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Semiconductor devices — Micro-electromechanical devices

Part 21: Test method for Poisson's ratio of thin film MEMS materials

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National foreword

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

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English Version

Semiconductor devices - Micro-electromechanical devices - Part 21: Test method for Poisson's ratio of thin film MEMS materials (IEC 62047-21:2014)

Dispositifs à semiconducteurs - Dispositifs microélectromécaniques - Partie 21: Méthode d'essai relative au coefficient de Poisson des matériaux MEMS en couche mince (CEI 62047-21:2014)

Halbleiterbauelemente - Bauelemente der Mikrosystemtechnik - Teil 21: Prüfverfahren zur Querkontraktionszahl von Dünnschichtwerkstoffen der Mikrosystemtechnik (IEC 62047-21:2014)

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Foreword

The text of document 47F/185/FDIS, future edition 1 of IEC 62047-21, prepared by SC 47F “Microelectromechanical systems” of IEC/TC 47 “Semiconductor devices" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62047-21:2014.

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)	2015-04-24
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2017-07-24

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Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

Publication	Year	Title	EN/HD	Year
IEC 62047-8	2011	Semiconductor devices - Micro-electromechanical devices - Part 8: Strip bending test method for tensile property measurement of thin films	EN 62047-8	2011
ASTM E132-04	2010	Standard test method for Poisson's ratio at room temperature	-	-

CONTENTS

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 21: Test method for Poisson's ratio of thin film MEMS materials

1 Scope

This part of IEC 62047 specifies the determination of Poisson's ratio from the test results obtained by the application of uniaxial and biaxial loads to thin-film micro-electromechanical systems (MEMS) materials with lengths and widths less than 10 mm and thicknesses less than 10 μm.

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.

IEC 62047-8:2011, *Semiconductor devices – Micro-electromechanical devices – Part 8: Strip bending test method for tensile property measurement of thin films*

ASTM E 132-04:2010, *Standard test method for Poisson's ratio at room temperature*

3 Terms, definitions, symbols and designations

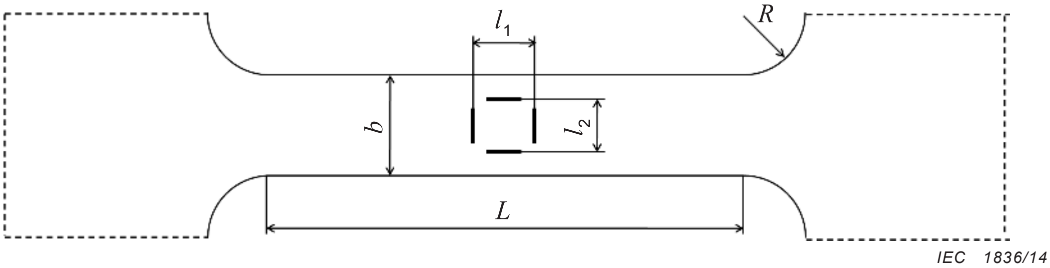
3.1 Terms and definitions

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

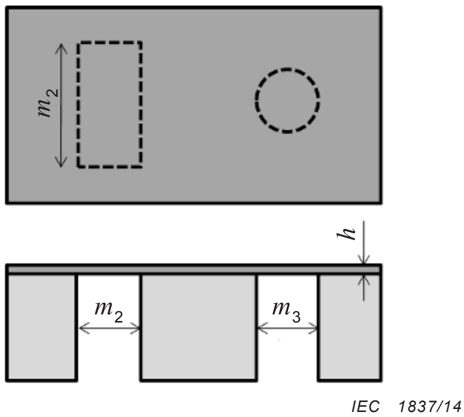
3.1.1
Poisson's ratio
ν
ratio of transverse strain multiplied by (-1) to the corresponding longitudinal strain resulting from uniformly distributed longitudinal stress below the proportional limit of the material, expressed as $-\varepsilon_t/\varepsilon_l$, where ε_t is transverse strain, and ε_l is longitudinal strain

3.2 Symbols and designations

Symbols and designations of two types of test pieces are presented in Figure 1 and Table 1, respectively.



a) Type 1 test piece for uniaxial tensile machine



b) Type 2 test piece for membrane bulging machine

Figure 1 – Two types of test pieces for the measurement of Poisson's ratio

Table 1 – Symbols and designations of a test piece

Symbol	Unit	Designation
l_1	μm	Gauge length for longitudinal strain measurement
l_2	μm	Gauge length for transverse strain measurement
b	μm	Width of test piece
L	μm	Overall length
R	μm	Filet radius of test piece
m_1	μm	Length of a rectangular membrane
m_2	μm	Width of a rectangular membrane
m_3	μm	Diameter of a circular membrane
h	μm	Thickness of membrane

4 Test piece

4.1 General

The test piece should be prepared using a fabrication process similar to the actual fabrication of devices. It should have dimensions on the same order as those of the mother device to minimise the effect of size-dependent properties. An example of the fabrication process can be found in IEC 62047-8. The gradient of the internal stress in the direction of thickness should be minimised using an annealing process, but the annealing process should be avoided when Young's modulus and Poisson's ratio of the sample can be affected. Two types of test pieces are utilised in this standard and are described in the following 4.2 and 4.3.

4.2 Shape of the test piece

Two types of test pieces are specified in this standard. Type 1 has a shape similar to a tensile specimen (Figure 1a), whereas type 2 has two membranes (Figure 1b). In type 1, two pairs of gauge markers shall be fashioned to define both longitudinal and transverse strains. By measuring the longitudinal and transverse strains, the Poisson’s ratio is calculated by the ratio of $-\varepsilon_t/\varepsilon_l$ specified in 3.1. When a wrinkle forms in the test piece during the tensile test due to compressive strain in the transverse direction, undesirable out-of-plane deformation can lead to an error in the optical measurement, obscuring the optical measurement of transverse strain. In this case, a type 2 test piece should be used instead of a type 1 test piece. In type 2, circular and rectangular membranes are included in the test piece. The maximum deflections of the two membranes are measured simultaneously under a given pressure. The pressure applied to the two membranes should be identical. The out-of-plane deflection due to the applied pressure should be measured using an optical technique or atomic force microscopy (AFM) to minimise the mechanical disturbance of the test piece. For the rectangular membrane, the ratio between the length and width (m_1/ m_2) should be larger than 4.

4.3 Measurement of dimensions

To analyse the test results, an accurate measurement of the test-piece dimensions is required because the dimensions are used to extract the mechanical properties of test materials. In the type 1 test piece, the longitudinal and transverse gauge lengths (l_1, l_2), width (b), and thickness (h) shall be measured with an error of less than ± 5 %. In the type 2 test piece, the width (m_2) of the rectangular membrane, the diameter (m_3) of the circular membrane, and the film thickness (h) shall be measured with an error of less than ± 5 %.

5 Testing method and test apparatus

5.1 Test principle

With a type 1 test piece, the test is performed by applying a tensile load to the test piece. The longitudinal and transverse strains induced by the tensile load should be uniform over a pre-defined gauge section in the elastic region of the test piece. The longitudinal and transverse strains should be measured simultaneously, and the time delay between them should be less than 1/100 of the data-sampling period. When there is curling in the test piece, it is difficult to measure the transverse strain. In this case, Poisson's ratio should be measured using a type 2 test piece. With a type 2 test piece, the test is performed by applying air pressure to the test piece. The circular and rectangular membranes should experience the same applied pressure. The deflections of both membranes should be measured simultaneously, and the time delay between them should be less than 1/100 of the data-sampling period.

5.2 Test machine

The test machine for a type 1 test piece is similar to a conventional tensile test machine, except that it is capable of measuring transverse strain. Due to the thinness of the test piece, the longitudinal and transverse strains shall be measured using optical techniques such as laser interferometry or digital image correlation (DIC). The test machine for a type 2 test piece consists of an air compressor, air regulator, pressure sensor, and displacement sensor for measuring out-of-plane deflections.

5.3 Test procedure

5.3.1 Test procedure for type 1 test piece

a) Fix the test piece using the tensile grip. The longitudinal direction of the test piece shall be aligned with the actuating direction of the test apparatus, and the deviation angle shall be less than 1 degree, as specified in 4.4 of IEC 62047-8:2011.

b) Verify the strain measurement unit for longitudinal and transverse strains. These strain signals shall be measured simultaneously with the load signal.

c) Apply a tensile load to the test piece at a constant strain rate (or grip-to-grip displacement rate). The strain rate shall range from 0,01 min^{-1} to 10 min^{-1} depending on the material system of the test piece and the actual usage condition of the customer.

d) Unload the test apparatus when the load sufficiently exceeds the proportional limit.

e) Draw a graph of the longitudinal and transverse strains with respect to load as described in ASTM E 132-04 and determine Poisson's ratio.

5.3.2 Test procedure for type 2 test piece

a) Fix the test piece to the grip of the test apparatus. The grip should have inlet and outlet ports for air pressure and a connection port that allows air pressure to be applied to the test piece. The air pressure line in the grip should be designed to deliver identical pressure to both membranes in the test piece.

b) Apply air pressure to both the circular and rectangular membranes in the test piece and measure the central deflections of both membranes and the applied pressure.

c) Unload the test apparatus when the pressure exceeds the proportional limit of the test piece or if the membranes rupture.

d) Analyse the test results and determine Poisson's ratio according to Annex B.

5.4 Test environment

Because the mechanical properties are temperature and humidity sensitive, fluctuations in temperature during the test shall be controlled to be less than ± 2 °C, and the change in relative humidity (RH) in the testing laboratory shall be controlled to be less than ± 5 % RH.

6 Test report

The test report shall contain the following information.

a) Reference to this international standard;

b) Test piece identification;

c) Test piece material;

   – using a single crystal: crystallographic orientation;

   – using a poly-crystal: texture and grain size;

d) Shape and dimensions of the test piece;

e) Test piece fabrication method details:

   – deposition method;

   – annealing conditions;

   – fabrication conditions;

f) Testing system:

   – testing apparatus;

   – load and strain measurement method (or pressure and deflection);

g) Measured properties and results: Poisson's ratio, longitudinal and transverse strains versus applied load (or pressure) curve.

Annex A
(informative)

Measurement example of Poisson's ratio using type 1 test piece

A.1 Fabrication of the test piece

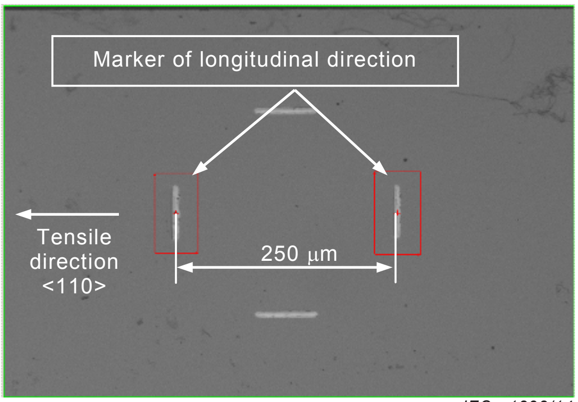
The test piece for measurement of Poisson's ratio is fabricated by MEMS processes. Similar fabrication processes can be found in Annex B of IEC 62047-8:2011.

A.2 Dimensions of the test piece

The test pieces should be fabricated with a length of 2 mm, a width of 500 μm, and a filet radius of 5 mm (Figure 1). To analyse the test data, dimensions of the test pieces should be measured accurately. The thickness of the test piece is measured to be 2,8 μm using a scanning electron microscope. As shown in Figure A.1, longitudinal and transverse strains are measured after the markers for strain measurement are defined.

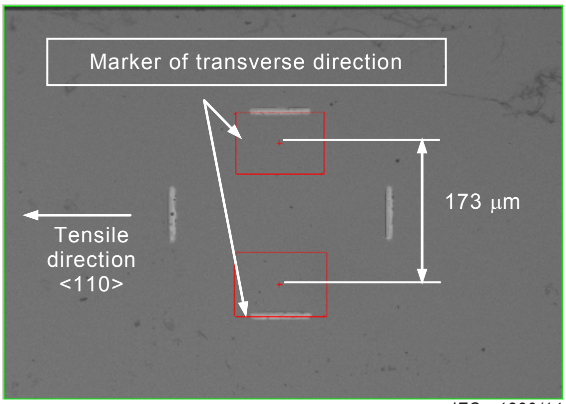
A.3 Test procedures

Tests are performed using a micro-tensile testing apparatus. After the test piece is fixed on jigs, uni-axial tensile force is applied in the longitudinal direction of the test piece using a piezoelectric actuator. The longitudinal direction coincides with the <110> direction of the test piece made of single-crystal silicon. The strain rate is 5×10^{-4}/s during the test. Longitudinal and transverse strains are measured using DIC with the images acquired from a microscope. Markers for DIC are shown in Figure A.1. Larger spacing between the two markers of the longitudinal direction leads to higher resolution of the strain measurement for a given optical system. In this test, the longitudinal and transverse gauge lengths are 250 μm and 173 μm, which are taken from the field of view of the optical system and maximum displacement of the test piece. Both longitudinal and transverse strains (ε_l, ε_t) and load (F) are acquired simultaneously by a data-acquisition module.



IEC 1838/14

a) **Markers for longitudinal strain**



IEC 1839/14

b) **Markers for transverse strain**

Figure A.1 – Optical images of markers for strain measurement by DIC

A.4 Test results

From the measured data, a $F\text{–}\varepsilon$ curve can be obtained (Figure A.2). After fitting the two curves linearly, the slopes of the two curves are obtained as $d\varepsilon_l/dF$ = 0,004 43 and $d\varepsilon_t/dF$ =–0,001 13. Then, Poisson's ratio is calculated by

$$\upsilon = -\frac{d\varepsilon_t/dF}{d\varepsilon_l/dF} = 0{,}267. \tag{A.1}$$

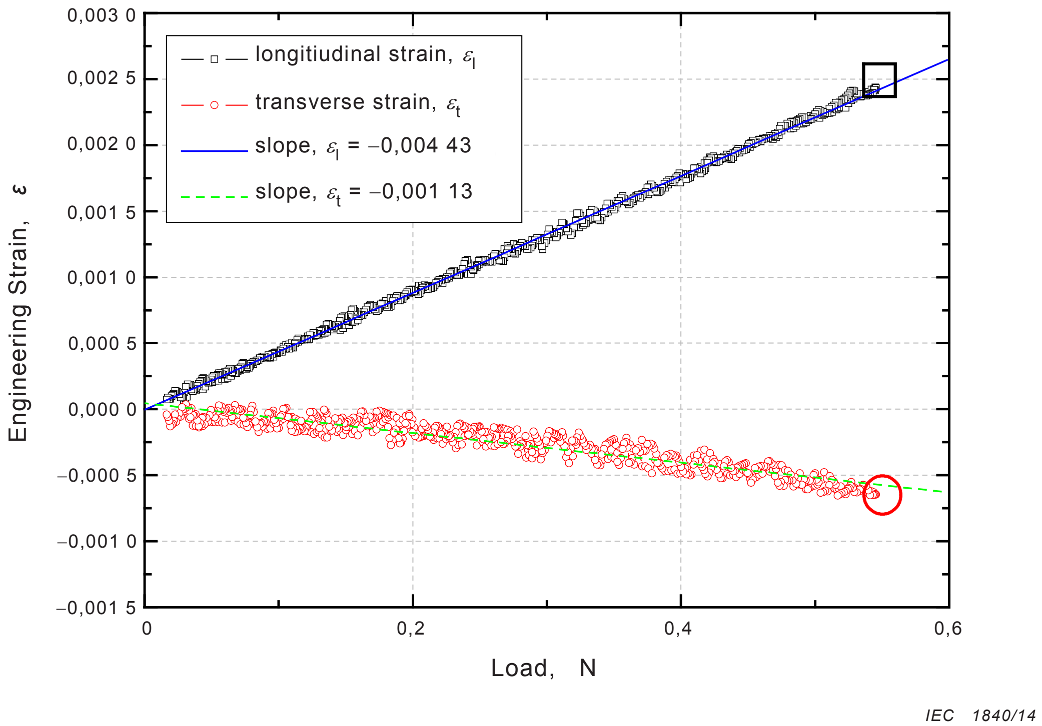


Figure A.2 – Graphs of load and strain in the longitudinal and transverse directions

Annex B
(informative)

Analysis of test results obtained from a type 2 test piece

B.1 General

The type 2 test piece membranes are isotropic and homogeneous. Bending stiffness of the membranes is assumed to be negligible, and this is acceptable for membranes for which the thickness is much less than the width and the diameter. The ratio between the length and the width of the rectangular membrane should be greater than 4.

B.2 Evaluation of stress and strain in circular and rectangular membranes

When air pressure (p) is applied to the two membrane types, circular and rectangular, the membranes are strained, and the corresponding stress builds up. For the circular membrane with a diameter D, a thickness h, and a central deflection δ_{circular}, the equi-biaxial stress (σ_{circular}) and strain ($\varepsilon_{\text{circular}}$) in the membrane are evaluated using the following equations according to [1][1]:

$$\sigma_{\text{circular}} = \frac{pD^2}{16h\delta_{\text{circular}}} \tag{B.1}$$

$$\varepsilon_{\text{circular}} = \frac{2\delta_{\text{circular}}^2}{D^2} \tag{B.2}$$

The stress and strain are related by the following equation:

$$\sigma_{\text{circular}} = \frac{E}{1-\nu}\varepsilon_{\text{circular}}. \tag{B.3}$$

Here, E is Young's modulus, and ν is Poisson's ratio. For the rectangular membrane with a width W, a thickness h, and a central deflection δ_{rec}, the stress (σ_{rec}) and strain (ε_{rec}) are evaluated using the following equations:

$$\sigma_{\text{rec}} = \frac{pW^2}{8h\delta_{\text{rec}}} \tag{B.4}$$

$$\varepsilon_{\text{rec}} = \frac{8\delta_{\text{rec}}^2}{3W^2} \tag{B.5}$$

The stress and strain in the rectangular membrane are related by the following equation:

____

1 Numbers in square brackets refer to the Bibliography.

$$\sigma_{\text{rec}} = \frac{E}{1-\nu^2}\varepsilon_{\text{rec}} \tag{B.6}$$

B.3 Evaluation of Poisson's ratio

From Equations (B.3) and (B.6), the following equation is obtained:

$$\frac{\sigma_{\text{circular}}}{\sigma_{\text{rec}}} = (1+\nu)\frac{\varepsilon_{\text{circular}}}{\varepsilon_{\text{rec}}} \tag{B.7}$$

By inserting Equations (B.1), (B.2), (B.4), and (B.5) into Equation (B.7), the following equation is obtained:

$$\nu = 2\left(\frac{D}{W}\right)^4\left(\frac{\delta_{\text{rec}}}{\delta_{\text{circular}}}\right)^3 - 1 \tag{B.8}$$

To measure Poisson's ratio using a type 2 test piece, it is not necessary to measure the applied pressure on the membranes when the two membranes undergo the same pressure. It is necessary to measure the dimensions and the deflections of the membranes during the test.

Bibliography

[1] Xu, D., Liechti, K.M., *Bulge Testing Transparent Thin Films with Moiré Deflectometry*, Experimental Mechanics, Vol.50 (2010), pp. 217-225.

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