BS EN 62047-26:2016

BSI Standards Publication

Semiconductor devices — Micro-electromechanical devices

Part 26: Description and measurement methods for micro trench and needle structures

bsi.

National foreword

This British Standard is the UK implementation of EN 62047-26:2016.

The UK participation in its preparation was entrusted to Technical Committee EPL/47, Semiconductors.

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

Published by BSI Standards Limited 2016

ISBN 978 0 580 85309 8
ICS 31.080.99

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 May 2016.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 62047-26

April 2016

ICS 31.080.99

English Version

Semiconductor devices - Micro-electromechanical devices - Part 26: Description and measurement methods for micro trench and needle structures (IEC 62047-26:2016)

Dispositifs à semiconducteurs - Dispositifs microélectromécaniques - Partie 26: Description et méthodes de mesure pour structures de microtranchées et de microaiguille
(IEC 62047-26:2016)

Halbleiterbauelemente - Bauelemente der Mikrosystemtechnik - Teil 26: Beschreibung und Messverfahren für Mikro-Rillen und Nadelstrukturen
(IEC 62047-26:2016)

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Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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European foreword

The text of document 47F/233/FDIS, future edition 1 of IEC 62047-26, prepared by SC 47F "Micro-electromechanical systems", of IEC/TC 47 "Semiconductor devices" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62047-26:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2016-11-11
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2019-02-11

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ISO 3274:1996	NOTE	Harmonized as EN ISO 3274:1997 (not modified).

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 26: Description and measurement methods for micro trench and needle structures

FOREWORD

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International Standard IEC 62047-26 has been prepared by subcommittee 47F: Microelectromechanical systems, of IEC technical committee 47: Semiconductor devices.

The text of this standard is based on the following documents:

FDIS	Report on voting
47F/233/FDIS	47F/239/RVD

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

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

A list of all parts in the IEC 62047 series, published under the general title *Semiconductor devices – Micro-electromechanical devices*, can be found on the IEC website.

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

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

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SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 26: Description and measurement methods for micro trench and needle structures

1 Scope

This part of IEC 62047 specifies descriptions of trench structure and needle structure in a micrometer scale. In addition, it provides examples of measurement for the geometry of both structures. For trench structures, this standard applies to structures with a depth of 1 μm to 100 μm; walls and trenches with respective widths of 5 μm to 150 μm; and aspect ratio of 0,006 7 to 20. For needle structures, the standard applies to structures with three or four faces with a height, horizontal width and vertical width of 2 μm or larger, and with dimensions that fit inside a cube with sides of 100 μm.

This standard is applicable to the structural design of MEMS and geometrical evaluation after MEMS processes.

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.

None.

3 Terms and definitions

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

3.1
trench structure
one or more rectangular structures engraved in a planar substrate, with a constant trapezoidal cross section profile

3.2
needle structure
projecting structures with a pointed tip formed of three or more faces, formed on a planar substrate with the plane of symmetry in the vertical plane

3.3
wall and trench
two or more of the trench structures arranged in parallel at regular intervals

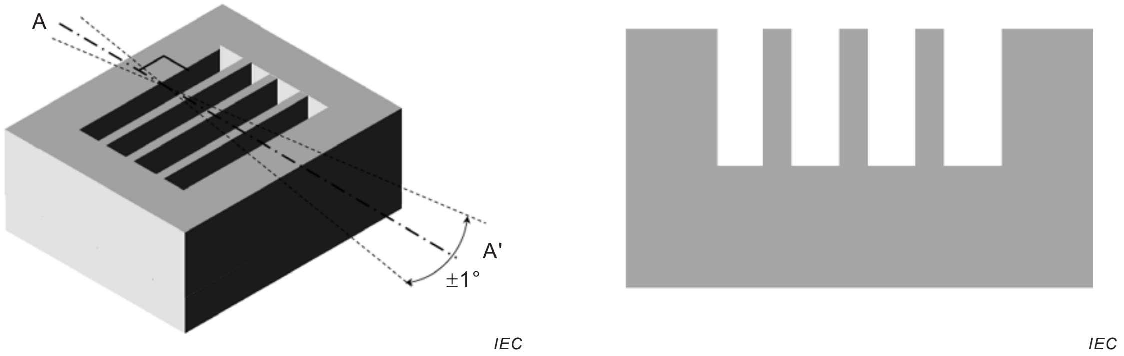
3.4
scallop
irregularity formed cyclically in the side walls after a deep-reactive ion etching (DRIE) process with repeated deposition and selective etching of polymeric passivation layer and then etching of a silicon substrate

4 Description of trench structures in a micrometer scale

4.1 General

This standard specified the method of indicating the cross-sectional geometry of trench structures with micrometer scale dimensions. Figure 1 is a diagram of the cross section required for indicating the cross-sectional geometry of trench structures in this standard. The cross-sectional geometry of trench structures is the cross-sectional shape at a line longitudinally intersecting the trench structure at right angles as viewed from the upper surface of the substrate, with an error of ±1° or less.

See Clause 6 and Annex A for the method of measuring the cross-sectional dimensions of trench structures.



a) Example of trench structure

b) Cross section of trench structure at the A_A' line

Figure 1 – Schematic of example for trench structure in a micrometer scale and its cross section

4.2 Symbols and designations

The cross section of a typical trench structure is shown in Figure 2, and the symbols, designations and units used for indicating the cross section of the trench structures are listed in Table 1.

The horizontal datum line for indicating the cross section in Figure 2 is a straight line approximating the upper surface of the planar substrate. The vertical datum line is defined as a line intersecting the horizontal datum line at right angles. The trench side wall is indicated by its straight line approximation. The bottom of trench is expressed as its approximate straight or curved line. On the upper surface of the trench structure, the wall is defined as the area that is considered same as the horizontal datum line without etching, and the trench is defined as the etched area. According to these definitions, the widths of the wall and trench at the upper surface are expressed as shown in Figure 2. The trench side wall angle is defined as the angle between the horizontal datum line and approximate line of the side wall, and it is indicated with a value measured clockwise from the horizontal datum line positioned on the top of the wall to the trench side wall by the shortest distance, as shown in Figure 2. The widths of the wall and trench at the bottom of the trench are expressed by distances between intersection points with the approximate line of the side wall and approximate straight or curved line at the bottom of the trench. The depth of the trench is defined as the shortest distance from the horizontal datum line at the middle of the trench to the bottom surface of the trench.

When the trench structure is fabricated by the DRIE process with repeated deposition and selective etching of polymeric passivation layer and then etching of a silicon substrate, scallops are formed in the trench side walls after etching. Figure 3 shows a cross section of a trench structure with inverse taper side walls prepared with the DRIE etching process, including symbols for the geometry.

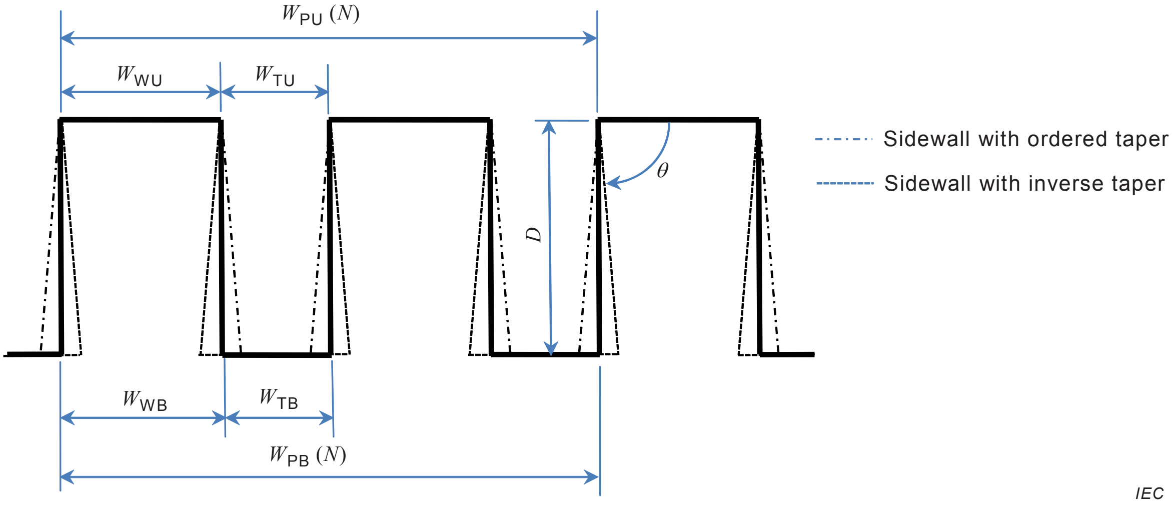


Figure 2 – Cross section of trench structure in a micrometer scale

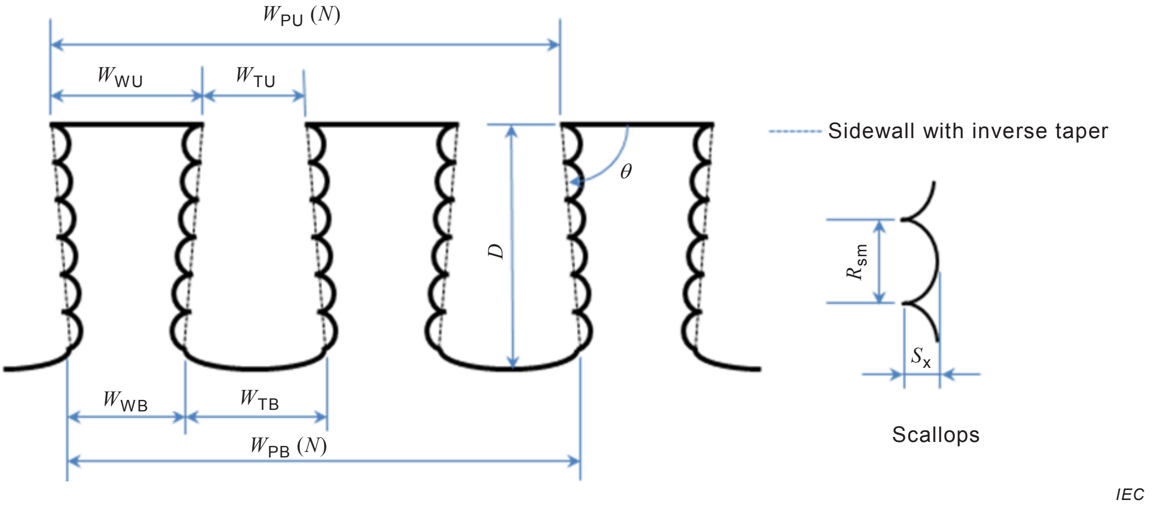


Figure 3 – Cross section of trench structure in a micrometer scale fabricated by a deep-reactive ion etching process with repeated deposition and etching of silicon

Table 1 – Symbols and designations of trench structure in a micrometer scale

Symbol	Unit	Designation
W_{WU}	µm	Width of wall part at the upper surface
W_{TU}	µm	Width of trench part at the upper surface
W_{WB}	µm	Width of wall part at the bottom of trench
W_{TB}	µm	Width of trench part at the bottom of trench
$W_{PU}(N)$	µm	Distance of N pitches of Wall and Trench at the upper surface
$W_{PB}(N)$	µm	Distance of N pitches of Wall and Trench at the bottom of trench
N	–	Number of pitches
D	µm	Depth of trench at the center of trench
θ	Deg	Sidewall angle
S_x	µm	Horizontal distance of scallop
R_{sm}	µm	Mean vertical distance of scallop

4.3 Description

Trench structures shall be dimensioned using Figure 2 or Figure 3 in accordance with 4.1 and 4.2. See ISO 129-1[1][1] for indicating dimensions.

5 Description of needle structures in a micrometer scale

5.1 General

This standard specifies the method of indicating the geometry of needle structures in a micrometer scale. Figure 4 shows an external view of a typical needle structure. The needle structures defined in this standard are projecting structures with a pointed tip formed of three or four faces, formed on a planar substrate with the plane of symmetry in the vertical plane. The hatching plane in the figure is the plane of symmetry. The bottom face of the needle structure corresponds to the surface of the planar substrate.

See Clause 6 and Annex A for the method of measuring the geometry of needle structures.

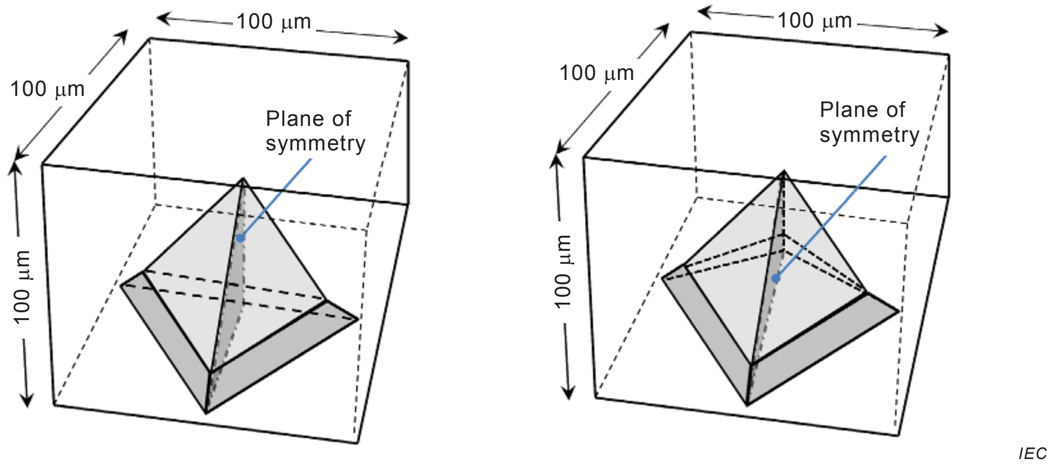


Figure 4 – Schematic of typical needle structures formed of three and four faces

5.2 Symbols and designations

Figure 5 is a three-view drawing of a typical needle structure. Table 2 lists the symbols, designations and units used for indicating the geometrical dimensions of the needle structures.

The front position of the needle structures is defined as the position where the structure shows bilateral symmetry with the plane of symmetry in the center and where the bottom face of the structure corresponds to the horizontal plane. The front position of needle structures with tips formed of three faces is the location where the two faces are in front with the plane of symmetry in the center. The front position of needle structures with tips formed of four faces is the location where the two faces with the largest area are in front with the plane of symmetry in the center.

The geometric dimensions of the needle structures specified in this standard are height of needle, H, widths at the bottom face of the needle structure, W_1 and W_2, and distance, D_1, that is the dimension shown in the top view or side view in Figure 5.

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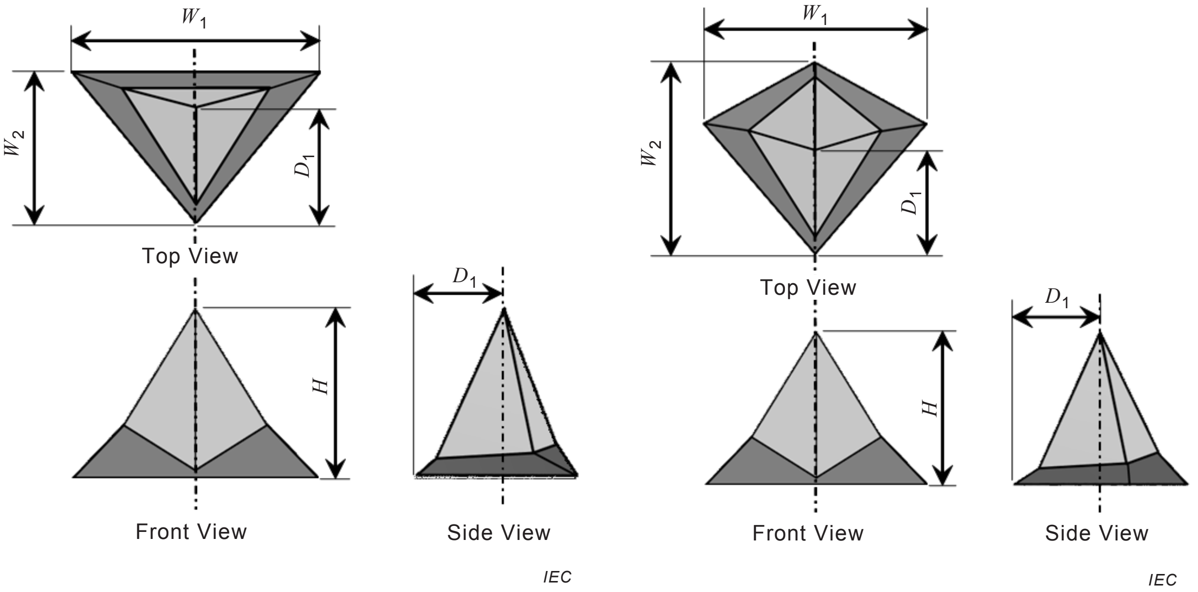
[1] Numbers in square brackets refer to the Bibliography.



a) Typical needle structure with three faces **b) Typical needle structure with four faces**

Figure 5 – Front, side and top views of typical needle structures

Table 2 – Symbols and designations of needle structure in a micrometer scale

Symbol	Unit	Designation
W_1	µm	Horizontal width of needle structure at top view
W_2	µm	Vertical width of needle structure at top view
D_1	µm	Distance between tip and front point of needle structure
H	µm	Height of needle structure

5.3 Description

Needle structures shall be dimensioned using Figure 5 in accordance with 5.1 and 5.2. See ISO 129-1[1] for indicating dimensions.

6 Measurement method

See Annex A for examples of measurement for indicating the geometry of trench and needle structures. The measurement conditions required for all measurements are described as follows.

a) Record the temperature, humidity and necessary measurement conditions for each measurement.

b) Perform measurement within the dimensional scale guaranteed in the instrument used for each measurement.

c) Use instruments calibrated before each measurement.

d) For calibration of the instruments, consult the equipment supplier if necessary.

e) Maintain the levelness and perpendicularity of the sample when set in the instrument within the range guaranteed in the instrument.

f) Specify the method of straight line approximation and curve approximation required for indicating the geometry of trench structures.

g) The measurement results should be recorded in accordance with Clause B.2.

Annex A
(informative)

Examples of measurement for trench and needle structures in a micrometer scale

A.1 General

Annex A describes examples of measurement for the geometry of trench and needle structures in a micrometer scale. Clauses A.2 to A.6 summarize the principles of the measurement, the methods of the sample preparation, and the procedures of measurement in respective geometry of structures, providing one or more specific examples for measuring the geometry of trench and needle structures.

A.2 Measurement for depth of trench

A.2.1 Field emission type scanning electron microscopy

A.2.1.1 Principle of measurement

A field emission type scanning electron microscope (FE-SEM) is a device that illuminates the sample with an electron beam to produce an image of its surface features. The electron beam source is a silicon or tungsten tip which can emit electrons by applying an electric field to the tip. When the FE-SEM illuminates the sample with the electron beam, secondary electrons are also emitted from the surface of the sample. During scanning a highly focused electron beam over the surface of the sample, the secondary electrons are detected. Converting the emissions of secondary electrons into a brightness signal produces an electron micrograph.

A.2.1.2 Preparation of sample

For measuring the depth of a trench with FE-SEM, it is necessary to observe and measure the cross section of the sample directly. In order to show the cross section of the sample clearly as shown in Table 1 of 4.2, the sample should be bisected.

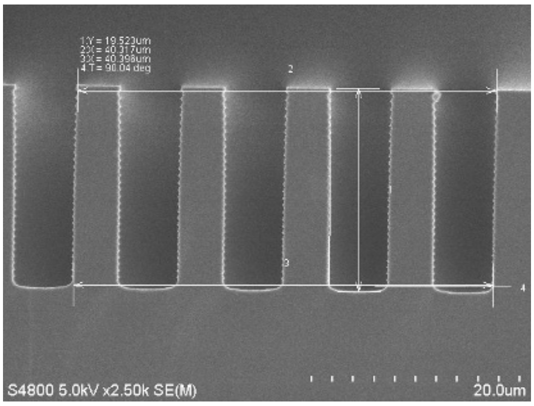
A.2.1.3 Procedure of measurement

The depth of the trench is the shortest distance from the horizontal datum line at the middle of the trench to the bottom surface of the trench, as described in 4.2. Perform measurement according to the procedures specified by the equipment supplier. The following points should be observed.

a) Place the sample in the SEM sample chamber so that the orientation of the FE-SEM electron beam corresponds to the normal vector of the sample cross section. The levelness of the sample should be maintained within the range guaranteed in the equipment.
b) Set the magnification so that the whole trench fits inside the SEM image.
c) Adjust the focus, the contrast and so on according to the procedures specified by the equipment supplier.
d) Measure the relevant dimensions using the length measuring function provided by the equipment supplier.
e) Measure a single location the recommended number of times (see Clause B.2), and use the average of the measurement results as the measured value. See Annex B for the repeatability of measurements.

A.2.1.4 Measureable range

Measurement is applicable to trench structures within the dimensional range indicated in 4.1. Figure A.1 and Table A.1 show an example of measurement of trench depth with 2 500 times magnification using FE-SEM.



IEC

Figure A.1 – FE-SEM image of trench structure with 5 μm-wide wall and 5 μm-wide trench

Table A.1 – Example of measured data of trench depth

No.	1	2	3	4	5	6	7	8	9	10
Trench depth, D [μm]	19,6	19,5	19,6	19,6	19,5	19,6	19,5	19,5	19,5	19,6

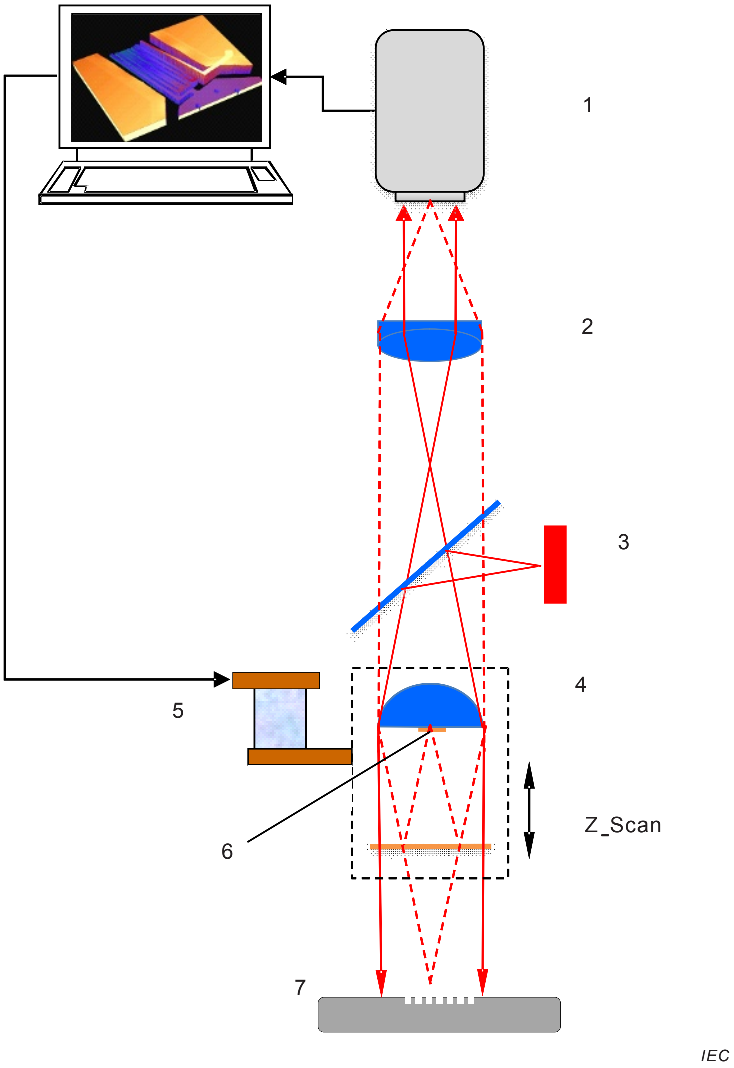
A.2.2 Coherence scanning interferometer (CSI)

A.2.2.1 Principle of measurement

A Coherence Scanning Interferometer (CSI) is a system for measuring surface profile by scanning the surface of a sample vertically with an objective lens comprising an equal-light-path interferometer.

Figure A.2a) shows the basic configuration of a CSI microscope. The sample has irregularities in the height, h, of the surface overall. The CSI microscope uses an actuator to move the interferometer objective lens smoothly and continuously in a scanning motion in the Z-scan direction shown in the figure. During scanning the sample surface, a computer records the interference brightness signal of each CCD pixel of each frame in sequence.

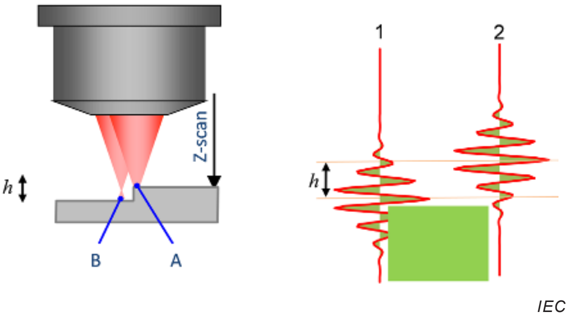
Figure A.2b) shows the two interference strength signals acquired from the vertical difference in height, h, in the surface of the sample (points A and B in the figure). The surface height of the object is determined by comparing the interference strength signal of the CCD pixels corresponding to both points. Specifically, the scanning position (the equal-light-path position) corresponding to the interference signal with the greatest contrast is found by processing each pixel in the field of view.



Key

1	CCD Camera	5	Actuator for Z-scan
2	Image lens	6	Reference mirror
3	White light source	7	Object
4	Interference objective		

a) Basic features of CSI microscope



Key

1	Intensity signal at camera pixel “B”
2	Intensity signal at camera pixel “A”

b) Intensity signal as captured by two camera pixel “A” and “B”

Figure A.2 – Schematic of CSI microscope comprising an equal-light-path interferometer

A.2.2.2 Preparation of sample

The sample is not cut.

A.2.2.3 Procedure of measurement

The depth of the trench is the shortest distance from the horizontal datum line at the middle of the trench to the bottom surface of the trench, as described in 4.2. Perform measurement according to the procedures specified by the equipment supplier. The following points should be observed.

a) Select an interference lens with magnification that allows observation of the walls and trenches to be measured. If necessary, change the magnification of the interference lens to intermediate lens magnification. It is advisable to select measurement magnification with wall and trench dimensions that do not depend on the depth of the trench. Table A.2 lists an example of the measurement magnifications for various wall and trench dimensions;

b) Set the sample so that the optical axis of the microscope corresponds to the normal vector of the surface of the sample;

c) Adjust the focus, contrast and so on according to the procedures specified by the equipment supplier;

d) Set the measurement conditions such as the scanning range in the z axis according to the procedures specified by the equipment supplier and measure the profile of the sample surface;

e) Using the length measuring function provided by the equipment supplier, analyze the measurement data obtained to find the trench depth, wall width, and trench width;

f) Measure a single location the recommended number of times (see Clause B.2), and use the average of the measurement results as the measured value. See Annex B for the repeatability of measurements.

Table A.2 – CSI magnification (objective lens/ imaging lens) for measurement of all trench

Wall and trench (nominal dimensions)	Magnification for interference objective lens	Magnification for imaging lens
5 μm-wide wall & 5 μm-wide trench	50	2,0
15 μm-wide wall & 5 μm-wide trench	50	2,0
20 μm-wide wall & 10 μm-wide trench	50	1,0
30 μm-wide wall & 20 μm-wide trench	50	1,0
50 μm-wide wall & 50 μm-wide trench	50	1,0
150 μm-wide wall & 100 μm-wide trench	10	1,0

A.2.2.4 Measurable range

Measurement is applicable to trench structures within the dimensional range indicated in 4.1.

A.2.3 Stylus surface profiler

A.2.3.1 Principle of measurement

A stylus surface profiler is an instrument that measures the surface roughness and waviness by scanning a pointed stylus on the surface of a sample. A conical shape with a spherical tip is used for the stylus, and its shape is indicated by the radius of the stylus tip and taper angle of the cone. The measuring instrument presses the stylus against the sample with a specified measurement force and precisely measures the vertical displacement of the stylus. Machines typically measure a one-directional profile (total profile) by a horizontal scan. The resolution of stylus displacement measurement is typically 0,1 nm. There are limitations of measurement shape depending on the shape of the stylus.

A.2.3.2 Preparation of sample

The sample is not cut.

A.2.3.3 Procedure of measurement

Perform measurement according to the procedures specified by the equipment supplier. See ISO 3274[3] for the characteristics of the measurement instrument. The following points should be observed.

a) Observe the stylus used for measurement with an optical microscope and confirm that the tip and taper surface are not damaged or contaminated;

b) Adjust the measuring force and scanning speed of the stylus to a value that can follow the deep height in the trench structure and set the evaluation length so that the trench width is sufficiently covered;

c) Perform a scanning measurement and save the one-directional profile (total profile) as an electronic data. Filtering should not be performed;

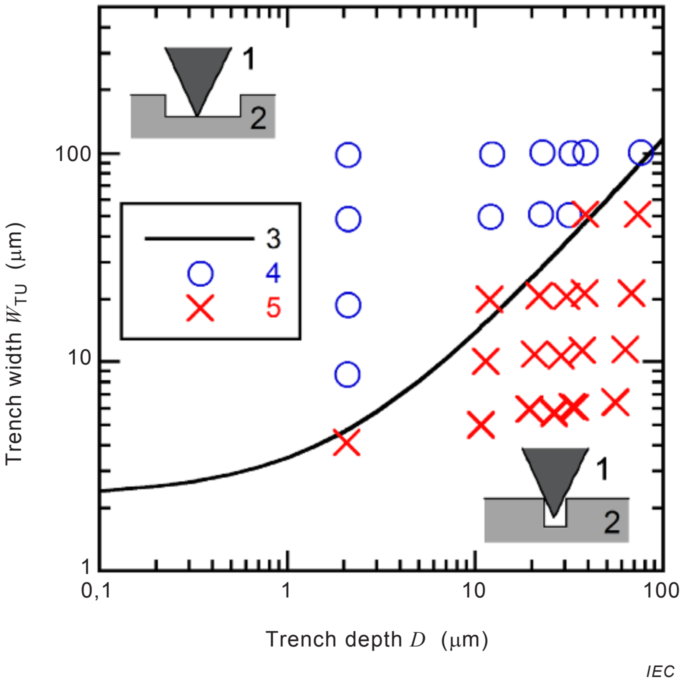
d) From the total profile, define the horizontal datum joining the two points on either side of the trench on the upper surface of the substrate;

e) From the shape of the total profile, determine whether the bottom surface of the trench has been measured. A V-shaped profile is usually obtained when the stylus cannot reach the bottom surface of the trench. If the bottom surface of the trench has been measured, the distance from the horizontal datum at the middle of the trench to the bottom of the trench is the measured value for trench depth, D;

f) Measure a single location the recommended number of times (see Clause B.2), and use the average of the measurement results as the measured value. See Annex B for the repeatability of measurements.

A.2.3.4 Measurable range

When the stylus tip cannot reach the bottom surface of the trench, the trench depth cannot be measured. Figure A.3 shows an example examining whether the trench depth measurement was achieved using a stylus having a tip with a radius of 2 μm and cone angle of 60°. The boundary of successful measurement roughly corresponds to the geometric contact criteria (see the solid line in Figure A.3 determined by the top width of the trench, W_{TU}, and the depth of the trench, D. This criterion is dependent also on the stylus tip shape. In addition, it is impossible to measure the depth larger than the upper limit of the vertical measurement range which is specified for a stylus surface profiler.



Key

1	Stylus tip
2	Trench specimen
3	Geometric criteria
4	Depth measurable case
5	Depth unmeasurable case

Figure A.3 – Measurability for depth of trench structure with a depth of D and a width of W_{Tu} using a stylus surface profiler

A.2.4 Confocal laser scanning microscopy

A.2.4.1 Principle of measurement

Confocal laser scanning microscope (CLSM) is a device for observing the surface morphology of the sample at high resolution using laser beam scanning. The surface of the sample is scanned two-dimensionally with a focused laser beam and light reflected from the surface is captured with a photodetector, providing information about the surface. Furthermore, since the image sensor of the confocal microscope only detects the reflected light from the highly limited focal position, it can obtain high definition images. A precise 3D image can be obtained by moving the focus position through various heights, collecting 2D (x-y plane) images.

The resolution of the CLSM is determined by the wavelength of the laser source, the NA (Numerical aperture) of the lens and so on.

A.2.4.2 Preparation of sample

The sample is not cut.

A.2.4.3 Procedure of measurement

Perform measurement according to the procedures specified by the equipment supplier. The following points should be observed.

a) Align the observing sample surface perpendicular to the optical axis (z axis). Namely, align the surface parallel to the x-y plane;

b) Set the magnification so that the trench to be measured fits in the area for measurement. The highest magnification possible should be used;

c) Set the scanning range of z direction deeper than the depth of the trench to be measured;

d) Measure a single location for the recommended number of times (see Clause B.2), and use the average of the measurement results as the measured value. See Annex B for the repeatability of measurements.

A.2.4.4 Measurable range

Measurement is applicable to trench structures within the dimensional range indicated in 4.1.

A.2.5 Atomic force microscopy

A.2.5.1 Principle of measurement

An atomic force microscope (AFM) is a high-resolution type of scanning probe microscope for obtaining surface profile images by using the interatomic force between an AFM probe and the surface of the sample. A sharp probe is scanned two-dimensionally over the surface of the sample (x-y plane) maintaining a constant interatomic force, and the height profile of the sample surface is measured three-dimensionally by measuring the displacement in the probe height (z position) in the respective x-y positions. There are several measurement methods with AFM measurement including contact mode, non-contact mode, and tapping mode. With the contact mode (static measurement mode), the probe makes light contact with the surface of the sample, and the surface of the sample is scanned maintaining a fixed repulsion between the needle point tip and the surface of the sample. With the non-contact mode (dynamic mode), the probe is vibrated slightly, and the surface of the sample is scanned maintaining a fixed amplitude of attraction between the needle point tip and the surface of the sample. With the tapping mode, a vibrating probe scans the surface of the sample continuously tapping the surface of the sample. The resolution of AFM depends on the precision of the probe tip radius, the measurement mode and the scanner.

A.2.5.2 Preparation of sample

The sample is not cut.

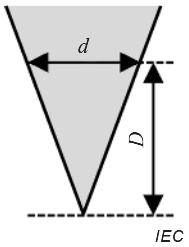
A.2.5.3 Procedure of measurement

Perform measurement according to the procedures specified by the equipment supplier. The following points should be observed.

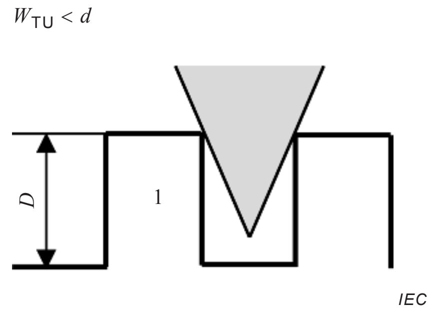
a) Set the sample so that its surface (the surface to be observed) is vertical in relation to the z axis direction and so that the edge line of the trench wall on the sample surface is vertical in relation to the horizontal (x-y) scanning direction;

b) Select an AFM probe with a shape that can reach the bottom of the trench (See Figure A.4);

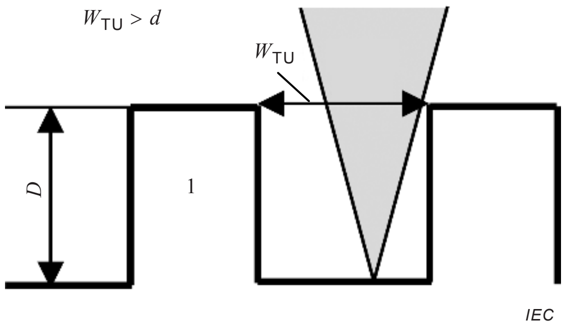
c) Measure a single location the recommended number of times (see Clause B.2), and use the average of the measurement results as the measured value. See Annex B for the repeatability of measurements.



a) A schematic of AFM probe tip



b) In case of inappropriate AFM probe



c) In case of appropriate AFM probe

Key

1	Trench structure specimen
d	Diameter of AFM probe tip at D away from the end of the tip

Figure A.4 – Relationship between shape of AFM probe tip and trench structure

A.2.5.4 Measurable range

With this method of measurement, the measurement performance of the AFM places restrictions on the trench structures that can be measured. The following point should be observed.

The trench depth, D, should be within the maximum scanning range of the AFM Z scanner.

A.3 Measurement for width of wall and trench at the upper surface of trench

A.3.1 Field emission type scanning electron microscopy

A.3.1.1 Principle of measurement

See A.2.1.1.

A.3.1.2 Preparation of sample

See A.2.1.2.

A.3.1.3 Procedure of measurement

See A.2.1.3, items a) to e). Measurement of the width of the wall and trench at the upper surface can also be performed from the surface of the sample.

A.3.1.4 Measurable range

See A.2.1.4.

A.3.2 Coherence scanning interferometer

A.3.2.1 Principle of measurement

See A.2.2.1.

A.3.2.2 Preparation of sample

See A.2.2.2.

A.3.2.3 Procedure of measurement

See A.2.2.3, items a) to f).

A.3.2.4 Measurable range

See A.2.2.4.

A.3.3 Stylus surface profiler

A.3.3.1 Principle of measurement

The measurement principle for one-directional shape profiles conforms to A.2.3.1. At the top edge of the trench, the spherical part of the stylus tip makes contact with the edge of the sample and produces a total profile that connects two straight lines with an arc reflecting the stylus tip shape. The edge position can be estimated from this profile if the stylus tip shape was assumed. The trench widths, W_{TU} and W_{WU}, can be calculated from the positions of the two edge position values for either side of the trench and the edge position value of the adjacent trench.

A.3.3.2 Preparation of sample

See A.2.3.2.

A.3.3.3 Procedure of measurement

See A.2.3.3, items a) to f).

A.3.3.4 Measurable range

Measurement is applicable to trench structures within the dimensional range indicated in 4.1.

A.3.4 Confocal laser scanning microscopy

A.3.4.1 Principle of measurement

See A.2.4.1.

A.3.4.2 Preparation of sample

See A.2.4.2.

A.3.4.3 Procedure of measurement

See A.2.4.3.

A.3.4.4 Measurable range

See A.2.4.4. With this measurement method, if the side angle of the wall, θ, is less than 90°, the trench width at the bottom of the trench, W_{TB}, and the wall width, W_{WB}, cannot be measured.

A.3.5 Optical microscopy

A.3.5.1 Principle of measurement

With this method, a reflected light microscope (metallurgical microscope) is used to measure the intervals between the edges of the trench structures, measuring the width of the walls and trench of the trench structure by comparing the dimensions with a calibration scale. When visible light is used, resolution is about 200 nm. The measurement is determined by the magnification of the lens used.

A.3.5.2 Preparation of sample

The sample is not cut.

A.3.5.3 Procedure of measurement

Perform measurement according to the procedures specified by the equipment supplier. The following points should be observed.

a) For length calibration, take a photograph of a micrometer scale for optical microscopy at the magnification used when measuring the trench interval, or capture an image using an image pickup device and calibrate the length. Select an appropriate micrometer interval for calibration according to the measurement magnification;

b) Place the sample under the objective lens and take a photograph of the trench structure at the magnification used for calibration, or capture an image using an image pickup device and measure the intervals of the trench structure required;

c) Calculate the upper wall width and the upper trench width, W_{WU} and W_{TU}, using the calibration value obtained in a);

d) Measure a single location for the recommended number of times (see Clause B.2), and use the average of the measurement results as the measured value. See Annex B for the repeatability of measurements.

A.3.5.4 Measurable range

Measurement is applicable to trench structures within the dimensional range indicated in 4.1.

A.4 Measurement for side wall angle of trench by field emission type scanning electron microscopy

A.4.1 Principle of measurement

See A.2.1.1.

A.4.2 Preparation of sample

See A.2.1.2.

A.4.3 Procedure of measurement

See A.2.1.3, items a) to e). If the side wall of the trench has obvious scallop structures, measure the dimensions, S_x and R_Sm, shown in Figure 3 and Table 1.

A.4.4 Measurable range

See A.2.1.4.

A.5 Measurement for wall and trench width at the bottom of trench by field emission type scanning electron microscopy

A.5.1 Principle of measurement

See A.2.1.1.

A.5.2 Preparation of sample

See A.2.1.2.

A.5.3 Procedure of measurement

See A.2.1.3, items a) to e).

A.5.4 Measurable range

See A.2.1.4.

A.6 Measurement for geometry of needle

A.6.1 Field emission type scanning electron microscopy

A.6.1.1 Principle of measurement

See A.2.1.1.

A.6.1.2 Preparation of sample

Damaged needle structures shall not be taken for the measurement.

A.6.1.3 Procedure of measurement

a) Place the sample on the sample stage in the SEM sample chamber so that the orientation of the FE-SEM electron beam corresponds to the normal vector of the bottom face of the needle structure. The levelness of the sample should be maintained within the range guaranteed in the equipment;

b) Set the magnification so that the whole needle fits inside the SEM image.

c) Adjust the focus, contrast and so on according to the procedures specified by the equipment supplier;

d) Measure the relevant dimensions W_1, W_2 and D_1 using the length measuring function provided by the equipment supplier;

e) Tilt the sample stage 30° in the plane of symmetry of the needle structure as shown in Figure A.5a), and measure D_2 shown in Figure A.5a) using the length measuring function provided by the equipment supplier;

f) Calculate the needle height, H, using the following formulae based on the geometrical conditions shown in Figure 5 and Figure A.5a).

$$\tan\theta = \frac{D_1}{H} \tag{1}$$

and

$$\cos(60° - \theta) = \frac{D_2}{L} \tag{2}$$

$$\cos\theta = \frac{H}{L} \tag{3}$$

Formulae (2) and (3) give

$$\frac{\cos(60° - \theta)}{\cos\theta} = \frac{D_2}{H} \tag{4}$$

Then,

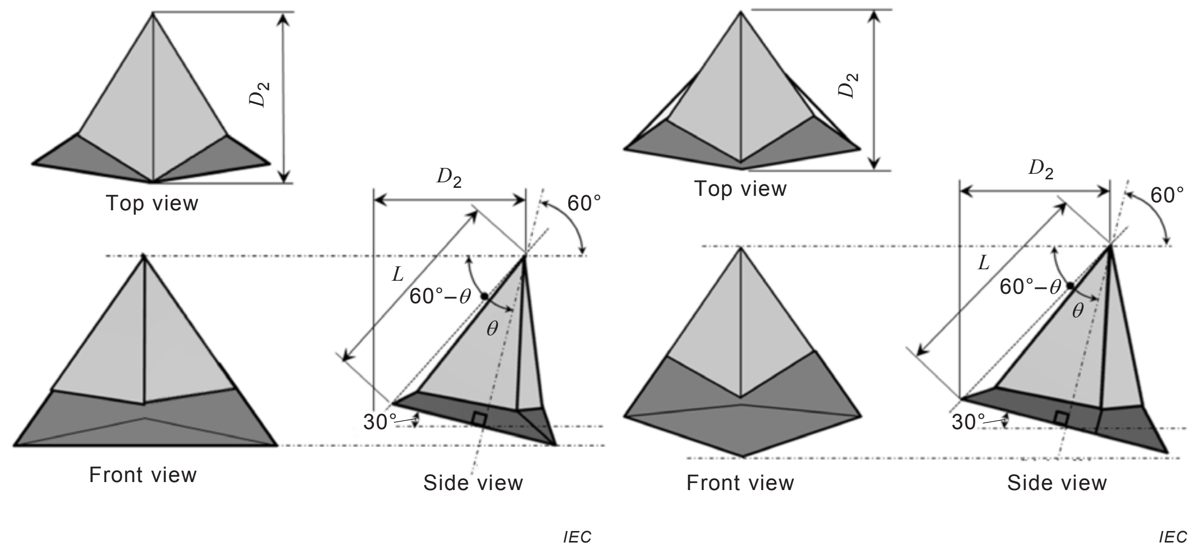
$$\cos 60° + \sin 60° \tan\theta = \frac{1}{2} + \frac{\sqrt{3}}{2}\tan\theta = \frac{D_2}{H} \tag{5}$$

When Formula (1) is substituted in Formula (5)

$$H = 2D_2 - \sqrt{3}D_1 \tag{6}$$

results, giving the needle height, H.

g) Measure a single location for the recommended number of times (see Clause B.2), and use the average of the measurement results as the measured value. See Annex B for the repeatability of measurements.



a) Typical needle structure with tree faces **b) Typical needle structure with four faces**

Figure A.5 – Front, side and top views of typical needle structures tilted to the back side with 30°

A.6.1.4 Measurable range

Measurement is applicable to needle structures within the dimensional range indicated in 5.1.

A.6.2 Atomic force microscopy

A.6.2.1 Principle of measurement

See A.2.5.1.

A.6.2.2 Preparation of sample

The sample is not cut.

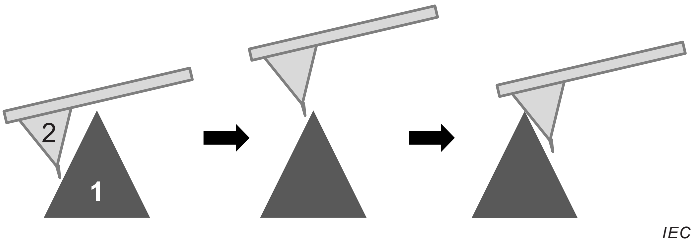
A.6.2.3 Procedure of measurement

Perform measurement of each dimension of the needle structure according to the procedures specified by the equipment supplier. The following points should be observed.

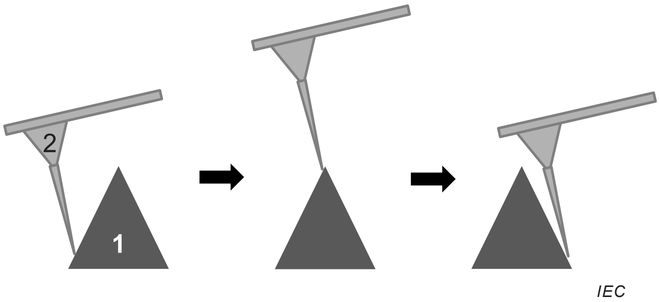
a) Arrange the needle bottom face (or substrate surface) so that it is vertical in relation to the Z-scanning direction of the AFM.

b) To measure the side height profile of the needle, select an AFM probe tip with a shape that can reach the needle side and base (see Figures A.6a) and A.6b)).

c) Measure a single location the recommended number of times (see Clause B.2), and use the average of the measurement results as the measured value. See Annex B for the repeatability of measurements.



a) In case of inappropriate AFM probe



b) In case of appropriate AFM probe

Key

1	Needle structure specimens
2	AFM probe

Figure A.6 – Relationship between shapes of AFM probe tip and needle structure

A.6.2.4 Measurable range

With this method of measurement, the measurement performance of the AFM places restrictions on the needle structures that can be measured. The following points should be observed.

a) The horizontal direction needle width, W_1 and W_2, should be smaller than the scanning range of the AFM X-Y scanner by a sufficient margin.

b) The needle height, H, should be within the maximum scanning range of the AFM Z scanner.

Annex B

(informative)

Uncertainty in dimensional measurement

B.1 General

Annex B covers the reliability of the measurement results of dimensions shown in the method of indicating shapes specified in the standard, restricted to the trench and needle structures used in MEMS (micro-electromechanical systems). The reliability of the measurement results of MEMS dimensions is evaluated and expressed in terms of uncertainty based on repeatability of measurement. The definition and expression of uncertainty specified here follows the Guide to the expression of uncertainty in measurement (GUM) issued as ISO/IEC Guide 98-3[2] by JCGM (Joint Committee for Guides in Metrology). In addition, the terms used in the standard are those defined in GUM.

B.2 Basic concepts

Annex B covers the expression of the measurement results of MEMS dimensions performed using the recommended methods and common requirements shown in Annex A.

The measured value (reported value) is expressed as the best estimate X, calculated using the values obtained by repeating the measurement n times. Here, the recommended number of iterations of measurement n is four to ten. The principles and methods of measurement and the equipment and procedures used are described briefly. In addition, the calibration of measured values as shown by the measuring equipment and analysis procedures (data processing) such as averaging are described. The measurement results are expressed as follows using the best estimate X and expanded uncertainty U.

$$X \pm U(k = 2)$$

However, k indicates the coverage factor.

B.3 Example of evaluating uncertainty of the average depth of trench

B.3.1 Sample and measured data for evaluating uncertainty

Uncertainty analysis of measurement using actual measurement results with FE-SEM is shown in Table B.1. The measurand is the “trench structure depth: dimension D” defined in 4.2. A sample with a trench structure with a wall of 150 μm, a trench of 100 μm, and depth of 70 μm is used as an example. Dimension D of the cross section of the sample was measured directly using the length measuring function of FE-SEM. The procedure in A.2.1.3 was used for measurement. For analysis of uncertainty, a single location in the same sample was measured for the recommended number of iterations of measurement (see Clause B.2) to gather data. In this case, the sample was measured ten times.

Table B.1 shows the measurement data for trench depth D for a trench structure with a wall of 150 μm, a trench of 100 μm, and depth of 70 μm, used for uncertainty analysis described in B.3.2 to B.3.7.

Table B.1 – Example of measured data of trench depth

The number of trials	1	2	3	4	5	6	7	8	9	10
Trench depth, D [μm]	68,5	68,0	68,0	68,5	68,0	68,0	68,0	68,5	68,0	68,0

B.3.2 Source of uncertainty

Uncertainty analysis of sample measurement uses cause and effect diagrams and so on to examine uncertainty in as much detail as possible. In this example, the following three uncertainty factors are considered.

a) Measurement repeatability $u(s)$: Test standard deviation found from the measured data for the number of recommended measurement iterations for the same sample.

b) Measuring equipment resolution $u(R)$: Minimum resolution of the FE-SEM used for measurement (value at ×400).

c) Uncertainty of calibration of measuring equipment $u(C)$: Calibration uncertainty of the FE-SEM corresponding to uncertainty in the calibration of the standard.

B.3.3 Type A evaluation of standard uncertainty

The test standard deviation was found using the results of repeated measurement of the same sample. The best estimate was 68,2 μm (68,15 μm), the test standard deviation was 0,2 μm (0,242 μm), and the average test standard deviation was 0,08 μm (0,076 μm). Therefore, it may be estimated as $u(s)$ = 0,08 μm.

B.3.4 Type B evaluation of standard uncertainty

a) The minimum resolution of the FE-SEM used for measurement was ×400 magnification at 0,1 μm, therefore $u(R)$ is estimated as a ±0,05 μm rectangular distribution. $\sqrt{3}$ is used as the divisor of the rectangular distribution, therefore uncertainty may be estimated as $u(R)$ = 0,03 μm.

b) The uncertainty shown on the calibration certificate of the FE-SEM of 0,05 μm in a normal distribution is used for $u(C)$. 2 is used as the divisor of the normal distribution, therefore uncertainty may be estimated as $u(C)$ = 0,025 μm.

B.3.5 Combined standard uncertainty

Composite uncertainty u_c comprising standard uncertainty components $u(s)$, $u(R)$ and $u(C)$ is found to be 0,09 μm (0,089 μm).

B.3.6 Expanded uncertainty and result

Assuming a coverage factor of 2, expanded uncertainty U is found to be 0,18 μm (0,178 μm). Therefore the measurement result is 68,2 μm ± 0,18 μm (k = 2).

B.3.7 Budget table

An uncertainty estimation table is shown in Table B.2.

Table B.2 – Estimation of uncertainty in measurement

Symbol	**Uncertainty factors (type)**	**Value** (μm)	**Probability distribution**	**Divisor**	**Standard uncertainty** (μm)v	**Sensitivity coefficient**	**Standard uncertainty components** (μm)
$u(s)$	measurement repeatability (A)	0,08	normal distribution	1	0,08	1	0,08
$u(R)$	measuring equipment resolution (B)	0,05	rectangular distribution	√3	0,03	1	0,03
$u(C)$	calibration of measuring equipment (B)	0,05	normal distribution	2	0,025	1	0,025
u_c	standard uncertainty components						0,09
U	expanded uncertainty						0,18 (k = 2)

Bibliography

[1] ISO 129-1, *Technical drawings – Indication of dimensions and tolerances – Part 1: General principles*

[2] ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM: 1995)*

[3] ISO 3274:1996, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments*

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