BS ISO 16700:2016

BSI Standards Publication

Microbeam analysis — Scanning electron microscopy — Guidelines for calibrating image magnification

bsi.

National foreword

This British Standard is the UK implementation of ISO 16700:2016. It supersedes BS ISO 16700:2004 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee CII/9, Microbeam analysis.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2016.
Published by BSI Standards Limited 2016

ISBN 978 0 580 89052 9

ICS 37.020

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 July 2016.

Amendments/corrigenda issued since publication

Date	Text affected

INTERNATIONAL STANDARD

ISO 16700

Second edition
2016-08-01

Microbeam analysis — Scanning electron microscopy — Guidelines for calibrating image magnification

Analyse par microfaisceaux — Microscopie électronique à balayage — Lignes directrices pour l'étalonnage du grandissement d'image

Reference number
ISO 16700:2016(E)

© ISO 2016

COPYRIGHT PROTECTED DOCUMENT

© ISO 2016, Published in Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Page

Foreword iv
Introduction v
1 Scope 1
2 Normative references 1
3 Terms and definitions 1
4 Image magnification 3
4.1 Scale marker 3
4.2 Expressing magnification 3
5 Reference material 3
5.1 General 3
5.2 Requirements for CRM 4
5.3 Pitch patterns on CRM 4
5.4 Storage and handling 4
6 Calibration procedures 5
6.1 General 5
6.2 Mounting CRM 5
6.3 Setting SEM operation conditions for calibration 5
6.4 Image recording 6
6.5 Measurement of image 6
6.6 Calibration of magnification and scale marker 7
6.6.1 General 7
6.6.2 Magnification 7
6.6.3 Scale marker 7
7 Accuracy of image magnification and scale marker 8
8 Calibration report 9
8.1 General 9
8.2 Contents of calibration report 9
Annex A (informative) **Reference materials for magnification** 11
Annex B (informative) **Parameters that influence the resultant magnification of an SEM** 13
Annex C (informative) **Uncertainties in magnification measurements** 15
Annex D (informative) **Example of a test report** 16
Bibliography 18

© ISO 2016 – All rights reserved

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 202, *Microbeam analysis*, Subcommittee SC 4, *Scanning electron microscopy (SEM)*.

This second edition cancels and replaces the first edition (ISO 16700:2004), which has been technically revised.

© ISO 2016 – All rights reserved

Introduction

The scanning electron microscope is widely used to investigate the surface structure of a range of important materials such as semiconductors, metals, polymers, glass, food and biological materials, and this International Standard is relevant to the need for magnification calibration of the images. It describes the requirements for calibration of the image magnification in the scanning electron microscope using a reference material or a certified reference material.

© ISO 2016 – All rights reserved

Microbeam analysis — Scanning electron microscopy — Guidelines for calibrating image magnification

1 Scope

This International Standard specifies a method for calibrating the magnification of images generated by a scanning electron microscope (SEM) using an appropriate reference material. This method is limited to magnifications determined by the available size range of structures in the calibrating reference material. This International Standard does not apply to the dedicated critical dimension measurement SEM.

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 17025:2005, *General requirements for the competence of testing and calibration laboratories*

ISO Guide 30, *Reference materials — Selected terms and definitions*

ISO Guide 34, *General requirements for the competence of reference material producers*

ISO Guide 35, *Reference materials — General and statistical principles for certification*

3 Terms and definitions

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

3.1
scanning electron microscope
SEM
instrument that produces magnified images of a specimen by scanning its surface with an electron beam

3.2
image
two-dimensional representation of the specimen surface generated by *SEM* (3.1)

Note 1 to entry: A photograph of a specimen taken using an SEM is a good example of an image.

3.3
image magnification
ratio of the linear dimension of the scan display to the corresponding linear dimension of the specimen scan field

3.4
scale marker
line/generated line (intervals) on the *image* (3.2) representing a designated actual length in the specimen

3.5
reference material
RM
material, sufficiently homogeneous and stable with respect to one or more specified properties, which has been established to be fit for its intended use in a measurement process

© ISO 2016 – All rights reserved

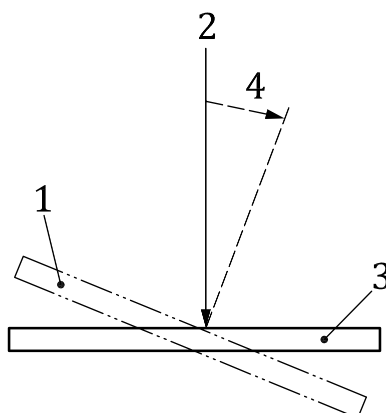
3.6
certified reference material
CRM
reference material (3.5) characterized by a metrologically valid procedure for one or more specified properties, accompanied by a certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability

Note 1 to entry: For the purposes of this International Standard, an RM/CRM possesses pitch pattern(s) with the desired range of pitch size(s) and accuracy, to be used for the calibration of the *image magnification* (3.3).

3.7
calibration
set of operations which establish, under specified conditions, the relationship between the magnification indicated by the *SEM* (3.1) and the corresponding magnification determined by examination of an *RM* (3.5) or a *CRM* (3.6)

3.8
tilt angle
angle of the inclined specimen surface from the plane perpendicular to the electron beam axis

Note 1 to entry: See Figure 1.



Key
1 tilted specimen
2 electron beam
3 specimen
4 tilt angle

Figure 1 — Tilt angle

3.9
display
analog or digital device used for visualization of *images* (3.2)

Note 1 to entry: Examples of display are a cathode ray tube, plasma display panel, liquid crystal display, etc.

3.10
working distance
distance between the specimen surface and the bottom plane of the objective lens of the *SEM* (3.1)

3.11
pitch
closest separation of two similar features on a specimen which are equivalent points on a repeat pattern

 © ISO 2016 – All rights reserved

3.12
accuracy
closeness of agreement between a test result and the accepted reference value

Note 1 to entry: A "test result" constitutes the observed values of a *pitch* (3.11) of a *CRM* (3.6) obtained by the procedure outlined in this International Standard.

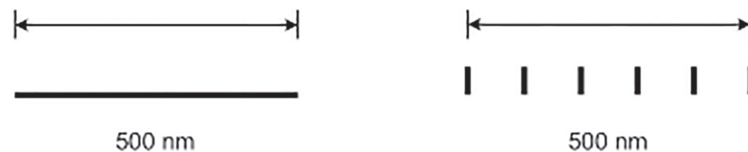
Note 2 to entry: The term "accepted reference value" is a value certified by a national or an international calibrating laboratory. There will be an uncertainty associated with this value which should also appear on the certificate.

Note 3 to entry: Accuracy and precision are different. Precision is defined as the closeness of agreement between independent test results obtained under stipulated conditions. See ISO 5725-1.

4 Image magnification

4.1 Scale marker

To indicate magnification, superimpose on the image a scale marker and the corresponding length, in SI units, that it actually represents on the specimen. An example is shown in Figure 2.



NOTE In Figure 2, the length indicated by the arrows corresponds to 500 nm after the calibration.

Figure 2 — Scale marker and its length

4.2 Expressing magnification

Magnification of an image is given by a number representing the number of times the object has been magnified and it is accompanied by the symbol "×" (e.g. 100 ×, 10 000 ×, 10k × or × 100, × 10 000, × 10k, where 100, 10 000 and 10k are magnitude numbers).

NOTE 1 It is not always necessary to show the magnification when the scale marker is shown on the image.

NOTE 2 The magnification shown on the image corresponds to a chosen output device, which can be a display monitor or a printer or a photographing device. The scale marker shown on the image is independent from the output device chosen by the operator of the SEM. The magnification shown corresponds to the scale marker only when the image is displayed or printed on the operator-chosen output device.

5 Reference material

5.1 General

See ISO Guide 30.

For calibrating the magnification of an image, wherever possible, choose a CRM that is produced in accordance with ISO Guide 34 and certified in accordance with ISO Guide 35.

When a suitable CRM is not available, an RM produced in accordance with ISO Guide 34 may be used.

© ISO 2016 – All rights reserved

5.2 Requirements for CRM

Ensure that the chosen CRM

— is stable with respect to vacuum and repeated electron beam exposure,

— provides good contrast in the SEM image,

— is electrically conductive,

— can be cleaned to remove contamination occurring during normal use without causing mechanical damage or distortion, and

— has an associated valid calibration certificate.

5.3 Pitch patterns on CRM

Pitch patterns on the CRM may be in any one or more of the following forms:

— an orthogonal cross grid;

— a line array;

— a dot array;

— an orthogonal dot array.

Ensure that the chosen CRM contains pitch patterns that allow for calibration in at least one direction, and that the uncertainty in the pitch patterns is consistent with the targeted accuracy.

NOTE 1 There are cases where the CRM contains pitch patterns both in X and Y directions so that the measurements can be performed in orthogonal directions without the necessity of mechanically rotating the CRM. In some cases, the CRM additionally contains other structures for testing image distortion and/or resolution.

NOTE 2 There are instances where the chosen CRM has different-sized pitch patterns to cover the whole range of magnifications for which calibration is needed. It can also be necessary to have more than one CRM to cover the desired range of magnifications.

5.4 Storage and handling

Store the CRM in a desiccating cabinet or in a vacuum container.

NOTE To ensure minimal handling of the actual CRM, it can be permanently mounted on a stub.

Handle the CRM using fingerstalls, clean room gloves or tweezers.

Visually inspect the CRM surface for contamination and deterioration, as this may affect calibration. Do not use the CRM if it is damaged or grossly contaminated.

Remove any dust, loose debris or other contamination from the CRM using clean dry air or nitrogen gas, taking care not to damage the CRM.

Check the calibration of the CRM at intervals by comparison with other CRMs; record the results. The frequency of verification may depend on the nature and usage of the CRM.

Use the CRM for calibration purposes only.

 © ISO 2016 – All rights reserved

6 Calibration procedures

6.1 General

Parameters that influence the resultant magnification of an SEM may cause systematic errors. These are listed in Annex B.

The stability of the SEM will be a major factor in determining the calibration interval. Initially, it will be necessary to perform calibration at frequent intervals in order to verify that the SEM is stable.

The results obtained will provide an estimate of the reproducibility within the laboratory and the bias inherent in both the display and the data automatically superimposed on any output.

The selection of the CRM depends on the magnification being used and accuracy required. For the purposes of this International Standard, ensure that the accuracy of calibration is better than 10 %.

6.2 Mounting CRM

At the time of mounting the specimen, ensure that handling of the CRM is carried out in accordance with 5.4.

Mount the CRM in accordance with the SEM and the CRM manufacturer's instructions.

Ascertain that there is a good electrical contact between the CRM and the specimen stage of the SEM.

Check that the CRM is securely fixed on the specimen stage so that it does not move from its mounting. This enables one to minimize any image degradation caused by vibration.

6.3 Setting SEM operation conditions for calibration

Evacuate the specimen chamber to the working vacuum in accordance with the SEM manufacturer's instructions.

Optimize the electron beam brightness and alignment in accordance with the SEM manufacturer's instructions.

Set tilt angle to 0°, following the SEM manufacturer's instructions so that CRM surface is perpendicular to the electron beam axis during operation.

Check the tilt of the CRM by the following procedures.

a) Turn off the tilt angle correction, the scan rotation and the zoom control of the magnification.

b) Select the imaging mode (secondary electron and/or back scattered electron).

c) Bring the image into focus without visible stigmatic distortions in the image.

d) Select the magnification at which the entire area of measurement is visible.

e) Determine the tilt position where the measured value of pitch is maximum. If the difference of measured values is not found, assume that the tilt angle is 0°. Carry out subsequent recording of the image in this position.

   NOTE 1 If the image of the whole area cannot be brought into focus, then it is necessary to remount the CRM or readjust the mechanical alignment of the SEM.

f) Select the accelerating voltage and the working distance for which the calibration is to be performed and bring the CRM into the correct position using the specimen stage controls.

g) Wait until the instrument is fully stabilized at the desired operating conditions in accordance with the SEM manufacturer's instructions.

© ISO 2016 – All rights reserved

h) Focus and adjust the image of the CRM on the display.

i) If necessary, mechanically rotate the CRM so that the pattern to be measured is parallel to the X and/or Y directions of the display.

j) Translate the CRM so that the end markings of the pitch pattern, on being measured, span about 80 % of the length and/or the width of the viewing display using the SEM specimen stage X and/or Y controls.

k) If necessary, rotate again the CRM so the measurement patterns are parallel to the X and/or Y directions of the display and bring the image of the CRM pitch pattern back into sharp focus.

NOTE 2 It is practical that the actual number of pitches on the screen is about 10; e.g., for a 100 mm display screen, the values of typical pitch at the various magnifications are as follows.

× 50 000 0,2 µm

× 10 000 1 µm

× 1 000 10 µm

6.4 Image recording

Ensure that the pitch patterns are properly lined up in X and/or Y directions corresponding to those directions in the SEM.

Specify the photograph scanning speed.

Once the desired image is obtained, do not alter any other parameters of the SEM. Record the displayed image of the CRM with a scale marker on a photograph, or on a photographic film or in a digital form.

In the case of a photographic medium, allow sufficient time for it to stabilize prior to the measurement. This will minimize the effects of dimensional changes of the medium.

NOTE When, for the purpose of measurement, the recorded image in digital form is reproduced on paper or display, the length and the aspect ratio of the image could be different to that of the originally recorded image. In this case, it is useful to record the length and the aspect ratio of the original image.

6.5 Measurement of image

For generating a calibration report, perform all measurements on a good reliable paper reproduction of the recorded image.

Use a traceable, calibrated ruler of a known accuracy, capable of measuring to less than 1 mm, to measure the length of the recorded image.

In order to minimize edge distortion effects, avoid measurements near the edges. Restrict measurements to the central 80 % of the image area.

Measure the pitch in the X and/or Y directions of the recorded image. This is achieved by measuring the distance between two of the markings, corresponding to an integral number of the pitch, within the area of the recorded image as specified above.

The measured distance should be approximately ten times larger than the pitch.

Repeat the measurement at least three times at separate locations at least 3 mm apart on the recorded image.

NOTE The pitch can be measured as the centre-to-centre or the edge-to-edge distance between the repeating features of the CRM.

 © ISO 2016 – All rights reserved

6.6 Calibration of magnification and scale marker

6.6.1 General

Perform a calibration for magnification(s) commonly used in the laboratory.

6.6.2 Magnification

Determine the magnification, *M*, using Formula (1):

$$M = \frac{D}{d} \quad (1)$$

where

D is the measured mean pitch (distance) on the recorded image (see Figure 3);

d is the actual pitch (distance) of the CRM corresponding to *D* (see Figure 4).

Obtain mean distances in both X and Y directions; then values of magnifications should be calculated for each direction.

If the difference of the magnification between X and Y directions exceeds an allowance set by the user, check the CRM mounting and possible misalignment in the SEM. Readjust and repeat the calibration.

6.6.3 Scale marker

Carry out the calibration of the scale marker for each calibration run.

Calculate the length, *L*, on the recorded image corresponding to the length of the value, f_{ind}, of the scale marker using Formula (2):

$$L = f_{\text{ind}} \times M = f_{\text{ind}} \times \frac{D}{d} \quad (2)$$

where

L is the calculated length of the scale marker on the recorded image;

f_{ind} is the indicated value of the scale marker on the recorded image (see Figure 3).

NOTE If the length of the scale marker is adjusted to correspond to the calibrated magnification, the discrepancy is minimized.

© ISO 2016 – All rights reserved

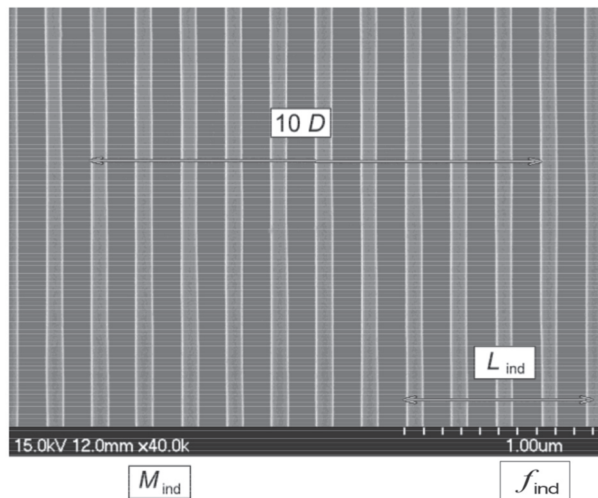


Figure 3 — Recorded image

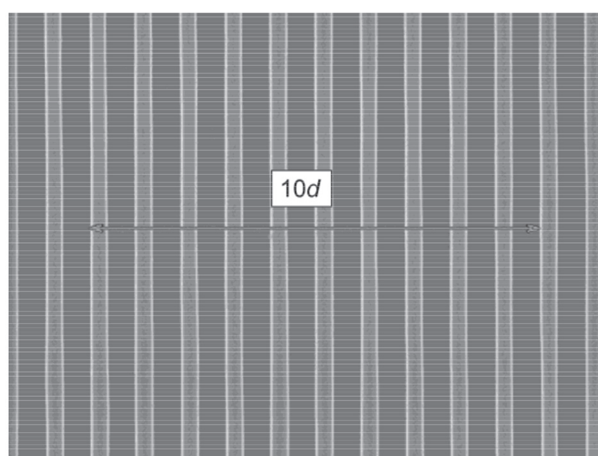


Figure 4 — Specimen (CRM)

7 Accuracy of image magnification and scale marker

The accuracy, A_m, in percent of the magnification can be determined by calculating the difference, ΔM, using Formula (3) and Formula (4):

$$\Delta M = M_{ind} - M = M_{ind} - \frac{D}{d} \quad (3)$$

$$A_m = \frac{\Delta M}{M} \times 100 \quad (4)$$

where M_{ind} is the indicated magnification (see Figure 3).

The accuracy, A_s, in percent of the scale marker can be determined by calculating the difference, ΔL, using Formula (5) and Formula (6):

$$\Delta L = L_{ind} - L = L_{ind} - f_{ind} \frac{D}{d} \quad (5)$$

© ISO 2016 – All rights reserved

$$A_s = \frac{\Delta L}{L} \times 100 \qquad (6)$$

where L_{ind} and f_{ind} are the indicated length and the indicated value of scale marker on the recorded image individually (see Figure 3).

NOTE 1 Even if D and/or L_{ind} is measured with high accuracy (e.g. caliper), the minimum measurement error would be ±0,2 mm, because this is the resolution limit of the human eye.

NOTE 2 In digitally recorded images, accuracy can be determined by assuming that D and L_{ind} can be measured accurately to ±1 pixel. D and L_{ind} can be expressed in terms of pixel length (in mm) to calculate A_m and A_s.

NOTE 3 It is noted that the uncertainty due to operating conditions of the SEM apparatus and statistical errors due to any unavoidable inhomogeneity of the CRM, are included in the result of the magnification calibration. (See Annex C.)

8 Calibration report

8.1 General

The calibration report carried out by the laboratory shall be accurate, clear, unambiguous and in accordance with the specific instructions in the calibration methods listed in this International Standard.

The results of the measurements shall be in a test report and, in addition to the information requested by the customer, shall include all the information necessary for the interpretation of the calibration results and that required by ISO/IEC 17025:2005, 5.10.2.

In the case of calibrations performed for internal customers, or in the case of a written agreement with the customer, the results may be reported in a simplified way. The information listed in ISO/IEC 17025:2005, 5.10.2, which is not reported to the customer, shall be readily available in the laboratory that carried out the calibrations.

8.2 Contents of calibration report

In the calibration report, include the following and any other relevant information which could affect the results of the calibration. An example is shown in Annex D.

a) the calibration report title;

b) the name and address of the laboratory;

c) the number of the calibration report;

d) the name and address of the customer, where relevant;

e) the identification of the method used (i.e. ISO 16700);

f) the manufacturer’s name, model name and the serial number of the instrument used;

g) the name and identification of the reference materials used;

h) the specific operating values of accelerating voltage, in kilovolts; working distance, in millimetres; imaging mode; scan speed and magnification setting;

i) the number of measurements taken, n, and results of calibration: length of the scale marker and/or magnifications in both X and/or Y directions with the accuracy expressed in percent;

j) the name of the person conducting the calibration;

k) the date and time of the calibration;

© ISO 2016 – All rights reserved

l) the name(s), function(s) and signature(s) of person(s) authorizing the calibration certificate;

m) where relevant, a statement to the effect that the results relate only to the items tested or calibrated.

NOTE If necessary, laboratories will include a statement specifying that the calibration report is not reproduced except in full, without written approval of the laboratory.

© ISO 2016 – All rights reserved

Annex A
(informative)

Reference materials for magnification

A.1 Overview

This annex gives examples of CRMs and RMs available at the time of drafting this International Standard for calibration of magnification scales for the SEM apparatus. In order to obtain some up-to-date information, several website links are provided in the Bibliography.

NOTE Other reference materials can be used.

A.2 Testing and calibration laboratories for certified reference materials (CRMs)

A.2.1 National Institute of Standards and Technology (NIST), USA

For more information, see Reference [3].

A.2.2 Physikalisch-Technische Bundesanstalt (PTB, The National Metrology Institute), Germany[4]

Calibration item: A pitch of 1D or 2D grating standards; Calibration method: Metrological Large-Range SPM; Pitch range: 50 nm to 50 um; Expanded uncertainty with coverage factor k=2: some ten picometers depending on the number of periods measured and the quality of the gratings; Accreditation: CIPM-MRA.

Calibration item: Average pitch; Calibration method: Diffractometry; Pitch range: 150 nm to 4 um; Accreditation: CIPM-MRA.

A.2.3 National Physical Laboratory (NPL), UK[5]

Calibration item: Average pitch of scale; Calibration method: Diffraction angle measurement; Pitch range, R_p: 350 nm to 50 µm; Expanded uncertainty, U, with coverage factor k=2: U = ±1 nm (for R_p = 350 nm to 400 nm), U = ±10 nm (for R_p = 400 nm to 10 µm), U = ±100 nm (for R_p = 10 µm to 50 µm); Traceable directly to National Length standards at NPL.

Calibration item: Selected structures; Calibration method: Metrological AFM with optical interferometry with traceability to National Standards of length; Structure size: Below 300 nm to about 100 nm; Expanded uncertainties, U, with coverage factor k=2: $U = \pm Q$ [2 nm, 2,03 × 10^{-4} L nm] where Q[A, B] represents the quadrature sum (square root of the sum of the squares) $(A^2 + B^2)^{1/2}$ and L in nm the total period measured; Traceable directly to National length standards at NPL.

A.2.4 Japan Quality Assurance Organization (JQA), JAPAN[6]

Calibration item: Average pitch of scale; Calibration method: Diffraction angle measurement; Range: 97 nm to 1 000 nm; Expanded uncertainty with coverage factor k=2: 0,04 nm; Accreditation: ILAC-MRA Mark.

Calibration item: A pitch length of scale; Calibration method: Laser interferometric optical microscope; Range: 1 um to 10 mm; Expanded uncertainty: 20 nm to 40 nm with coverage factor 2.

© ISO 2016 – All rights reserved

A.3 Reference materials (RMs)

A.3.1 General

Examples of RMs are shown. Some of them may be supplied as CRMs after certification.

A.3.2 Square grid

The 100 mesh in 254 µm pitch and 1 000 mesh in 25,4 µm pitch of gold, nickel or copper.

Grid pitch 10 µm, 20 µm and 40 µm accompanied by X and Y line arrays with pitch 1 µm and 5 µm (S5000-S1000-CRM).[7]

Si test specimen with pitch 10 µm.[8]

Metal film with typical pitch 1 µm, 25 µm, 100 µm, 1 000 µm on Si substrate.[9]

A.3.3 Nested square boxes

Pitch range from 0,08 µm to 500 µm nested square boxes accompanied by X and Y line arrays.[10]

A.3.4 Line array

Line and space, typical pitch 70 nm, 100 nm, 292 nm, 500 nm.[11]

Pitch range from 0,2 µm to 1 500 µm in the one chip (RM-8820).[12]

One-dimensional line arrays with pitch range from 6,9 nm to 587 nm (BAM-L200).[13]

A.3.5 Dot array

2-D dot array with typical pitch 144 nm and 300 nm, aluminium bumps on silicon.[8]

2-D dot array with pitch 1,16 µm, 1,843 µm and 4,8 µm fabricated as 3-D standard.[14]

© ISO 2016 – All rights reserved

Annex B
(informative)

Parameters that influence the resultant magnification of an SEM

The parameters listed below may interact with each other, and are considered in the order of their location in the instrument.

a) Electron gun high-voltage instability or drift can change the energy of the electrons, thereby changing the final focus that affects the working distance calibration which, in turn, determines the displayed magnification. In modern instruments, the magnification compensation is determined by a computer algorithm, the input of which may be subject to error.

b) Different condenser lens strength combinations change the focal point of the final lens.

c) Uncorrected final lens astigmatism can give a false indication of exact focus.

d) Residual magnetic hysteresis, particularly in the final lens, can change the focal conditions.

e) Long depth of focus, particularly at low magnification and small beam divergence controlled by lens and aperture selection can lead to incorrect focus.

f) Non-orthogonal deflection (X and Y axes) can be produced by the scan coils. Image distortion then appears.

g) Scan generator circuits may be non-linear or change with aging of circuit components or both.

h) Zoom control of magnification can be non-linear.

i) Non-linearity of scan rotation accessory can distort magnification at different degrees of rotation.

j) Distortion of the electron beam sweep may be produced by extraneous magnetic and electrostatic fields.

k) The percentage error in magnification may be different for each magnification range.

l) A tilted specimen surface (not perpendicular to the beam axis) will introduce foreshortening of the image and magnification variation.

m) The tilt correction applied may not be at 90° (in the plane normal to the electron beam) to the tilt axis of the specimen or to a particular area on the specimen surface.

n) Signal processing, particularly, differentiation or homomorphic processing, can give a false impression of focus.

o) For the same apparent magnification, different combinations of working distance, accelerating voltage and beam scan raster can produce different linear magnifications.

p) Thermal and electronic drift of circuit components related to the above parameters can affect magnification with time in a random manner.

q) Distortion of faceplate and non-orthogonal beam deflection of recording cathode ray tube (CRT) can produce non-uniform magnification.

r) The image magnification on the recording CRT may not be the same as that on the viewing CRT.

s) Recording camera lens distortion and change in ratio of the photographic image to CRT image can lead to magnification error.

© ISO 2016 – All rights reserved

t) Expansion or contraction of photographic material, photographic enlarging, and control of contrast can all have a significant effect on the final apparent image magnification.

u) In digitally recorded images, magnification errors may occur due to the inaccuracies or distortion of the digital devices (e.g. printers, etc.). The aspect ratio (X and Y magnification) may be different than that of the original image.

© ISO 2016 – All rights reserved

Annex C
(informative)

Uncertainties in magnification measurements

The uncertainty is the range of values into which any measurement errors of the magnification can, with a specified level of confidence, be expected to fall. This uncertainty, u, can be determined from all the components of uncertainty, σ_i, using Formula (C.1):

$$u = \sqrt{(\Sigma \sigma_i^2)} \tag{C.1}$$

For example, the components of uncertainty and typical values for them for certified grid are as follows.

A: that associated with the calibrant/certified reference material, ±1 %

B: repeatability, ±4 %

(The variation in magnification due to these components shows a normal distribution and the uncertainty, if determined as 95 % confidence limits, should be divided by 2, before combining them using Formula (C.1).)

C: temperature effects, < ±0,5 %

D: resolution of the feature being measured, ±1 %

E: the uncertainty in the measuring device and the effects of temperature on this, ±1 %

(The effect of these factors results in a rectangular distribution, and therefore, magnitudes should be divided by √3 prior to combining them.)

The uncertainty expressed using the above approach will only be correct at the time that the calibration is performed. Repeat calibrations, over an extended period of time, lead to different results due to uncertainty in operating conditions (specimen positioning, operator, instrument). For a given instrument configuration, a further component of uncertainty,

F: drift, ±3 %

needs to be considered.

After several recalibrations at a fixed (displayed) magnification, M_d, a measured (true) magnification, M_t, together with some measure, σ_t, of the distribution about this value, can be determined. σ_t, by virtue of its method of determination, offers a practical method of combining the above components of uncertainty. With the exception of A, there will be two components of uncertainty which, when combined, will provide an uncertainty, u, the magnitude of which will tend towards that of u to be quoted.

$|M_t - M_d|$ will be a measure of the accuracy of the display on the instrument and output. For examination at a displayed magnification of M_d, the results should be reported as using a magnification of $M_t \pm nu$. With $n = 2$, the operator is 95 % confident that the magnification at the time of examination was within the range expressed by these limits. The same argument applies to scale marker. Uncertainties in the magnification and scale marker length can be expressed by quoting respective standard deviations of these measurements.

© ISO 2016 – All rights reserved

Annex D
(informative)

Example of a test report

The magnification calibration table is an example of a “conditions” matrix for tracking calibrated magnifications as part of a quality control programme.

In Table D.1, insert the actual magnification measured against the calibration standard.

The given accelerating voltage, magnifications and working distances are for example only. These values should be adjusted to represent those settings that are used in practice. Different numbers of settings to those given in this example may be used.

The data should be plotted as a control chart to show variability over time.

© ISO 2016 – All rights reserved

Table D.1 — Test report for calibration of scale maker

Name of the laboratory:
Address of the laboratory:
Number of the calibration report:
ISO Standard reference: ISO 16700
Name of the manufacturer:

Model: Serial Number:
Operator:
Date:
Name and signature of person authorizing:

							Accelerating voltage			2kV				(C)RM	
Magnification	WD (mm)	Measurement	D_x	D_y	M_x	M_y	L_{ind} and f_{ind}	L_x	L_y	ΔL_x	ΔL_y	A_{xs}	A_{ys}	d	Name of (C)RM
(M_{ind})	5	1			$(=\frac{D_{xm}}{d})$	$(=\frac{D_{ym}}{d})$		$(=f_{ind} \times M_x)$	$(=f_{ind} \times M_y)$	$(=L_{ind} - L_x)$	$(=L_{ind} - L_y)$	$(=\frac{\Delta L_x}{L_x} \times 100)$	$(=\frac{\Delta L_y}{Ly} \times 100)$		
		2													
		3													
		mean value	D_{xm}	D_{ym}											
× 100	10	1													
		2													
		3													
		mean value													
	15	1													
		2													
		3													
		mean value													
	5	1													
		2													
		3													
		mean value													
× 1 000	10	1													
		2													
		3													
		mean value													
	15	1													
		2													
		3													
		mean value													

$L = f_{ind} \times M$

L is the calculated length of the scale marker on the recorded image

f_{ind} is the indicated value of the scale marker on the recorded image

M is the calibrated magnification

$\Delta L = L_{ind} - L$

ΔL is the difference

L_{ind} is the indicated length of the scale marker on the recorded image

A_s is the accuracy of the scale marker

© ISO 2016 – All rights reserved

Bibliography

[1] ISO 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

[2] ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

[3] National Institute of Standards and Technology (NIST). USA, Calibrations, Length Measurements. Available (viewed 2015-06-13) at http://www.nist.gov/calibrations/length.cfm#other_length

[4] Physikalisch-Technische Bundesanstalt (PTB), Germany, Dimensional Nanometrology. Available (viewed 2015-06-13) at http://www.ptb.de/cms/en/ptb/fachabteilungen/abt5/fb-52.html

[5] National Physical Laboratory (NPL). Micro & Nanotechnology Measurement Services, Issue 2. Available (viewed 2015-06-13) at http://www.npl.co.uk/upload/pdf/micro_nanotech_brochure_jan2011.pdf

[6] Japan Quality Assurance Organization (JQA). Calibration of Measuring Instruments; Standard micro scales. Available (viewed 2015-06-13) at http://www.jqa.jp and http://www.jqa.jp/service_list/measure/service/length_angle/micro_scale.html.

[7] Chinese Microbeam Analysis. Available (viewed 2016-03-09) at http://www.microbeam.com.cn/.

[8] agar Scientific, Available (viewed 2015-06-13) at http://www.agarscientific.com/sem/calibration-standards.html

[9] NTT Advanced Technology Corporation. Advanced Products Business Headquarters, Nano-Technology Business Unit. Available (viewed 2015-06-13) at http://www.ntt-at.com/prdsvc/nanotech.html.

[10] Geller MicroÅnalytical Laboratory, Inc.. Available (viewed 2015-06-13) at http://www.gellermicro.com/index.htm

[11] Plano GmbH. Available (viewed 2015-06-13) at http://www.plano-em.de/.

[12] National Institute of Standards and Technology (NIST). Standard Reference materials, Available (viewed 2015-06-13) at https://www-s.nist.gov/srmors/viewTableV.cfm?tableid=135

[13] Bundesanstalt für Materialforschung und –prüfung (BAM), Germany. Layered and surface reference materials. Available (viewed 2015-06-13) at http://www.rm-certificates.bam.de/de/rm-certificates_media/rm_cert_layer_and_surface/bam_l200e.pdf

[14] m2c microscopy measurement & calibration. Available (viewed 2015-06-13) at http://www.m2c-calibration.com/

 © ISO 2016 – All rights reserved

ICS 37.020

Price based on 18 pages

© ISO 2016 – All rights reserved

This page deliberately left blank

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Copyright in BSI publications

All the content in BSI publications, including British Standards, is the property of and copyrighted by BSI or some person or entity that owns copyright in the information used (such as the international standardization bodies) and has formally licensed such information to BSI for commercial publication and use.

Save for the provisions below, you may not transfer, share or disseminate any portion of the standard to any other person. You may not adapt, distribute, commercially exploit, or publicly display the standard or any portion thereof in any manner whatsoever without BSI's prior written consent.

Storing and using standards

Standards purchased in soft copy format:

- A British Standard purchased in soft copy format is licensed to a sole named user for personal or internal company use only.
- The standard may be stored on more than 1 device provided that it is accessible by the sole named user only and that only 1 copy is accessed at any one time.
- A single paper copy may be printed for personal or internal company use only.

Standards purchased in hard copy format:

- A British Standard purchased in hard copy format is for personal or internal company use only.
- It may not be further reproduced – in any format – to create an additional copy. This includes scanning of the document.

If you need more than 1 copy of the document, or if you wish to share the document on an internal network, you can save money by choosing a subscription product (see 'Subscriptions').

Reproducing extracts

For permission to reproduce content from BSI publications contact the BSI Copyright & Licensing team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email subscriptions@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Useful Contacts

Customer Services
Tel: +44 345 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 345 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.