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BSI Standards Publication

Semiconductor devices — Micro-electromechanical devices

Part 8: Strip bending test method for tensile property measurement of thin films

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National foreword

This British Standard is the UK implementation of EN 62047-8:2011. It is identical to IEC 62047-8:2011.

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

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Semiconductor devices - Micro-electromechanical devices - Part 8: Strip bending test method for tensile property measurement of thin films

(IEC 62047-8:2011)

Dispositifs à semiconducteurs -
Dispositifs microélectromécaniques -
Partie 8: Méthode d'essai de la flexion de bandes en vue de la mesure des propriétés de traction des couches minces
(CEI 62047-8:2011)

Halbleiterbauelemente -
Bauelemente der Mikrosystemtechnik -
Teil 8: Streifen-Biege-Prüfverfahren zur Messung von Zugbeanspruchungsmerkmalen dünner Schichten
(IEC 62047-8:2011)

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Foreword

The text of document 47F/71/FDIS, future edition 1 of IEC 62047-8, prepared by SC 47F, Micro-electromechanical systems, of IEC TC 47, Semiconductor devices, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 62047-8 on 2011-04-18.

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The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2012-01-18
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-04-18

Endorsement notice

The text of the International Standard IEC 62047-8:2011 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 62047-2:2006	NOTE Harmonized as EN 62047-2:2006 (not modified).
IEC 62047-3:2006	NOTE Harmonized as EN 62047-3:2006 (not modified).

CONTENTS

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 8: Strip bending test method for tensile property measurement of thin films

1 Scope

This international standard specifies the strip bending test method to measure tensile properties of thin films with high accuracy, repeatability, moderate effort of alignment and handling compared to the conventional tensile test. This testing method is valid for test pieces with a thickness between 50 nm and several µm, and with an aspect ratio (ratio of length to thickness) of more than 300.

The hanging strip (or bridge) between two fixed supports are widely adopted in MEMS or micro-machines. It is much easier to fabricate these strips than the conventional tensile test pieces. The test procedures are so simple to be readily automated. This international standard can be utilized as a quality control test for MEMS production since its testing throughput is very high compared to the conventional tensile test.

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.

NONE

3 Terms and definitions

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

3.1
deflection

w

displacement of a test piece at the middle of the length, which is measured with respect to the straight line connecting two fixed ends of the test piece

3.2
deflection angle

β

angle between the deformed test piece and the straight line connecting two fixed ends of the test piece

NOTE Test piece in this document is often referred to as a strip bending specimen.

4 Test apparatus

4.1 General

A test apparatus is composed of an actuator, a load-sensor, a displacement sensor, and alignment mechanism as other mechanical testers such as micro-tensile tester and nanoindentation apparatus. A test piece in a form of strip is very compliant and experiences large deflection under a small load when comparing it with a micro-tensile test piece with similar dimensions. In this respect, the load-sensor should have an excellent resolution and the displacement sensor should have a long measuring range. Details on each component of test apparatus are described as follows.

4.2 Actuator

All actuating devices that are capable of linear movement can be used for the test, e.g. piezoelectric actuator, voice coil actuator, servo motor, etc. However, a device with fine displacement resolution is highly recommended due to small dimensions of the test piece. The resolution shall be better than 1/1 000 of maximum deflection of test piece.

4.3 Load tip

The load tip which applies a line contact force to the test piece is shaped like a conventional wedge type indenter tip and can be made of diamond, sapphire or other hard materials. The radius of the tip shall be comparable to or larger than the thickness of the test piece, and less than $L/50$ (refer to Annex C.3).

4.4 Alignment mechanism

The load tip shall be installed on the test apparatus aligned with the load and the displacement measuring axes, and the misalignment shall be less than 1 degree. The load tip shall be also aligned to the surface of the test piece with the deviation angles less than 1 degree (refer to Annex C for definition of deviation angles and error estimation of misalignment). It is desirable to equip the apparatus with tilt stages for adjusting the deviation angle. The load tip is to be positioned at the centre of the test piece and the positional accuracy shall be less than $L/100$.

4.5 Force and displacement sensors

Force and displacement sensors shall have resolutions better than 1/1 000 of the maximum force and deflection during the test. The accuracy of the sensors shall be within ± 1 % of the range. The displacement sensors can be capacitive type, LVDT type, or optical type with acceptable resolution and accuracy. In practice, the deflection can be measured from the motion of the load tip using a capacitive sensor or from the deflection of the test piece using an optical method.

4.6 Test environment

It is recommended to perform a test under constant temperature and humidity. Temperature change can induce thermal drift during deflection measurement. The temperature change or thermal drift shall be checked before and after the test.

5 Test piece

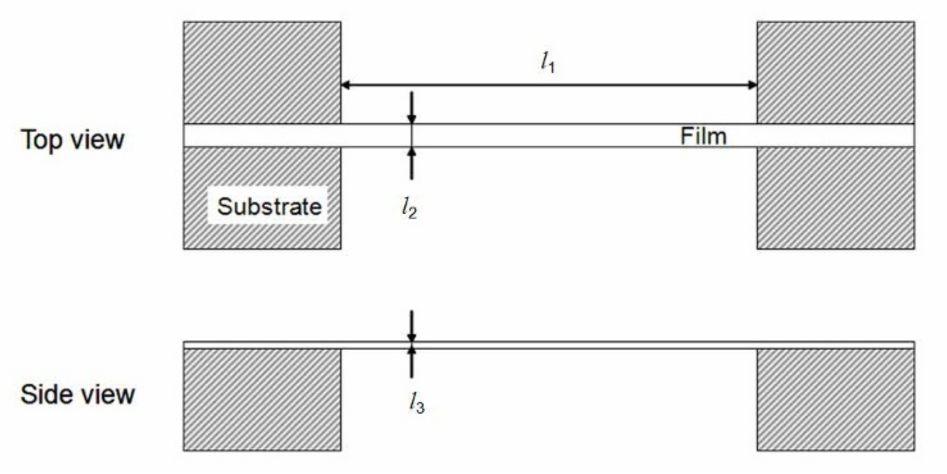
5.1 General

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 shall be similar to those of the device components.

There are many fabrication methods of the test piece depending on the applications. As an example, the fabrication of the test piece based on MEMS process is described in Annex B. A lot of strip bending test pieces can be fabricated on a die or a substrate.

5.2 Shape of test piece

The shape of test piece and symbols are given in Figure 1 and Table 1, respectively. The test piece shall be designed to minimize the bending moment effect. In order to minimize the effect, the maximum deflection shall be more than 40 times the thickness of the test piece, and the length of the test piece shall be more than 300 times the thickness of the test piece, and the width shall be more than 10 times the thickness of the test piece, and the length shall be 10 times larger than the width. The thickness of the substrate shall be more than 500 times that of the test piece. The dimension of the substrate is limited by the capacity of the test apparatus. The geometry of the fixed ends supporting the test piece can affect the test results. When etching the sacrificial layer and the supporting substrate of test pieces, the region beneath the test pieces can be over-etched, and this is called by under-cut. The under-cut at the fixed ends shall be minimized (anisotropic etching would be desirable rather than isotropic etching).



IEC 499/11

Figure 1 – Thin film test piece

Table 1 – Symbols and designations of a test piece

Symbol	Unit	Designation
l_1	µm	Length of a test piece (=$2L$)
l_2	µm	Width of a test piece (=B)
l_3	µm	Thickness of a test piece (=h)

5.3 Measurement of test piece dimension

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 length ($2L$), width (B), and thickness (h) shall be measured with very high accuracy with less than ± 5 % error. Useful information on thickness measurement can be found in Annex C of [1] [1] and in Clause 6 of [2].

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

6 Test procedure and analysis

6.1 General

a) The substrate containing test pieces is attached to a sample holder. There are some recommendable methods for the sample attachment, such as magnetic attachment, electrostatic gripping, adhesive gluing, etc.

b) The translational and angular misalignment between the load tip and the test piece can affect the test results (refer to Figure C.2), and should be checked using an optical microscope. The misalignment error and the guideline for alignment are described in Annex C.

c) It is necessary to determine surface location of a test piece at the beginning of the test. The surface location is the position of the top surface of the test piece in the vertical direction when the strip deforms by the vertical movement of the load tip. This surface location can be determined by optical inspection using an optical microscope, or be determined by three successive indents. When the load tip touches the strip, the slight change in the strip configuration can be observed and identified using the optical microscope. The detailed method for determining the surface location using three successive indents is described in A.3.

d) The test is performed under a constant displacement rate until the strip ruptures. The displacement rate of $L\times10^{-4}/s$ or $L\times10^{-3}/s$ is recommended, which leads to the strain rate of approximately $1\times10^{-5}/s$ or $1\times10^{-4}/s$, respectively when the strain reaches 0,5 %. This method applies to strain rate insensitive materials since the strain rate changes during the test.

6.2 Data analysis

To obtain an actual force and deflection data of a test piece from the experimental results, several compensations may be required depending on the test apparatus. As an example, the data analysis procedures are described in Annex A for the case of a nanoindentation apparatus. These procedures can provide useful information for other types of apparatus. From the force and deflection measurements, stress and strain can be estimated by the following Equations (1) and (2). The equations are derived on the assumptions of negligible bending moment effect and uniform strain throughout the test piece [1-3]. See Figure 2.

$$\sigma = \frac{F}{2Bh\sin\beta}, \tag{1}$$

$$\varepsilon = \frac{\sqrt{L^2 + w^2}}{L} - 1. \tag{2}$$

Here, σ is the strip stress, ε is the strip strain, *F* is the force applied to a test piece during test and *w* is its corresponding deflection, β is defined as $\tan^{-1}(w/L)$. When L/h is larger than 300, these equations yield an excellent estimation of elastic modulus and yield strength as verified in Annex C. The effect of internal stress or residual stress could be considered with this method. When the internal stress exists, "F" in the equation (1) is affected by the internal stress and the strip stress changes also. The buckled test piece is excluded in this standard.

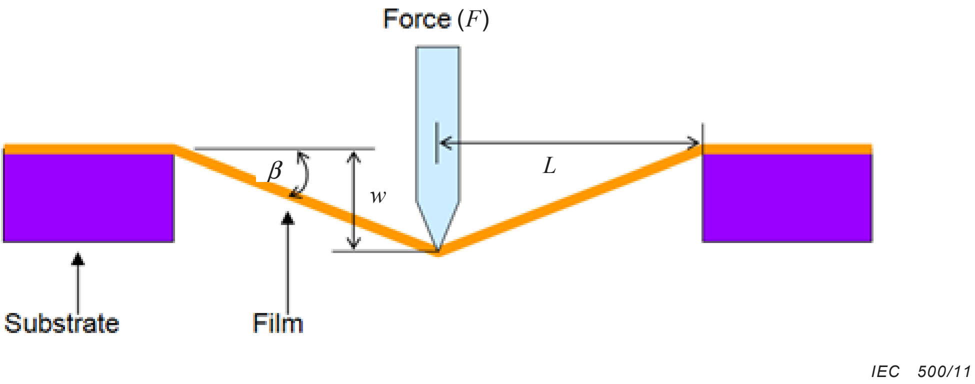


Figure 2 – Schematic of strip bending test

7 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 measurement method;
f) description of testing apparatus;
g) measured properties and results: elastic modulus, tensile strength, yield strength and stress-strain curve.

Annex A
(informative)

Data analysis: Test results by using nanoindentation apparatus

A.1 Cause of errors

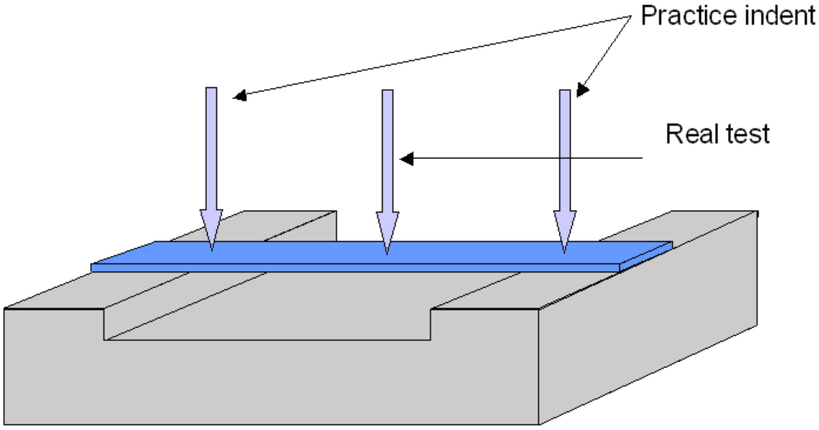
Thermal drift, difficulty of finding the surface location of the test piece and leaf spring stiffness of test apparatus can affect the test results.

A.2 Thermal drift compensation

Thermal drift is a common cause of error for a precise sensor measurement. This error is regarded as the result of thermal fluctuation from the test system. To measure thermal drift, the deflection is recorded for a period of time under a load controlled condition while a test piece is in contact with the wedge tip. Using the drift data, the deflection data of the strip bending test are corrected. This is a common compensation method of a nanoindentation test. Since the creep deformation is not clearly distinguished from the thermal drift, this compensation is not used in case of a test piece with creep behaviour.

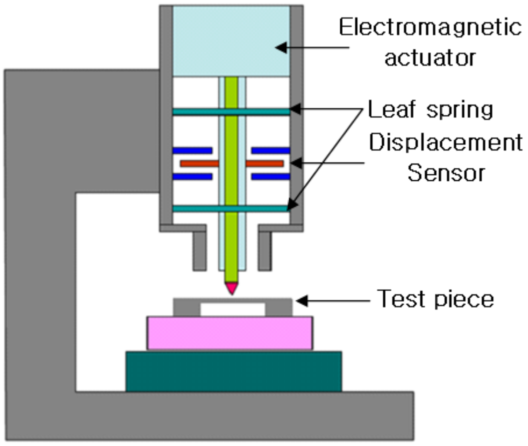
A.3 Determination of surface location

Finding the surface location of a test piece is very difficult since the stiffness change is too small to detect when the wedge tip is in contact with the test piece. As an alternative method, the surface locations of the two fixed strip ends to substrate are measured and the average value of the surface locations is taken as the surface location of the strip. See Figure A.1. This method can determine a reference surface location even for a wrinkled film caused by compressive residual stress. The deflection of a test piece is measured from that reference surface location.



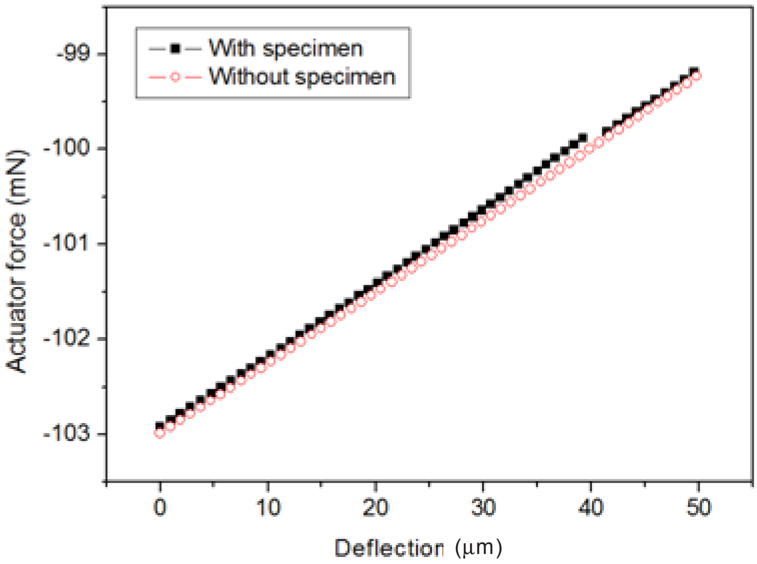
IEC 501/11

Figure A.1 – Three successive indents for determining the reference location of a test piece



IEC 502/11

Figure A.2 – A schematic view of nanoindentation apparatus



IEC 503/11

NOTE The test piece is Au film with a thickness of 0,1 µm, a width of 10 µm, and a length of 400 µm.

Figure A.3 – Actuator force vs. deflection curves for strip bending test and for leaf spring test

A.4 Leaf spring stiffness compensation

Many commercial nanoindenation systems are utilizing a leaf spring to achieve a highly repeatable linear motion. See Figure A.2. This apparatus applies a force on a test piece by controlling the electric current supplied to the electromagnetic actuator. The actuator force is obtained from the electric current multiplied by load calibration constant. The actual force on a test piece can be determined by subtraction of the force for the leaf spring deformation from the actuator force. The leaf spring force can be measured by moving actuator without any test piece. This is represented by the open circle curve in Figure A.3. In order to compensate for the leaf spring force, the force-deflection data without a test piece are subtracted from the force-deflection data with a test piece (the filled square curve in Figure A.3). The actual force signal on a strip can be determined by this procedure. See Figure A.4. The detailed information on the data analysis can be found in [3], [4] and [5].

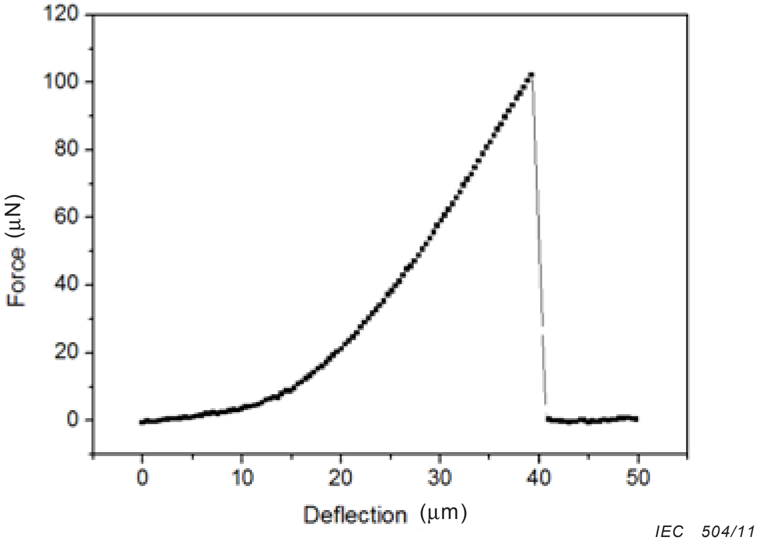


Figure A.4 – Force vs. deflection curve of a test piece after compensating the stiffness of the leaf spring

Annex B
(informative)

Test piece fabrication: MEMS process

B.1 Test piece fabrication

MEMS processes are possible candidates for fabricating the test piece. Several types of MEMS process can be developed depending on the test materials and the devices. Figure B.1 introduces one example among the various MEMS processes. Detail descriptions are given below.

a) deposit oxide film on a Si wafer.

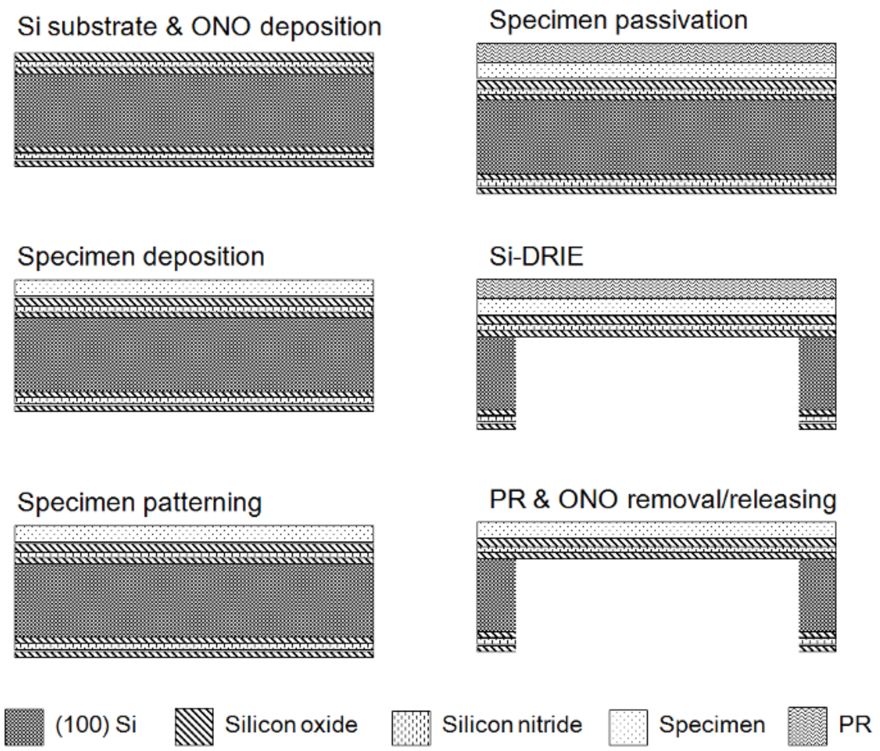
b) deposit a thin film of the test material on the oxide film. Au, Mo, SiNx can be used as a test material. A glue layer may be deposited to improve adhesion between oxide film and thin film. The thickness of the glue layer must be carefully chosen to minimize its stiffness effect on the measurement.

c) pattern the metal film to define the shape of a test piece. The patterning is done by a photolithography process.

d) protect the patterned test piece by oxide or photoresist passivation layer.

e) to make freestanding films, Si substrate is etched from back side by using deep RIE.

f) freestanding film is obtained by removing photoresist and oxide.



IEC 505/11

Figure B.1 – Fabrication procedure for test piece

B.2 Measurement of shape of test piece

The shape of test piece can be measured by various methods. Stylus profilers or AFM (atomic force microscope) can be used to measure the thickness of a test piece. The width and length of a test piece are measured by electron microscope or even optical microscope. In case of a wrinkled film caused by compressive residual stress, the length between the fixed ends of strip to substrate is taken as the length of a test piece.

Annex C
(informative)

Effect of misalignment and geometry on property measurement

C.1 Background

The results obtained by the strip bending test can be affected by several error sources. Some of them are the geometry of a test piece and others are translational and angular misalignments. Using finite element simulation, the effects of these error sources are estimated, and useful guidelines for the test are suggested. The test piece has three length parameters, length, width and thickness. The effects of these parameters are estimated under perfect alignment in terms of the error in elastic modulus and yield strength. The errors due to the translational and angular misalignments are estimated. The details on the simulation can be found in [6].

C.2 Finite element analysis

Three-dimensional finite element models are generated for the strip bending test pieces and are simulated using commercial finite element software, such as e.g. ABAQUS. By performing a mesh convergence study, the suitable finite element model is selected, which gives a convergent numerical solution. The material properties are adopted from the tensile test results [7] of Au thin film with a thickness of 1 μm, and the constitutive models for the simulation are elasticity and incremental plasticity. Using the finite element simulation, the force and deflection data for a test piece are extracted, and the corresponding stress and stress data are evaluated using the equations in 4.2. Elastic modulus and yield strength (0,2% offset) can be calculated from the evaluated stress-strain data. The error is estimated from the difference between the calculated ones and the simulation inputs.

C.3 Analysis results

The errors in elastic modulus and yield strength under perfect alignment are estimated from the finite element analysis and are plotted in Figure C.1. As the increase in length/thickness ratio, the errors in elastic modulus and yield strength decreases, and the estimated properties are a little less than the actual properties. When the length/thickness ratio is larger than 300, the errors become less than 1 %.

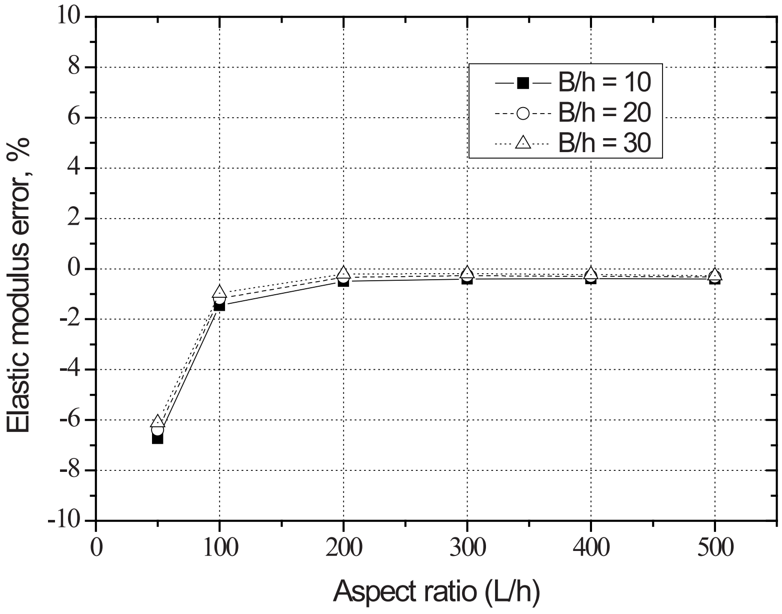


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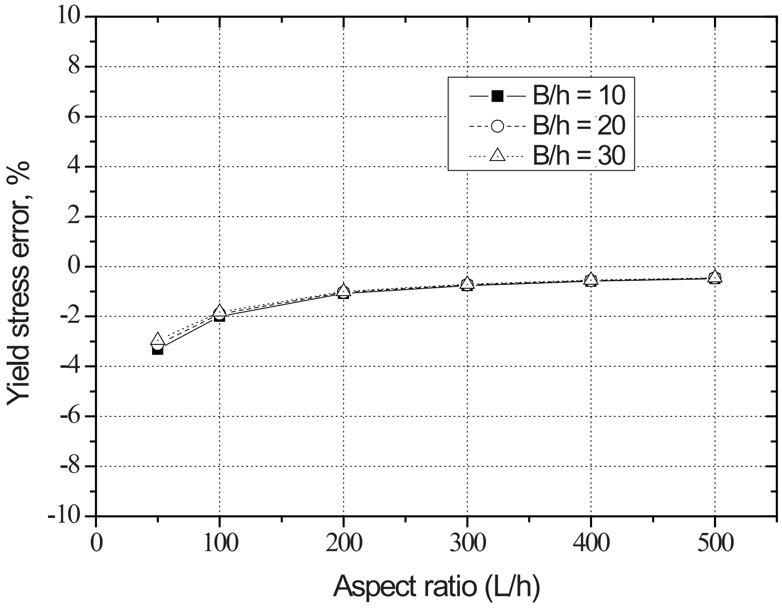
Figure C.1a) Finite element analysis of errors in elastic modulus with respect to aspect ratio (= length/thickness)



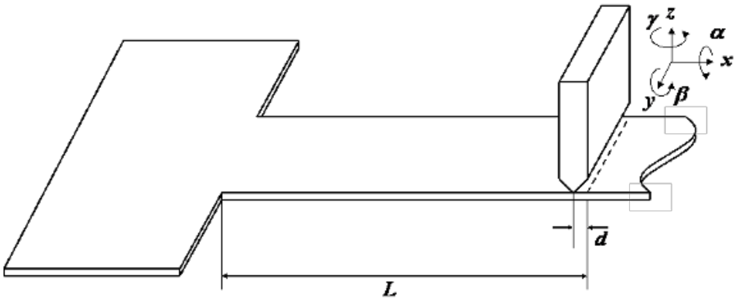
IEC 507/11

Figure C.1b) Finite element analysis of errors in yield strength evaluation with respect to aspect ratio (= length/thickness)

Figure C.1 – Finite element analysis of errors based on the constitutive data of Au thin film of 1 µm thick

The translational and angular misalignments are also analyzed for the configuration shown in Figure C.2. Based on the simulation results, it is found that the effect of the translational misalignment (d) on elastic modulus and strength is less than 0,1% when d is less than L/100. Among the angular misalignments, α has the most significant effect on the results, and the error caused by α increases as the width, B. When B/h is 10 and α is less than 1 degree, the errors in elastic modulus and yield strength is less than 0,5 %. The effects of β and γ on the elastic modulus and yield strength is less than 0,1 % when they are less than 1 degree.

The effect of the load-tip radius on elastic modulus and strength evaluation is also estimated. As the radius increases, the errors in elastic modulus and strength also increase. The error in strength grows faster than that in elastic modulus. When the radius is less than L/50, the errors are less than 0,5 %.



IEC 508/11

Figure C.2 – Translational (d) and angular (α, β, γ) misalignments

Bibliography

[1] IEC 62047-2:2006, *Semiconductor devices – Micro-electromechanical devices – Part 2: Tensile testing method of thin film materials.*

[2] IEC 62047-3:2006, *Semiconductor devices – Micro-electromechanical devices – Part 3: Thin film standard test piece for tensile testing.*

[3] Espinosa, H. D., Prorok, B. C., Fisher, M., *A methodology for determining mechanical properties of freestanding thin films and MEMS materials*, Journal of the Mechanics and Physics of Solids, Vol. 51 (2003), pp. 47-67.

[4] Baek, C. W., Kim, J. M., Kim, Y. K., Kim, J.-H., Lee, H.-J., Han, S.-W., *Mechanical Characterization of Gold Thin Films Based on Strip Bending and Nanoindentation Test for MEMS/NEMS Applications,* Sensors and Materials, Vol. 17 (2005), pp. 277-288.

[5] Kim, J.-H., Lee, H.-J., Han, S.-W., Kim, J. M., Baek, C. W., *Residual Stress Evaluation of Thin Film Using Strip Bending Test, Key Engineering Materials*, Vols. 321-323 (2006), pp. 121-124.

[6] Park, J.-M., Kim, J.-H., Lee, H.-J., *A study on error sources of strip bending test using finite element analysis*, Proc. of KSPE 2007 fall meeting (2007).

[7] Lee, S.-J., Hyun, S.-M., Han, S.-W., Lee, H.-J., Kim, J. H., Kim, Y. I., *A Study of Mechanical Behavior of Au Films by Visual Image Tracing System*, Advanced Materials Research, Vols. 26-28 (2007), pp. 1117-1120.

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