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INTERNATIONAL STANDARD

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Printed electronics –
Part 301-2: Equipment – Contact printing – Rigid master – Measurement method of plate master pattern dimension

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Part 301-2: Equipment – Contact printing – Rigid master – Measurement method of plate master pattern dimension

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PRINTED ELECTRONICS –

Part 301-2: Equipment – Contact printing – Rigid master – Measurement method of plate master pattern dimension

FOREWORD

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The text of this International Standard is based on the following documents:

FDIS	Report on voting
119/178/FDIS	119/187/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

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

A list of all parts in the IEC 62899 series, published under the general title *Printed electronics*, can be found on the IEC website.

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

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

When dissecting the term "printed electronics", it can be easily understood that this industry involves electronic devices and products that are made using some fashion of printing technique. Printing methods have been widely used in textile and paper type substrates for centuries. In the past, the advent of mass producible printouts has brought huge impacts on how knowledge is stored, transferred and reproduced. At this stage of technological development, printing on either rigid or flexible substrates is considered to supplement or replace traditional electronic device manufacturing processes. The difference between media printing and printed electronics stems from the fact that media print is used to convey information for human to process using eyes while printed electronics requires machine to process electronic information; the level of required resolution and functionality make the differences. Some of the widely used functional materials for printed electronics are, but not limited to nano- or micro-size metal particles, semiconductive polymers, and dielectric materials. Due to the available and required readout resolution, small feature size below 20 μm needs to be printed. Layer thickness and registration accuracy of printed products are closely related to quality control of electronic devices, and ink materials require a high level of quality. Overall, printing tolerance is much smaller in printed electronics.

There are mainly two categories in printing process for the printed electronics. One is a non-contact printing process such as inkjet printing and electrostatic discharge (ESD) printing process. The other is a contact printing process such as gravure printing, gravure offset printing, reverse offset printing and screen printing. This document provides a proposal for measuring and assessing the printing master, therefore the scope is limited to the printing process using the printing master.

The quality of the printing master is important because the ink is transferred from the printing master to the substrate directly in these processes and it means that the quality of the results of the printed circuit depends on the quality of the printing master. For a mass production of the printed electronic devices, many companies such as device manufacturers, printing master manufacturers and printing master manufacturing equipment vendors are related to manufacturing and they need to use the printing master and the standardized measurement and assessment methods.

PRINTED ELECTRONICS –

Part 301-2: Equipment – Contact printing – Rigid master – Measurement method of plate master pattern dimension

1 Scope

This part of IEC 62899 defines measurement terms and methods related to the critical dimension of features and the registration accuracy of features on rigid plate masters.

General critical dimensions are defined to evaluate the shape accuracy of features on the plate master. To evaluate the registration accuracy of features on the plate master, the specification for the registration mark for the plate master is specified. Then, common metrology procedures to measure the critical dimensions and the registration accuracy of the plate master are established for device manufacturers, printing master manufacturers and printing master manufacturing equipment vendors. The measurement terms which are measured by agreement between the user and the supplier are measured using the measurement methods given in this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
plate master
device that carries the image to be printed

Note 1 to entry: The image on the plate may be raised above the surface (relief) or may be carved into the surface.

3.2
machine direction
MD
direction in which the stock flows

3.3
CD
cross direction
direction at right angles to the machine direction of a substrate

3.4
pattern edge detection method
method for determining the edge position of a given pattern by a computer algorithm

3.5
feature
region within a single continuous boundary that is distinct from the region outside the boundary

Note 1 to entry The feature is called "CD feature" if the length of the feature is aligned with the cross direction while the feature is printed.

Note 2 to entry The feature is called "MD feature" if the length of the feature is aligned with the machine direction while the feature is printed.

3.6
nominal feature
intended or designed feature

3.7
actual feature
manufactured feature on the master plate

3.8
critical dimension
dimension of the geometrical features (width of interconnected lines, contacts, trenches, etc.) which can be formed during electronic device/circuit manufacturing and can be of interest for further qualification

3.9
1-D qualification features
features which can be qualified by single directional parameters

3.9.1
feature width
width of feature which will be printed on the substrate

Note 1 to entry Generally, feature width is measured for the line and space pattern. It can be expressed by line width or space width.

3.9.2
pitch
centroid-to-centroid distance between two repeatedly placed features

3.9.3
line edge roughness
LER
perpendicular point-to-point deviation of the feature's edge from the linear fitted feature edge

3.9.4
line width roughness
LWR
deviation of the point-to-point line width from the average width of the specified line width

3.10
2-D qualification feature
feature that is qualified by area-based qualification parameters

3.10.1
contact
rectangular feature whose length-to-width ratio ranges from 0,5 to 2

3.10.2
line-end shortening
deviation of the actual feature from the nominal feature at the nominal line-end

3.10.3
corner rounding
deviation of an actual feature corner from the nominal one

3.10.4
area gain
area in the actual feature contour outside the nominal feature contour

3.10.5
area loss
area outside the actual feature but still inside the nominal feature

3.10.6
area difference
feature area gain minus feature area loss

3.10.7
area deviation
sum of the values of the feature area gain and the feature area loss

3.11
cross-sectional qualification feature
feature which can be qualified by cross-sectional qualification parameters

3.11.1
feature height
feature depth
dimension of feature perpendicular to reference plane

3.11.2
feature model
solid geometrical shape, with well-defined parameters (e.g. length, width, height, centroid, etc), meant to approximate the actual shape of a feature boundary

3.11.3
reference plane
plane which is approximating the un-patterned surface on the master plate

3.12
registration accuracy
deviation of the measured feature position from the nominal feature position

3.12.1
registration accuracy of the reference marks relative to the reference edges
deviation of the measured feature position of the reference registration marks relative to reference edges from their nominal feature position

3.12.2
reference registration marks
registration marks whose distance from two reference edges is measured

3.12.3
reference edges
two edges adjacent to the orientation corner

3.12.4
orientation corner
asymmetric orientation corner specified for the purpose of mechanical orientation and operator's visual confirmation of plate orientation

4 Coordinate system [1] [1]

The coordinate system xyz for this document is defined in Figure 1. It is defined with the patterned mask side upwards. Cross direction is aligned with the x axis, and machine direction is aligned with the y axis. The z axis is the direction perpendicular to the xy plane; z is zero at reference plane and (x, y) = (0,0) is tool or application specific.

Features are called "CD features" when their length is along x, and feature width is then measured in y. The length of MD features is along y, and their feature width is measured in x. The registration accuracy is expressed with this coordinate system.

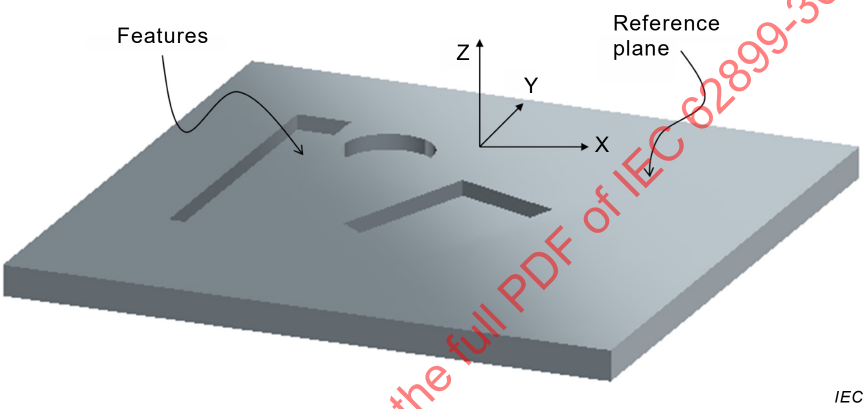

Figure 1 – Coordinate system for measuring patterns on the plate master

5 1-D qualification features [1]

5.1 Measurement instrument

The measurement instrument is as follows.

– Microscope or measurement instrument with sufficient resolution:
  - repeatability: less than 10 % of the tolerance specification of the width;
  - accuracy: less than 10 % of the tolerance specification of the width;
  - calibration: Calibration should be carried out periodically in accordance with the guidelines of the instrument manufacturer.
– Measurement temperature: it is recommended that the measurement is carried out at the temperature of 20 °C which is specified as the standard reference temperature in ISO 1.

5.2 Feature types

The feature types are as follows:

– feature width and pitch;
– line edge roughness (LER) and line width roughness (LWR).

1 Numbers in square brackets refer to the Bibliography.

5.3 Pattern edge detection method

There are several methods, such as the threshold method, the linear approximation method, and the curve fitting method for determining the edge position automatically from the obtained image. The method can be determined by the customer/vendor agreement. The pattern edge detection method and its parameter settings should be specified in the report as they affect the measurement results.

To enhance measurement accuracy, the measured feature width should be compared with the cross-sectional measurement result. This is because the feature width is different due to the distance from the reference plane. The measured feature width can be adjusted by modifying the edge detection method.

5.4 Feature width and pitch

5.4.1 Procedure

The procedure is as follows.

1) Align the sample so that the line pattern is approximately perpendicular to the x axis. For the convenience of explanation, the x axis is selected and the y axis can be applicable.
2) Acquire the two-dimensional signal intensity distribution of the line pattern.
3) Define the measurement area by determining the length of the evaluation interval (L) as shown in Figure 2.

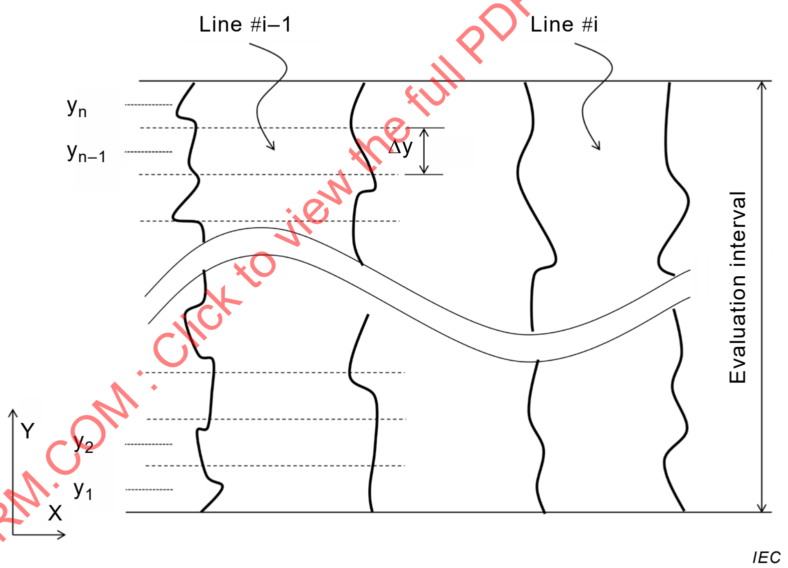

Figure 2 – Evaluation example of feature width and pitch

4) Average the signal intensity in the y axis for the whole evaluation interval.

$$I'(x) = \frac{1}{L}\int_0^L I(x,y)dy \quad (1)$$

5) Calculate the left and right edge positions ($x_{L,i}$, $x_{R,i}$) from the signal intensity distribution $I'(x)$. The subscript L and R indicate the left edge and right edge, respectively. The subscript i refers to the line number.
6) Calculate the distance between the left and right edge point for obtaining the feature width (w):

$$w = x_{R,i} - x_{L,i} \quad (2)$$

7) Calculate the distance between the centroids of two adjacent lines to obtain the pitch (p):

$$p = \frac{x_{\mathrm{L},i} + x_{\mathrm{R},i}}{2} - \frac{x_{\mathrm{L},i-1} + x_{\mathrm{R},i-1}}{2} \tag{3}$$

5.4.2 Report

The report should contain the following.

- Provide the measured feature width in units of 0,1 µm and specify the measurement location of features on the master plate and the length of the evaluation interval.
- Specify the measurement instrument.
- Specify the pattern edge detection method and its parameter settings.
- Specify the measurement temperature and temperature variation during measurement.
- Provide the acquired image for the measurement.

5.5 Line edge roughness (LER) and line width roughness (LWR)

5.5.1 Procedure

The procedure is as follows.

1) Align the sample so that the line pattern is approximately perpendicular to the x-axis.
2) Acquire the two-dimensional signal intensity distribution of the line pattern.
3) Define the measurement area by determining the length of the evaluation interval as shown in Figure 2.
4) Average the signal intensity in the y-axis and construct n averaging intervals of length equal to Δy.

$$I''(x, y^k) = \frac{1}{\Delta y} \int_{y^k - \Delta y/2}^{y^k + \Delta y/2} I(x, y) dy \tag{4}$$

5) Calculate the left and right edge positions ($x_{\mathrm{L},i}{}^k$, $x_{\mathrm{R},i}{}^k$) from the signal intensity distribution $I''(x,y^k)$. The subscript L and R indicate the left edge and right edge, respectively. The subscript i refers to the line number and the superscript k indicates the k^{th} averaging interval in the y axis in item 4).
6) Calculate the LER of left edge in line number i.
   a) Obtain an approximation line (line of best fit using the least square method) from the data set of $\{(x_{\mathrm{L},i}{}^1, y_1), (x_{\mathrm{L},i}{}^2, y_2), \ldots, (x_{\mathrm{L},i}{}^n, y_n)\}$.

$$x = my + b \tag{5}$$

   b) Obtain the data set of the edge point deviation $\{\Delta x_{1i}, \Delta x_{2i}, \ldots, \Delta x_{ni}\}$.

$$\Delta x_{\mathrm{L},i}^k = x_{\mathrm{L},i}^k - my_k - b(k = 1,2\ldots,n) \tag{6}$$

   c) Calculate the LER.

$$R_q^2 = \frac{1}{n-1} \sum_{k=1}^{n} \left(\Delta x_{\mathrm{L},i}^k\right)^2 \tag{7}$$

d) The LER of other edges can be measured by applying the above procedure of 6) a) to c).

7) Calculate the LWR of line number i.

a) Calculate the data set of averaged widths (w_i) from the left and right edge positions ($x_{L,i}^k$, $x_{R,i}^k$).

$$w_i^k = x_{R,i}^k - x_{L,i}^k \tag{8}$$

b) Calculate LWR.

$$R_q{}^2 = \frac{1}{n-1}\sum_{k=1}^{n}\left(w_i^k - \overline{w}\right)^2 \tag{9}$$

5.5.2 Report

The report should contain the following.

– Provide the measured LER and LWR in units of 0,01 µm and specify the measurement location of features on the master plate, the length of evaluation interval and Δy.
– Specify the measurement instrument.
– Specify the pattern edge detection method and its parameter settings.
– Specify the measurement temperature and temperature variation.
– Provide the acquired image for the measurement.

5.6 Discussion

To evaluate the accuracy of the feature shape on the plate master, features of several sizes should be qualified and the uniformity of qualification parameters over the whole area on the plate master should be tested by repeatedly measuring the same sized feature. The features to be measured and the measurement locations of each type of feature can be determined by customer/vendor agreement.

6 2-D qualification features [2]

6.1 Measurement instrument

The measurement instrument is as follows

– Microscope or measurement instrument with sufficient resolution
  - the measurement instrument can convert the interested area of drawing files of the plate master such as dwg and gds, into image files such as jpg, bmp, and tiff while matching the pixel resolution of its measured image of patterns;
  - repeatability: less than 10 % of the tolerance specification of the area;
  - accuracy: less than 10 % of the tolerance specification of the area;
  - calibration: calibration should be carried out periodically in accordance with the guidelines of the instrument manufacturer.
– Measurement temperature: it is recommended that the measurement is carried out at the temperature of 20 °C which is specified as the standard reference temperature in ISO 1.

6.2 Pattern edge detection method

There are several methods, such as the threshold method, the linear approximation method, and the curve fitting method for determining the edge position automatically from the obtained image. The pattern edge detection method and its parameter settings should be specified in the report because they affect the measurement results.

6.3 Image alignment

For the 2-D qualification of features, the measured image should be aligned with the nominal image of the same area. The alignment of two images can be done by the following methods. The method can be determined by customer/vendor agreement. The area based method is recommended. The method used for image alignment should be specified in the report.

– Center-of-gravity (COG) method: the COG of actual and nominal features is superimposed.

– Area based image correlation method: the absolute feature area between the actual and nominal features is minimized.

– Line-edge based method: the distance between multiple actual and nominal edges is minimized.

6.4 Feature types

The feature types are as follows:

– contact;

– corner rounding;

– line-end shortening.

6.5 Contact

6.5.1 Procedure

The procedure is as follows.

1) Align the sample so that the array of contacts is distributed in rectangular lattice within the image as shown in Figure 3.
2) Acquire the two-dimensional signal intensity distribution of the pattern.
3) Define the feature contour by the pattern edge detection method.
4) Convert the acquired image into the binary image by using the feature contour in item 3).
5) Align the binary image with the nominal image (see 6.3).
6) Define the measurement area by determining a region of interest (ROI) as shown in Figure 3. The ROI is selected to contain the whole area of an interested single contact and not to be interfered with by other contacts in which there is no interest.
7) Calculate the area gain, area loss, area difference and area deviation.

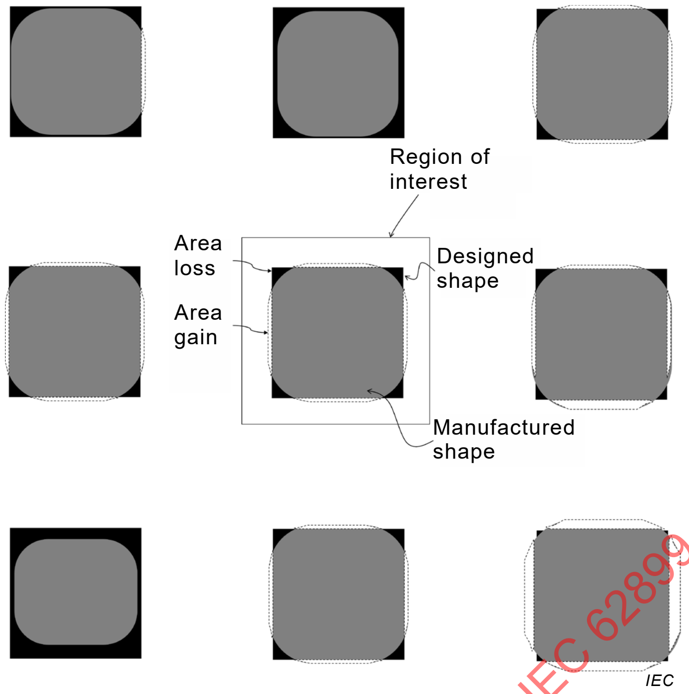

Figure 3 – 2-D qualification of contact hole or dot

6.5.2 Report

The report should contain the following.

- Provide the measured area gain, area loss, area difference and area deviation in units of 0,1 μm^2 and specify the measurement location of the features on the master plate.
- Specify the measurement instrument.
- Specify the pattern edge detection method and its parameter settings.
- Specify the image alignment method.
- Specify the measurement temperature and temperature variation during measurement.
- Provide the acquired image and the aligned image with the nominal image for the measurement.

6.6 Corner rounding

6.6.1 Procedure

The procedure is as follows.

1) Align the sample so that the CD features are aligned in parallel with the horizontal direction in the image.
2) Acquire the two-dimensional signal intensity distribution of the pattern.
3) Define the feature contour by the pattern edge detection method.
4) Convert the acquired image into the binary image by using the feature contour in item 3).
5) Align the binary image with the nominal image (see 6.3).
6) Define the measurement area by determining a region of interest (ROI) as shown in Figure 4.
7) Calculate the area gain, area loss, area difference and area deviation.

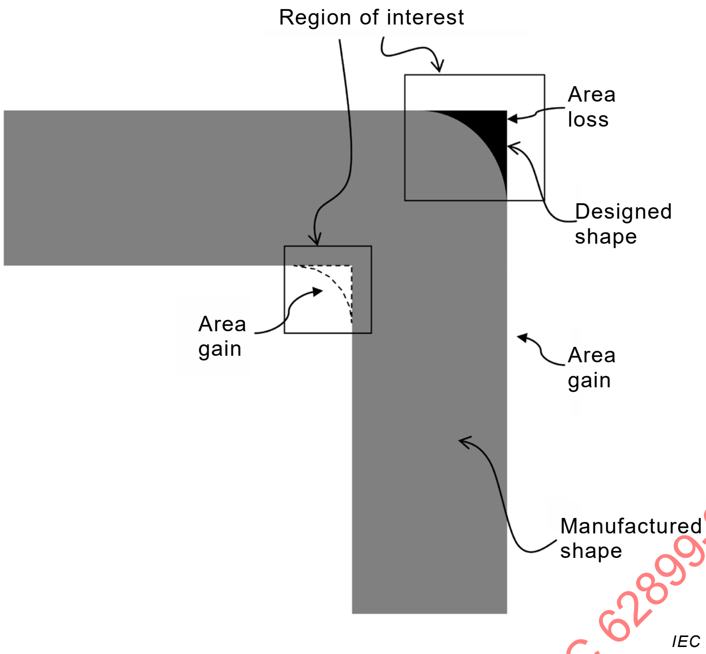

Figure 4 – 2-D qualification of corner rounding

6.6.2 Report

The report should contain the following.

– Provide the measured area gain, area loss, area difference and area deviation in units of 0,1 μm^2 and specify the measurement location of features on the master plate.

– Specify the measurement instrument.

– Specify the pattern edge detection method and its parameter settings.

– Specify the image alignment method.

– Specify the measurement temperature and temperature variation during measurement.

– Provide the acquired image and the aligned image with the nominal image for the measurement.

6.7 Line-end shortening

6.7.1 Procedure

The procedure is as follows.

1) Align the sample so that the CD features are aligned in parallel with the horizontal direction in the image.
2) Acquire the two-dimensional signal intensity distribution of the pattern.
3) Define the feature contour by the pattern edge detection method.
4) Convert the acquired image into the binary image by using the feature contour in item 3).
5) Align the binary image with the nominal image (see 6.3).
6) Define the measurement area by determining a region of interest (ROI) as shown in Figure 5.
7) Calculate the area gain, area loss, area difference and area deviation.

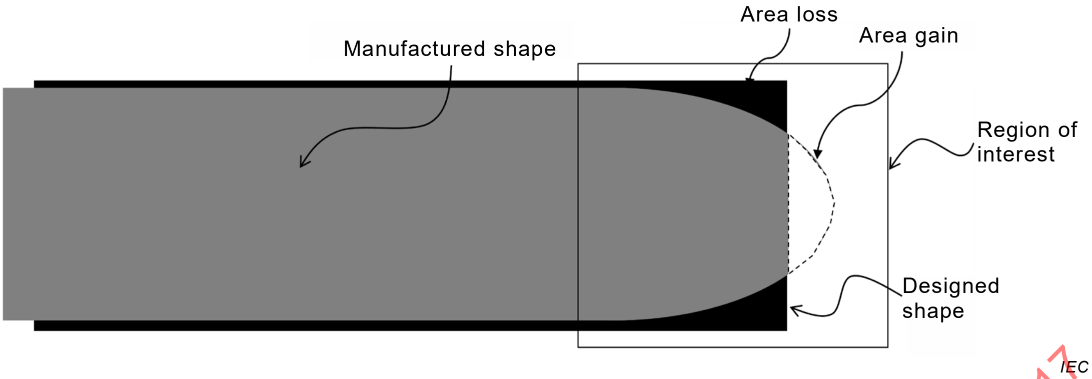

Figure 5 – 2D qualification of line-end shortening

6.7.2 Report

The report should contain the following.

- Provide measured area gain, area loss, area difference and area deviation in units of 0,1 µm^2 and specify the measurement location of the features on the master plate.
- Specify the measurement instrument.
- Specify the pattern edge detection method and its parameter settings.
- Specify the image alignment method.
- Specify the measurement temperature and temperature variation during the measurement.
- Provide the acquired image for the measurement.

6.8 Discussion

To evaluate the accuracy of the feature shape on the plate master, features of several sizes and types should be qualified and the uniformity of the qualification parameters should be also tested by repeatedly measuring the same type of feature over the whole area on the plate master. The features to be measured and the measurement locations of each type of feature can be determined by customer/vendor agreement.

Pattern alignment affects the obtained qualification parameters. It is recommended that the features that can effectively constrain the x and y axes for the image alignment should be included within the images obtained for the 2-D qualification to enhance the accuracy of the 2-D qualification of features.

Corner rounding and line-end shortening are affected by the error of the line width of the feature (see Figures 5 and 6). To eliminate this effect, the difference of the line width can be corrected as shown in Figures 7 and 8. The customer and vendor should agree on whether the correction will be applied or not.

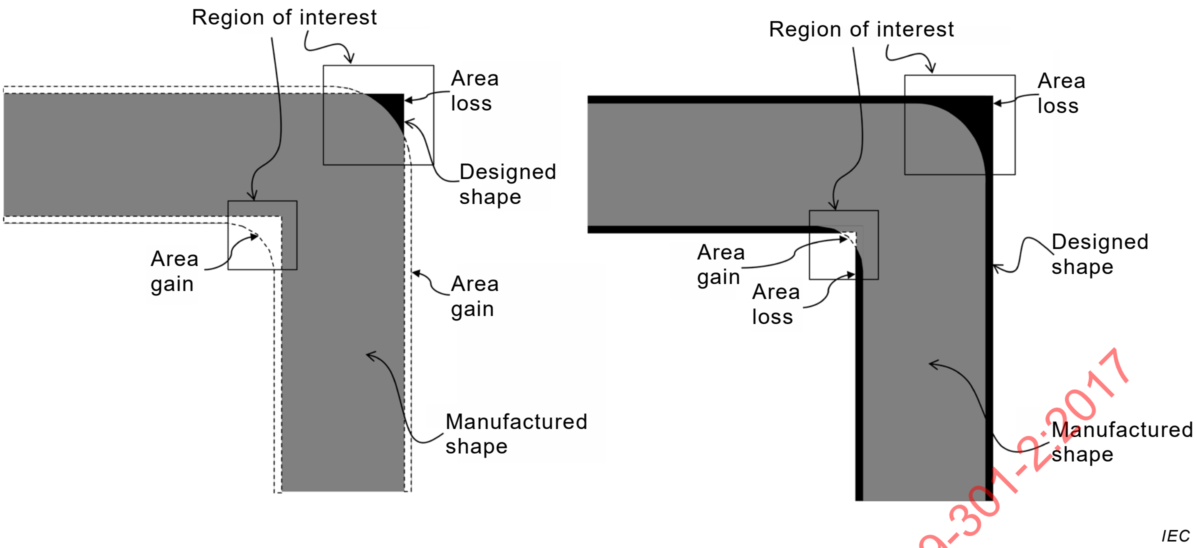

Figure 6 – Effect of 1-D parameter such as line width

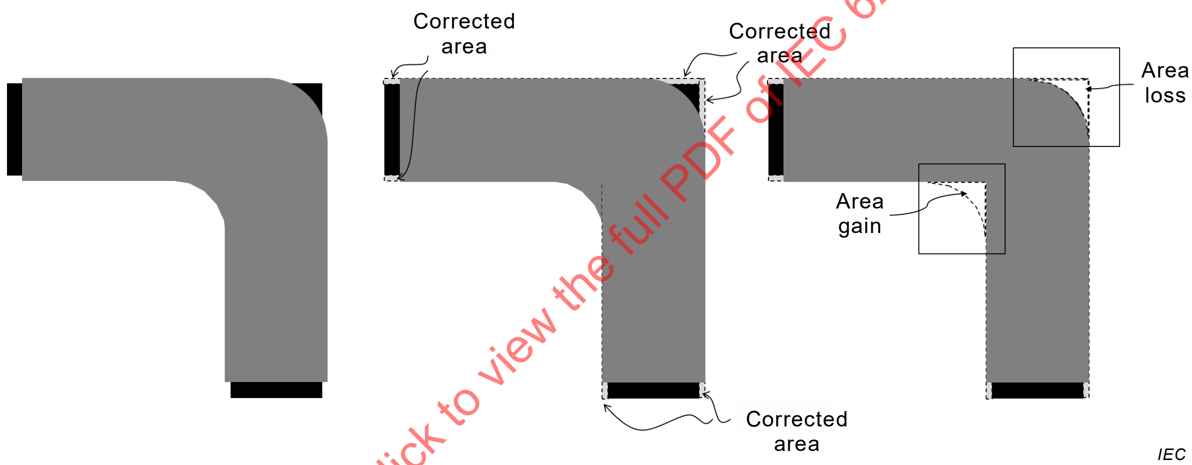

Figure 7 – Example of 1-D effect correction by reducing the line width

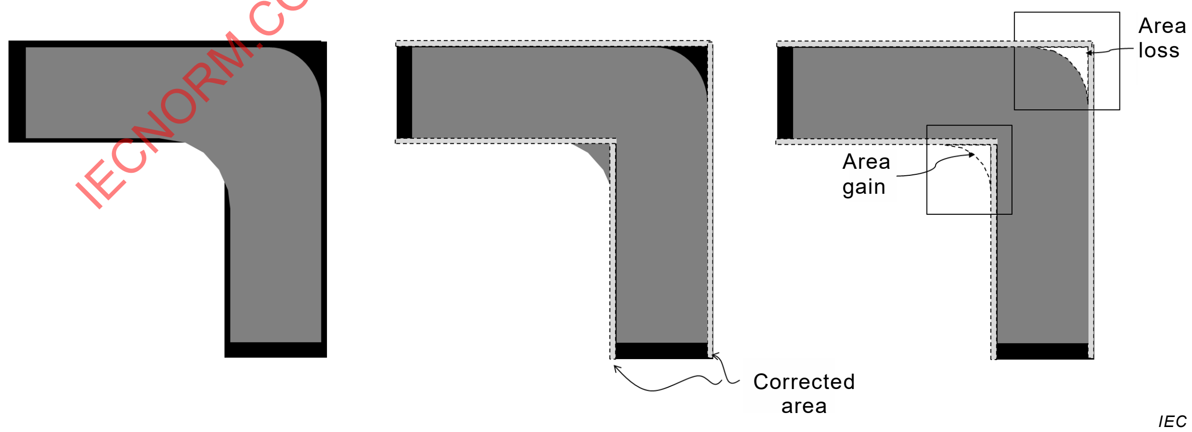

Figure 8 – Example of 1-D effect correction by enlarging the line width

7 Cross-sectional qualification features [3]

7.1 Measurement instrument

The measurement instrument is as follows.

– Measurement system:
  - optical stylus based measurement instrument such as a confocal scanning microscope;
  - mechanical stylus based measurement instrument such as an atomic force microscope (AFM).
– Repeatability:
  - lateral (XY) repeatability: less than 10 % of the smallest line-width in cross-section area;
  - axial (Z) repeatability: less than 10 % of the depth of cross-section profile.
– Accuracy;
  - lateral (XY) accuracy: less than 10 % of the smallest line-width in cross-section area;
  - axial (Z) accuracy: less than 10 % of the depth of cross-section profile.
– Calibration: calibration should be carried out periodically in accordance with the guidelines of the instrument manufacturer.
– Measurement temperature: it is recommended that the measurement is carried out at the temperature of 20 °C which is specified as the standard reference temperature in ISO 1.

7.2 Feature types

The feature types are as follows:

– cross-sectional area;
– feature height.

7.3 Cross-sectional area and feature height [3]

7.3.1 Procedure

The procedure is as follows.

1) Align the sample so that the MD features are aligned in parallel with the vertical direction on the image.
2) Acquire the three-dimensional height distribution of the pattern.
3) Adjust the acquired height distribution so that the measured height distribution of the un-patterned surface is parallel to the xy plane of the coordinate system on the plate master.
4) Obtain the cross-sectional height profile at the pre-defined measurement location from the acquired three-dimensional height distribution. To reduce the noise effect, the height profile can be averaged for the evaluation length. If the evaluation length is set to zero, the cross-sectional height profile is obtained without averaging (see Figures 9 and 10).

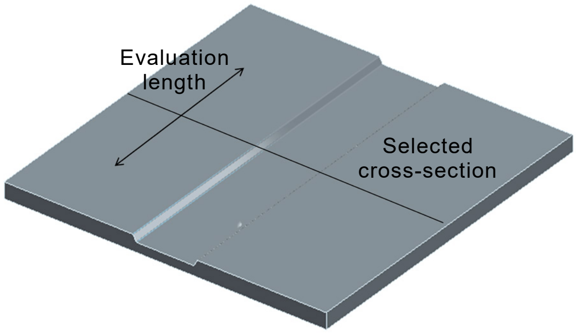

Figure 9 – 3-D height distribution

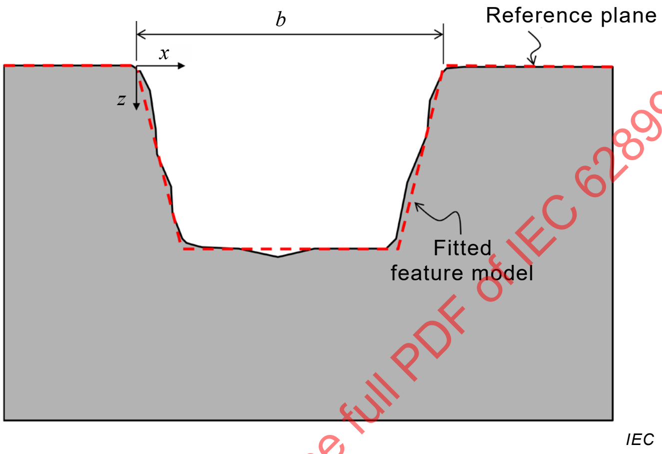

Figure 10 – Cross-sectional height profile

5) Obtain the best-fit feature model from the measured cross-sectional height profile.

NOTE There are several types of feature models such as rectangular, trapezoidal and hemisphere. The selection of the feature model is dependent on the actual cross-sectional shape of the features. The choice is left to the user. The more complex the model, the more degrees of freedom are available to better fit the model to the features.

6) Calculate the residual error of the measured profile (R_h) from the best-fit feature model.

$$R_\mathrm{h} = \sqrt{\frac{1}{b}\int_0^b \left(h(x) - f(x)\right) \cdot dx} \qquad (10)$$

NOTE $h(x)$ is the measured cross-sectional height profile and $f(x)$ is the best-fit feature model.

7) Calculate the cross-sectional area and the feature height from the best-fit feature model. Most features on the plate master can be suited to the trapezoidal feature model. In the trapezoidal feature model, the height is defined as h and the cross-sectional area is defined with the following Equation (11). In addition, two side wall angles (α β), top width (b) and bottom width (a) can be determined (see Figure 11).

$$A = (a + b) \cdot h / 2 \qquad (11)$$

where

A is the cross-sectional area.

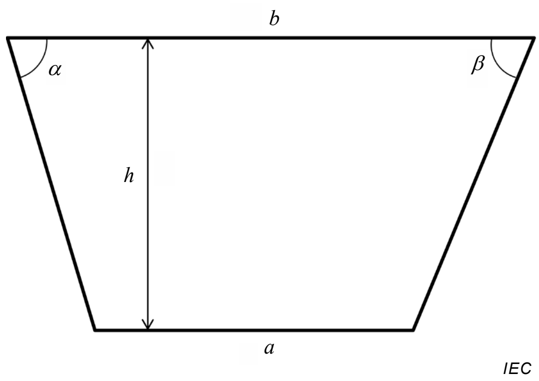

Figure 11 – Trapezoidal feature model

The cross-sectional profile and its parameters of the relief patterns can be measured using the same procedures mentioned above as shown in Figure 12 if the ROI is selected to contain the relief.

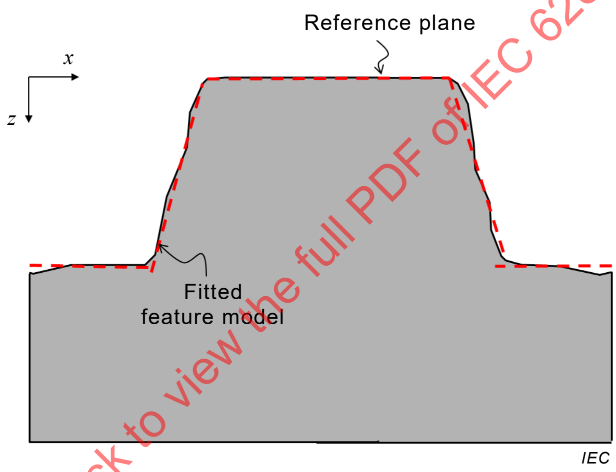

Figure 12 – Measurement of the relief pattern

7.3.2 Report

The report should contain the following.

– Provide cross-sectional area in units of 0,1 μm^2 and feature height in units of 0,01 μm and specify the measurement location of the feature on the master plate, the evaluation length, the applied feature model and the residual error of the feature model (Rh). If the trapezoidal feature model is used, it is recommended that the sidewall angles, top width and bottom width are combined in the report.

– Specify the measurement instrument.

– Specify the measurement temperature and the temperature variation during the measurement.

– Provide the acquired three-dimensional height distribution and the cross-sectional height profile for the measurement by overlapping the best-fit feature model.

7.4 Discussion

To evaluate the accuracy of the feature shape on the plate master, the features of several sizes and types should be qualified and the uniformity of the qualification parameters should be tested by measuring the same type of feature repeatedly over the whole area on the plate master. The features to be measured and the measurement locations of each type of feature can be determined by customer/vendor agreement.

8 Registration accuracy

8.1 Measurement instrument

The measurement instrument is as follows.

– Microscope or measurement instrument with sufficient resolution equipped with a precision stage system:
  - acquire the images of the registration marks with the movement of the precision stage;
  - the position of the registration marks can be obtained by adding the position of the precision stage at which the image is acquired and the position of the registration mark in the obtained image in the coordinate system given in Clause 4.

– Microscope:
  - resolution: less than 10 % of the smallest line width of the defined registration mark. A higher resolution is preferred;
  - field of view: larger than the length of registration mark.

– Precision stage:
  - repeatability: less than 10 % of the specification of the registration accuracy;
  - accuracy: less than 10% of the specification of the registration accuracy.

– Calibration: calibration should be carried out periodically in accordance with the guidelines of the instrument manufacturer.

– Measurement temperature: it is recommended that the measurement is carried out at the temperature of 20 °C which is specified as the standard reference temperature in ISO 1.

8.2 Specification for registration marks for the plate master [4]

8.2.1 Overview

The specification is as follows.

– The complete specification for this registration mark is to be agreed upon by the circuit designer, plate master maker, and the plate master user.

– This mark is not intended to be used for the determination of the overlay accuracy of a printed layer of a plate to any subsequent printed layers on the same substrate.

– This specification is a recommendation for an easy application of the registration marks. The vendor and customer can define their practical registration marks.

8.2.2 Guidelines for shape and sizes of registration mark

The guidelines are as follows.

– The shape of the mark shall be in the form of a cross or round (see Figure 13).

– Mark of the "cross" form (see Figure 11):
  - the area of the intersection of the horizontal and vertical lines shall be "user defined";
  - the width of both the horizontal and vertical lines shall be equal;
  - the length of both the horizontal and vertical lines shall be equal;
  - any of the four quadrants created on the outside of the cross shall be defined as "no-man’s land" and shall not have any geometry or marks placed within them;
  - the width and length of the horizontal and vertical lines vary due to the plate manufacturing procedure and the registration measurement system as shown in Table 1.