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INTERNATIONAL STANDARD

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Semiconductor devices – Micro-electromechanical devices – Part 47: Silicon based MEMS fabrication technology – Measurement method of bending strength of microstructures

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

Draft	Report on voting
47F/474/FDIS	47F/481/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 47: Silicon based MEMS fabrication technology – Measurement method of bending strength of microstructures

1 Scope

This part of IEC 62047 specifies the requirements and testing method to measure the bending strength of microstructures which are fabricated by micromachining technology used in silicon-based micro-electromechanical system (MEMS).

This document is applicable to the in-situ bending strength measurement of microstructures manufactured by microelectronic technology process and other micromachining technology.

With the devices scaling, the bending strength degradation, induced by defects and contaminations, becomes more severe. This document specifies an in-situ testing method of the bending strength based on MEMS technique. This document does not need intricate instruments (such as scanning probe microscopy and nanoindenter) and special test specimens.

Since in-situ on-chip tester in this document and device are fabricated with the same process on the same wafer, this document can give some practical reference for the design part.

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 terminology databases for use in standardization at the following addresses:

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

3.1
testing structure
nanostructure (for example, cantilevered or fixed beams) specially made to measure the properties of materials

[SOURCE: IEC 62047-45:2024, 3.1]

3.2
testing device
microstructure that transmits force or displacement to a testing structure and the force or displacement can be read out at the same time

[SOURCE: IEC 62047-45:2024, 3.2]

3.3
beam of constant strength
beam whose maximum normal stress on each cross-section is equal

3.4
in-situ on-chip tester
structure that integrates both the testing structure and the testing device on one chip, which is used to evaluate the process-related mechanical properties of MEMS devices

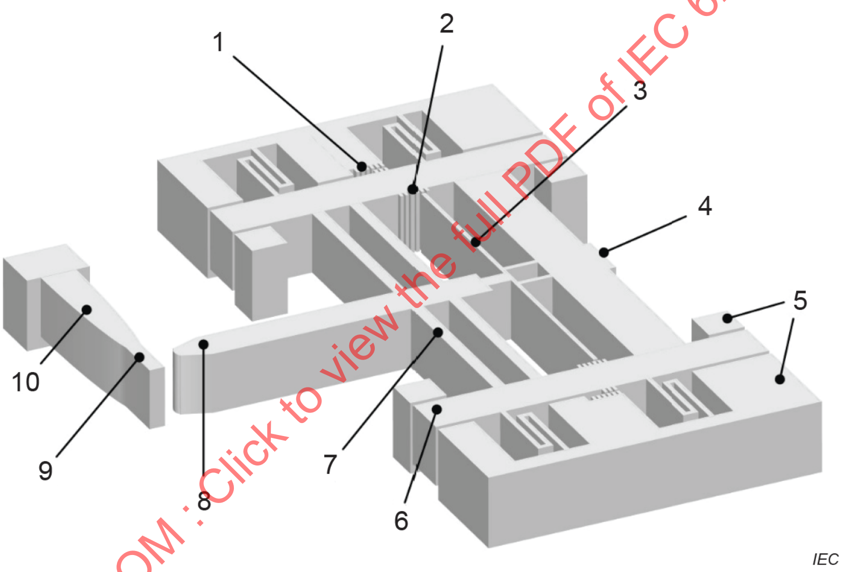
Note 1 to entry: In-situ on-chip tester and MEMS devices are manufactured simultaneously.

[SOURCE: IEC 62047-45:2024, 3.3]

4 Requirements

4.1 In-situ on-chip tester design requirements

The schemes of the in-situ on-chip tester are shown in Figure 1 and Figure 2.

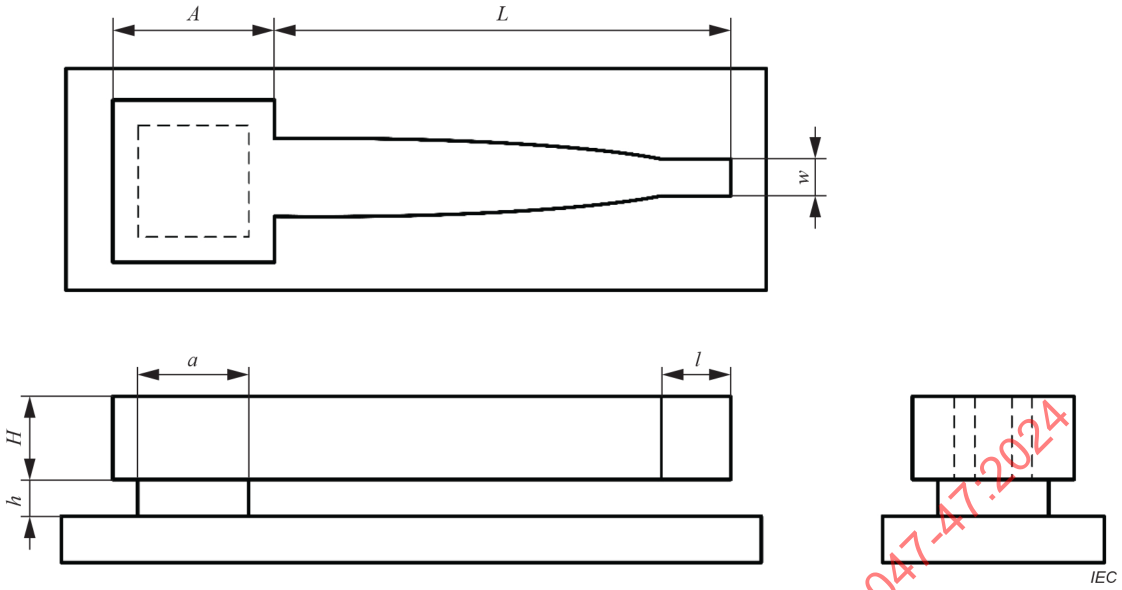


Key

1 displacement ruler
2 deflection ruler
3 magnifying lever
4 loading point
5 collision block
6 movable framework
7 elastic beam
8 on-chip needlepoint
9 loading segment
10 beam of constant strength

The testing device includes 1 to 10, and the testing structure includes 8 to 10.

Figure 1 – The in-situ on-chip bending strength tester



Key

H thickness of the beam of constant strength

h height of the anchor beam in the bonding area

A dimension of the bonding area of the beam of constant strength

a dimension of the bonding area

L length of the beam of constant strength arm, which should be designed with sequential values

l length of the loading segment

w width of the loading segment

Figure 2 – Three-view drawing of the testing structure

The design of the in-situ on-chip tester should be as follows:

a) The testing structure should adopt the structure of the beam of constant strength, which can eliminate the error caused by the stress concentration and extraction process defects;

b) The drive of the testing device should generate enough force to bend the testing structure, such as off-chip probe loading, on-chip thermal drive loading or on-chip electrostatic loading;

c) To prevent the elastic beam of the testing device breaking earlier than the beam of constant strength, the strength of the elastic beam should be designed high enough. Design dimensions are shown in Annex A;

d) To prevent the bonding surface of the testing structure breaking earlier than the beam of constant strength, the strength of the bonding surface should be designed high enough. Design dimensions are shown in Annex A;

e) The loading segment should meet the condition of l >20 µm to ensure that the influence of linewidth loss on the strength characteristics of the testing structure is less than 5 %;

f) The ruler design of the testing device should satisfy the resolution requirement. The ruler should be clearly monitored by optical microscopy;

g) The design of the testing structure should take full account of machining error and leave enough machining tolerance. The influence of the process during structure formation on the surface roughness of the structure should also be considered in the design of the testing structure.

4.2 In-situ on-chip tester fabrication requirements

Requirements for in-situ on-chip tester are as follows:

a) The fabrication process of the testing device and testing structure is the same as that of MEMS device;

b) The testing structure is applied to materials that can be used as the movable structure layer of MEMS devices, such as crystal silicon.

4.3 Testing environment requirements

Testing should be carried out in the actual manufacturing environment of the MEMS device chip.

5 Testing method

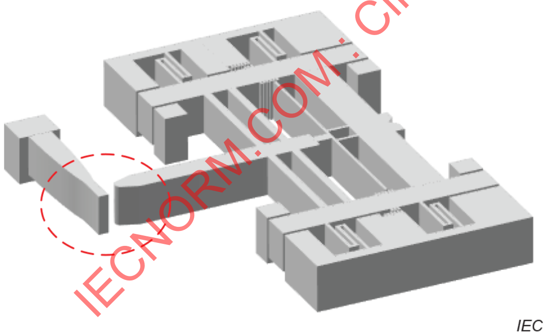
5.1 General

The detection of microstructure bending strength is to use the drive (this document takes off-chip probe loading as an example) to load the testing device, and then make the on-chip needlepoint of the testing device apply to the testing structure. The deformation and damage of the testing structure are monitored through the optical microscope, and the bending strength of the testing structure is determined by reading the number of the deflection ruler of the testing device.

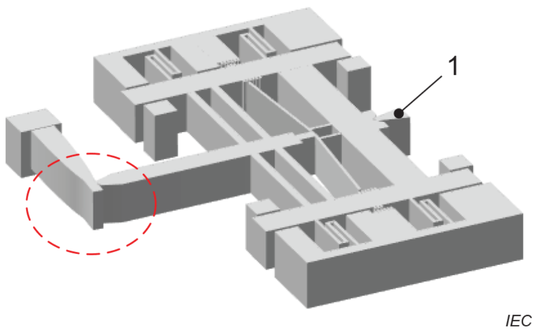
5.2 Microstructure bending strength testing method operation process

The microstructure bending strength testing method operation process is as follows:

a) As shown in Figure 3, when testing the bending strength of the microstructure, the chip of the in-situ on-chip tester is fixed on the probe station. A horizontal positive pressure is applied with the probe at the loading point until the fracture of the testing structure is observed through the microscope, and the maximum reading d of the deflection ruler is recorded in the process. The reading d is substituted into the Formula (1) to calculate the bending strength;



a) Before the probe is applied



b) After the probe is applied

Key

1 driven loading

Figure 3 – Microstructure bending strength testing method operation process

b) The probe and whole in-situ on-chip tester should be present in the field of view under optical microscopy. During the operation process, the probe loading should be less than 1 μm/s. After the testing structure breaks, the probe force should be stopped in time and the probe should be slowly withdrawn until it is separated from the testing device;

c) In order to obtain sufficient resolution and appropriate probe pressure, Table 1 gives the recommended dimension of the testing structure design.

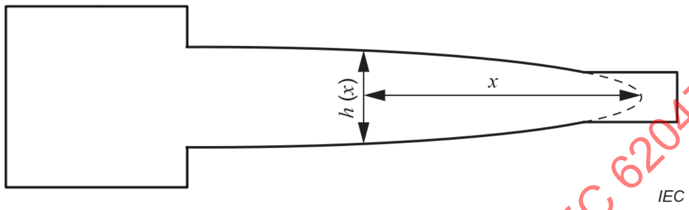
Table 1 – Dimensions for testing structure

Dimensions in μm

L	*l*	*w*	*A*	*a*	*H*	*h*
100 to 1 000	15 to 20	10	110	90	75	4

5.3 Microstructure bending strength testing method result process

The width of the beam of constant strength is designed as $h(x) = 5\sqrt{x}$, as shown in Figure 4. The changes in the magnifying lever before and after the test are shown in Figure 5. The dimension of the elastic beam is shown in Figure 6.



Key

x is the length of the beam of constant strength

h(*x*) is the width of the beam of constant strength

Figure 4 – Scheme of the beam of constant strength

a) Before the test **b) After the test**

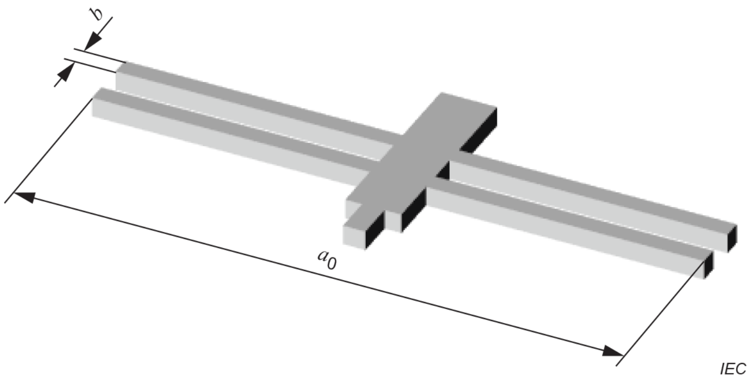
Key

a_1 is the spacing of the magnifying lever bracket

a_2 is the length of the magnifying lever

d is the reading after the magnifying lever is deformed

Figure 5 – Scheme of the magnifying lever



Key

a_0 is the length of the elastic beam

b is the width of the elastic beam

Figure 6 – Scheme of the elastic beam

The bending stress on the sidewall surface of the beam of constant strength can be calculated as,

$$\sigma(x) = 7{,}68 \times \frac{Eb^3 a_1}{a_0^3 (a_2 - a_1)} d \qquad (1)$$

where:

$\sigma(x)$ is the bending stress of the beam of constant strength, expressed in MPa;

E is the Young's modulus of silicon, which depends on the crystal orientation of the testing structure, expressed in MPa;

b is the width of the elastic beam, expressed in μm;

a_0 is the length of the elastic beam, expressed in μm;

a_1 is the spacing of the support beams of magnifying lever, expressed in μm;

a_2 is the length of the magnifying lever, expressed in μm;

d is the maximum reading of the deflection ruler, expressed in μm.

The dimensions of the testing structure and the testing device in Formula (1) should be the actual measured values after the fabrication.

6 Test report

The test report shall contain the following information:

a) reference to this international document;

b) testing device preparation procedures;

c) testing device dimensions;

d) constituent materials and their fabrication methods;

e) the date of the test;

f) measured results and properties: length of the beam of constant strength, maximum reading of the deflection ruler, bending stress of the beam of constant strength.

Annex A
(informative)

Examples of bending strength testing for microstructures

A.1 General

Annex A describes an example of measuring the bending strength of microstructures using an in-situ on-chip tester. Clauses A.2 and A.3 summarize the design dimensions of the testing device and the measurement results of the in-situ on-chip tester, respectively.

A.2 Design dimensions of the testing device

The dimensions of the testing device are marked in Figure A.1 and Figure A.2. Figure A.3 shows the design of the deflection ruler and the displacement ruler. Table A.1 shows the design dimensions of the testing device.

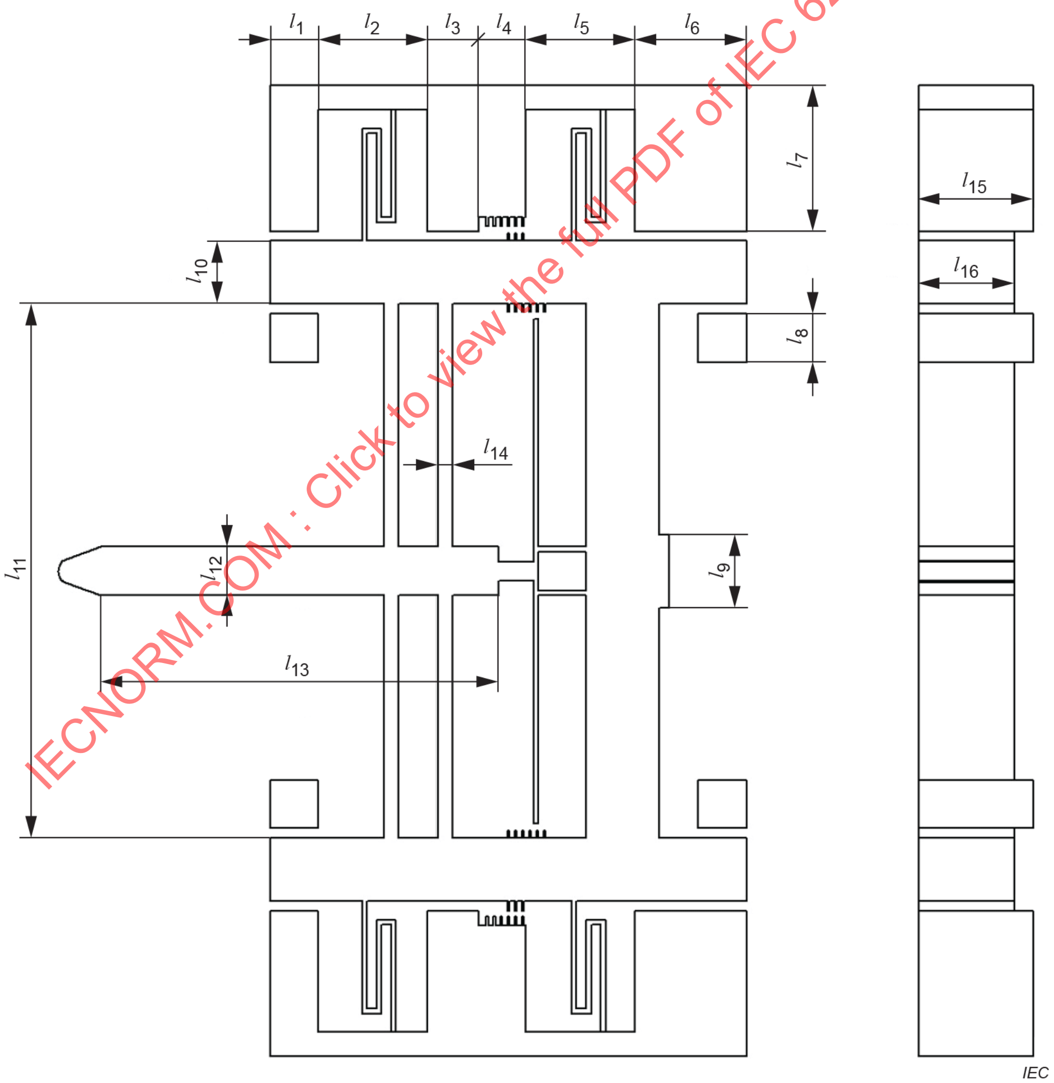


Figure A.1 – Overall dimension labelling of the testing device

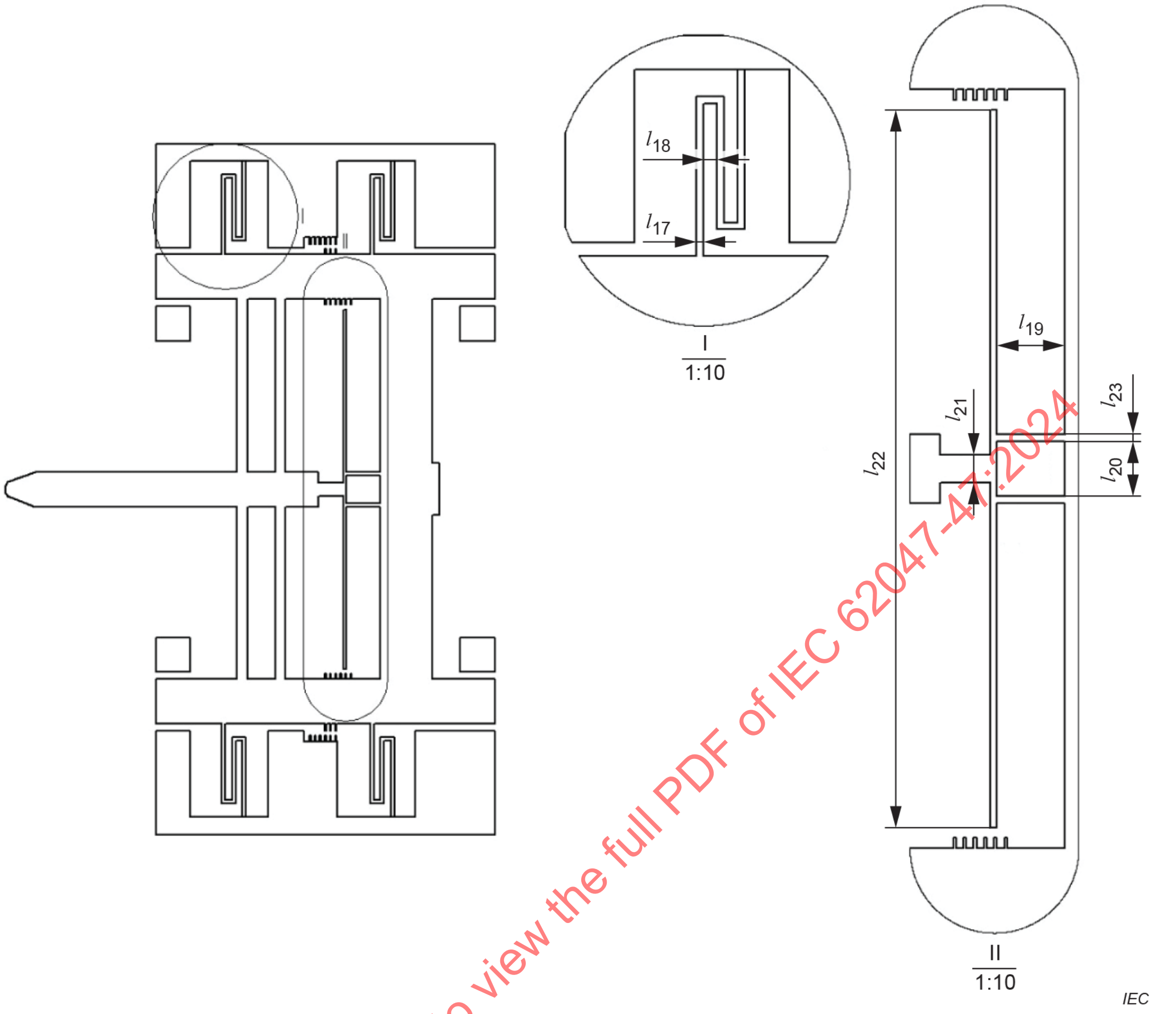
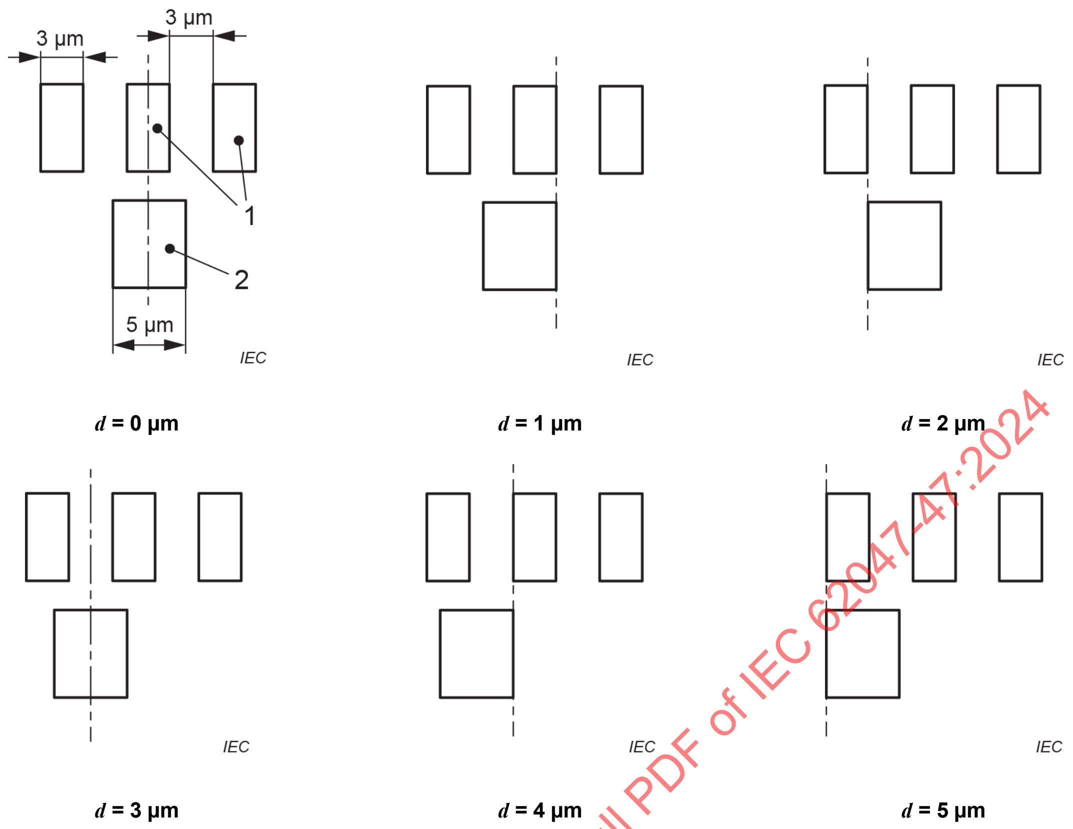


Figure A.2 – Local dimension labelling of the testing device



Key

1 stationary scale

2 gauge pointers

Figure A.3 – Design of the deflection ruler and the displacement ruler

Table A.1 – Design dimensions of the testing device

Dimensions in μm

Size code of testing device	Design size
l_1	60
l_2	130
l_3	80
l_4	70
l_5	130
l_6	100
l_7	280
l_8	60
l_9	50
l_{10}	100
l_{11}	380
l_{12}	80
l_{13}	365
l_{14}	20
l_{15}	79
l_{16}	75
l_{17}	5
l_{18}	5
l_{19}	20
l_{20}	60
l_{21}	40
l_{22}	360
l_{23}	3

In order to ensure that the testing device should not be damaged before the testing structure breaks, it is recommended to design the testing device according to the design size in Table A.1. When the line width loss is 0,5 μm and the required error is less than 10 %, l_{14} should be more than 15 μm.

A.3 Microstructures bending strength test

The dimension design of the testing device of the in-situ on-chip tester refers to Clause A.2. The dimension design of the testing structure refers to Table 1 in 5.2, where l = 20 μm. Refer to 5.2 for the operation process of the microstructure bending strength test. Partition tests are carried out on the in-situ on-chip tester of the same size, and the test area is shown in Figure A.4. Combined with the calculation formula of the sidewall bending strength of the beam of constant strength in Formula (1), this document extracts the measurement results under the HRM etching process conditions, as shown in Table A.2.