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INTERNATIONAL STANDARD

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colour inside

Semiconductor devices – Micro-electromechanical devices –
Part 10: Micro-pillar compression test for MEMS materials

Dispositifs à semiconducteur – Dispositifs microélectromécaniques –
Partie 10: Essai de compression utilisant la technique des micro-piliers pour les matériaux des MEMS

IEC 62047-10:2011

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SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 10: Micro-pillar compression test for MEMS materials

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 62047-10 has been prepared by subcommittee 47F: Micro-electromechanical systems, of IEC technical committee 47: Semiconductor devices.

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

FDIS	Report on voting
47F/85/FDIS	47F/94/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 of IEC 62047, 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 web site 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.

The contents of the corrigendum of February 2012 have been included in this copy.

IMPORTANT – The "colour inside" logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 10: Micro-pillar compression test for MEMS materials

1 Scope

This part of IEC 62047 specifies micro-pillar compression test method to measure compressive properties of MEMS materials with high accuracy, repeatability, and moderate effort of specimen fabrication. The uniaxial compressive stress-strain relationship of a specimen is measured, and the compressive modulus of elasticity and yield strength can be obtained.

The test piece is a cylindrical pillar fabricated on a rigid (or highly stiff) substrate by micro-machining technologies, and its aspect ratio (ratio of pillar diameter to pillar height) should be more than 3. This standard is applicable to metallic, ceramic, and polymeric materials.

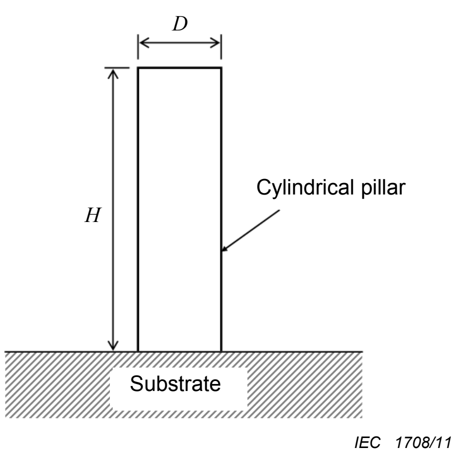
2 Normative references

The following referenced documents are indispensable for the application of this document. 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, *Semiconductor devices – Micro-electromechanical devices – Part 8: Strip bending test method for tensile property measurement of thin films*

3 Symbols and designations

For the purposes of this document, the shape of test piece and symbols are given in Figure 1 and Table 1, respectively. Test piece in this standard is often referred to as a pillar specimen.



Key

Components		**Dimensions of cylindrical pillar**	
cylindrical pillar:	a part of micro-pillars fabricated on a substrate using micro-machining process shaped in a cylinder as a test piece	D:	diameter of a test piece
substrate:	a kind of rigid (or highly stiff) material supporting the test piece	H:	height of a test piece

Figure 1 – Shape of cylindrical pillar (See Table 1 for symbols)

Table 1 – Symbols and designations of test piece

Symbol	Unit	Designation
H	µm	height of a test piece
D	µm	diameter of a test piece

4 Test piece

4.1 General

The test piece shall be prepared by using the same fabrication process as the actual device fabrication. To minimize the size effect of a test piece, the structure and size of the test piece should be similar to those of the device components. There are many fabrication methods of the test piece depending on the applications.

4.2 Shape of test piece

This standard specifies the compressive properties of a cylindrical micro-pillar. The micro-pillars are fabricated on a substrate using micro-machining process. The shape and the verticality of the pillars should be checked using electron or optical microscopy. The boundary condition on the bottom surface of the pillar is usually regarded as the fixed boundary, and these boundary conditions are different from those of bulk scale pillars where the top and bottom surfaces are usually lubricated and regarded as the frictionless boundary. Since it is also difficult to directly measure the compressive strain of the micro-pillar during the test, the strain is estimated from the displacement of the rigid punch using the Equation (2) of 5.1. This leads to errors in strain, and consequently errors in elastic modulus and yield strength as described in Annex A. The accuracy of this method depends on the friction coefficient between the punch and the top surface, and the aspect ratio of the micro-pillar. The pillar with high aspect ratio is desirable for reducing the errors in strain estimation unless the buckling occurs. The upper limit of aspect ratio is dependent on boundary conditions and material properties of the pillar. The maximum aspect ratio is suggested as 10 [4][1]. When there is no buckling after test for a pillar with an aspect ratio larger than 10, the test data should be considered as a valid one. The friction coefficient on the top surface can be reduced by applying a lubricating layer for bulk pillars (see [4]), but it is very difficult to apply the lubricating layer to micro-pillars. The maximum variation in diameter of a cross-section of a pillar should be less than 1 % of the nominal diameter. When this is not the case, the actual cross-sectional area should be measured.

4.3 Measurement of dimensions

To analyze the test results, the accurate measurement of the test piece dimensions is required since the dimensions are used to extract mechanical properties of test materials. The diameter and the height of the pillar should be measured with high accuracy with less than ±1 % error. Interferometric technique or FIB (Focused Ion Beam) sectioning can be utilized to measure the height accurately. The test piece can have a changing cross-section in the longitudinal direction and the diameter or the top surface can be different from that of the bottom surface. This dimensional error should be minimized with ±1 % error if possible. When it is impossible, the shape of the test piece should be measured using microscopic technique and finite element analysis should be adopted to analyze the test results.

1 Figure in square bracket refer to Bibliography.

5 Testing method and test apparatus

5.1 Test principle

$$\sigma = \frac{4P}{\pi D^2} \tag{1}$$

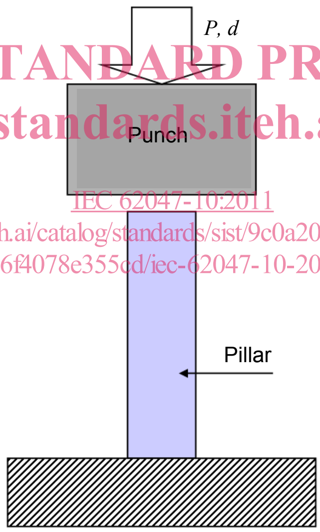
$$\varepsilon = \frac{d}{H} \tag{2}$$

where

σ is stress defined by an applied force divided by a cross-sectional area of the test piece;

d is a longitudinal displacement of the punch during the test;

ε is strain defined by a displacement divided by a height of the test piece.



IEC 1709/11

Key

Components		**Dimension of tool and supply**	
punch:	a kind of tool shaped as a disc with a large radius to reduce the error caused by misalignment between the tool and a part of micro-pillars	P	specified values of compressive force
pillar:	a part of micro-pillars fabricated on a substrate using micro-machining process shaped in a cylindrical pillar specimen as a test piece	d	values of longitudinal displacement of the pillar caused by applying specified values of compressive force

Figure 2 – Schematic of micro-pillar compression test

5.2 Test machine

Depending on the dimensions and materials of the micro-pillar, the force and displacement sensors need to be carefully chosen, and their resolutions should be better than 1/1 000 of the maximum force and displacement, respectively. The actuator should have a linear motion in the direction of the loading without any parasitic motion in the other directions, and its displacement resolution needs to be less than 1/10 of the displacement sensor resolution. Piezoelectric or voice-coil actuator is desirable for the actuator, and LDVT, capacitive, or optical sensor can be applicable to this type of test. The stiffness of the frame of the test machine should be much larger than the stiffness of the test piece. The deformation of the test machine should be checked and/or compensated, and an example for the compensation of test machine can be found in IEC 62047-8.

The punch is an important component in the testing apparatus. A flat-ended punch has been widely adopted in this type of test, and a spherical punch with a large radius can be used to reduce the error caused by misalignment between a punch and a specimen. The roughness of the surface of the punch should be better than that of the specimen. The flatness and the parallelism of the flat-ended punch should be better than 0,0002 m/m (see [4]). The radius of the spherical punch should be 100 times larger than the diameter of the test piece.

5.3 Test procedure

The test procedure used in this study is summarized as follows:

a) Attach a substrate to the stage of the test apparatus. A lot of micro-pillars can be fabricated on the substrate using batch fabrication process. It is important to minimize the deviation angle between the axial direction of the pillars and the loading direction of the punch and the deviation should be less than 0,0002 m/m (see [4]).

b) Identify the position of a test piece. The position of the test piece can be observed using an optical camera module, and the positioning error should be less than 1/10 of the diameter of the test piece.

c) Apply a compressive displacement to the top surface of the pillar with a constant velocity of the punch. The constant velocity results in a constant strain rate. The suggested strain rate is 5 x 10^3 /min (see [4]) for materials of rate-insensitive. For the materials of rate-sensitive, the effect of strain rate should be carefully investigated [3]. The maximum applied strain needs to be properly chosen depending on the materials and testing purpose. For the stress-strain curve measurement, the maximum strain range should be selected to take into account the plastic behaviour of a test piece. The suggested maximum strain range is 0,04 m/m for ductile materials and it can be less than 0,01 m/m for brittle materials.

d) Retract the punch under the same velocity as the loading-velocity after a period of holding time. The suggested holding period is 60 s for rate-insensitive materials. The elastic modulus can be determined from the slope of the unloading curve in stress-strain data.

e) If necessary, repeat b) to d) several times for a prescribed increment of strain to investigate the modulus change for a test piece.

f) The measured load and displacement are converted into stress and strain using Equations (1) and (2). The elastic modulus and yield strength is determined using a procedure described in Clause 4.

5.4 Test environment

It is recommended to perform a test under constant temperature and humidity. Temperature change can induce thermal drift of highly sensitive sensors for force and displacement, and should be less than 2 ºC. It is often necessary to check temperature change or thermal drift before and after the test. The relative humidity change during the test is suggested to be less than 2 percentage point.

6 Test report

The test report shall contain at least the following information:

a) Reference to this international standard;

b) Identification number of the test piece;

c) Fabrication procedures of the test piece ;

d) Test piece material:
   - in case of single crystal: crystallographic orientation,
   - in case of poly crystal: texture and grain sizes,

e) Test piece dimension and its measurement method;

f) Description of testing apparatus;

g) Measured properties and results: elastic modulus, yield strength and stress-strain curve.