating
L_c
length of a grating, based on the mean pitch and the number of grating features

$$L_c = p_m \cdot (N_f - 1)$$

Note 1 to entry: For an ideal grating the nominal length, the boundary length and the characteristic length values of a grating are identical. For real gratings, however, they are different.

3.3 Grating types

3.3.1
1D grating
grating in which features are repeated in only one direction within the reference plane