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INTERNATIONAL STANDARD

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Semiconductor devices – Micro-electromechanical devices –
Part 17: Bulge test method for measuring mechanical properties of thin films

Dispositifs à semiconducteurs – Dispositifs microélectromécaniques –
Partie 17: Méthode d'essai de renflement pour la mesure des propriétés mécaniques des couches minces

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SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

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

FDIS	Report on voting
47F/210/FDIS	47F/215/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 in 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- withdrawn,
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SEMICONDUCTOR DEVICES –
MICRO-ELECTROMECHANICAL DEVICES –

Part 17: Bulge test method for measuring mechanical properties of thin films

1 Scope

This part of IEC 62047 specifies the method for performing bulge tests on the free-standing film that is bulged within a window. The specimen is fabricated with micro/nano structural film materials, including metal, ceramic and polymer films, for MEMS, micromachines and others. The thickness of the film is in the range of 0,1 µm to 10 µm, and the width of the rectangular and square membrane window and the diameter of the circular membrane range from 0,5 mm to 4 mm.

The tests are carried out at ambient temperature, by applying a uniformly-distributed pressure to the testing film specimen with bulging window.

Elastic modulus and residual stress for the film materials can be determined with this method.

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

3 Terms, definitions and symbols

3.1 Terms and definitions

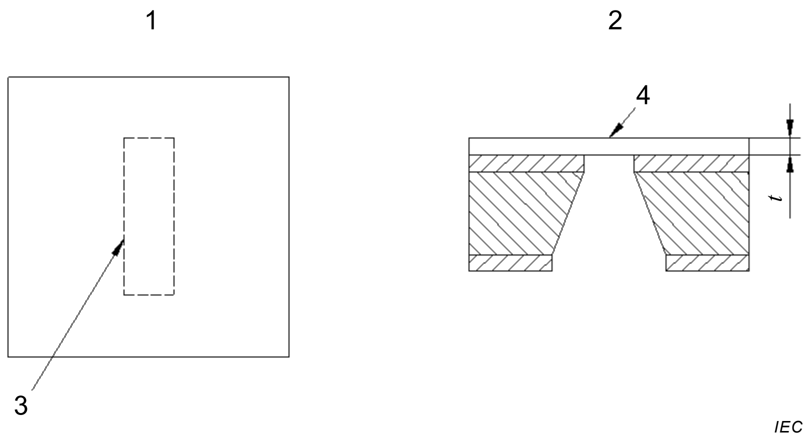
For the purposes of this document, the following terms and definitions apply.

3.1.1
residual stress
σ_0
stress which exists in a specimen in the absence of an external load

3.1.2
biaxial modulus
M
elastic modulus in plane strain condition

3.1.3
membrane window
testing area, contacted directly with the pressure media and surrounded by a frame, in the free standing film specimen

Note 1 to entry: See Figure 1.



Key

1	top view	2	side view
3	membrane window	4	thin film deposited

Figure 1 – Typical example of bulge specimen

3.2 Symbols

The symbols used in this document are presented in Table 1 below.

Table 1 – Symbols and designations of a specimen

Symbol	Unit	Designation
t	µm	thickness of a membrane or thin film
R	µm	radius of a bulged membrane window
h	µm	maximum vertical displacement at the centre of the bulged window
d	mm	diameter in a circular window
a,b	mm	half-width and half-length of the rectangular window, respectively. In case of square window, a equals to b.
p	MPa	differential pressure applied to the membrane window
C_1, C_2		coefficients in generalized linear-elastic bulge equation

4 Principle of bulge test

Nominally free-standing film specimen with a frame surrounding a bulging membrane window as shown in Figure 1 is required and it should be mounted on a bulge testing system which can apply differential pressure to the specimen. Here, the pressure should be uniformly distributed over the film in the window and loaded to the film in a constant and relatively static rate. The geometry of the membrane window can be circular, square and rectangular shape.

NOTE 1 With selection of window geometry, analysis for determining stress and strain of the bulged film is performed with different models, i.e. a spherical or a cyclindrical pressure vessel model.

The film, subjected to the differential pressure, over the window deforms in the out-of-plane bulged form. By measuring the height, h, and pressure, p, from the bulged window, as presented in Figure 2, pressure-deflection response and/or stress-strain relationship is obtained through analysis model which can be chosen. The mechanical properties of the film, such as elastic modulus and residual stress, can be determined with the pressure-deflection curve or stress-strain curve.

NOTE 2 The details of the analytic models are described in Annex A.

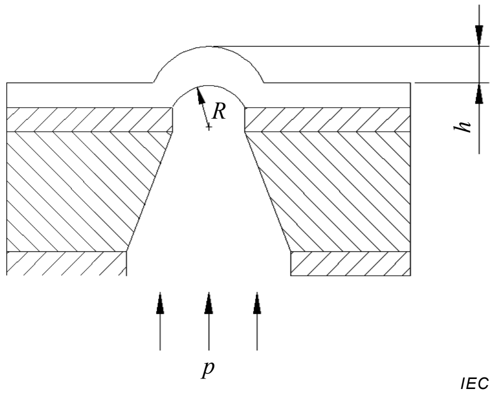
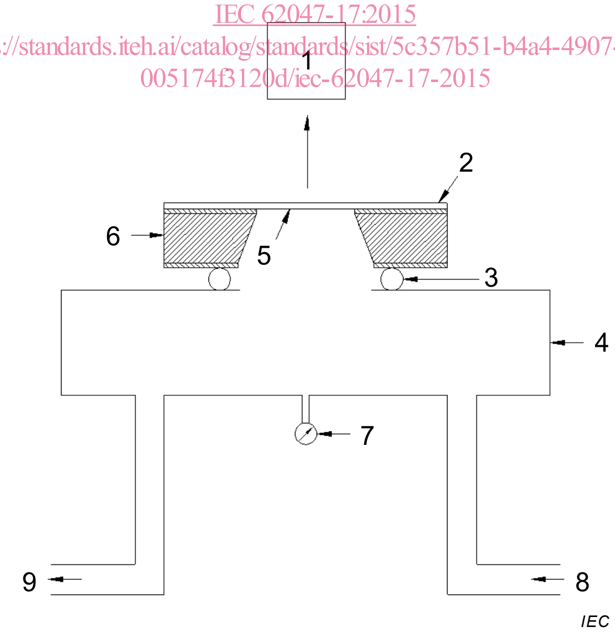


Figure 2 – Membrane window bulged by pressure

5 Test apparatus and environment

5.1 General

With applying pressure to the specimen, deformation response, i.e. change in bulge height, in the membrane window shall be measured. In general, bulge test apparatus can be composed of pressuring device, specimen holder and bulging height measurement units as shown in Figure 3.



Key

1 deflection measurement system
2 specimen
3 O-ring
4 pressure chamber
5 membrane window
6 substrate
7 pressure gauge
8 inlet
9 outlet

Figure 3 – Typical example of bulge test apparatus

5.2 Apparatus

5.2.1 Pressuring device

Pressuring device should be equipped to apply a specified continuous pressure with a controlled rate or a certain level of pressure to the membrane window to be bulged. Pressure media can be oil, gas and distilled water. In general, the device can be composed of a pressure sensor and pressure controller. The controller should be with accuracy of 1 % in full test scale.

NOTE At the pressures encountered in the tests, gas is over a million times more compressible than typical liquids such as oil and distilled water.

5.2.2 Bulge (pressure) chamber

The pressure chamber should be as compact as possible, to reduce the compliance of the test system. The volume, which has to be pressurized and which potentially contributes to the compliance, would be minimized.

In the case liquid is used to pressurize the test system, the system contains as little air as possible because even a small air bubble trapped inside the test system can dominate the system's compliance. It is recommended that the system including the chamber be designed so that there are no places where air bubbles can hide and that the liquid can be refilled easily. Special care shall be taken not to introduce air bubbles when samples is mounted and removed.

The material of the chamber should be chosen considering the pressure media for the test and testing pressure range.

In the case liquid is used to pressurize the test system, it is recommended that the testing apparatus be made out of transparent acrylic sheet in order to see air bubbles and then to minimize them trapped within the chamber.

The bulge chamber is connected to the pressurizing device and thus allows a specimen to be deformed with fine control. The specimen is mounted on the bulge chamber by mechanical clamping or epoxy gluing method, etc.

NOTE In the case of capacitance measurement type, the bulge chamber has an electrode and a mechanical spacer. The electrode, which measures height change of a bulge specimen due to the deformation, is made of copper-coated PCB. A mechanical spacer that is located between the specimen and the electrode controls a sensitivity of capacitance change by adjusting thickness of the spacer.

The pressure inside the chamber shall be monitored and measured through suitable pressure sensor which can be installed directly to the chamber or connected though tube transporting the pressure without loss of the pressure to be measured.

It is recommended that exposition of the area of the pressure sensor to the pressure media should be minimized and it has no indentation or internal cavities trapping air.

Nonlinearity and hysteresis of the pressure sensor is recommended to be less than 0,5 % and be calibrated according to the pressure standard established in each country as a National Standard.

5.2.3 Height measurement units

The height measurement unit should be installed in a position suitable to measure the deformation of the membrane window and have a function of a continuous measurement which is needed in order to determine the maximum deformation of the membrane window bulged with applying pressure. The maximum deformation of the membrane window can be determined from the measurement in full-field or top of the bulged area using the laser interferometric system or capacitance type measurement system, which is described in detail in Annex B.

The resolution of the measurement device for the deflection measuring a bulged membrane window by pressure should be in units of micrometer. The fine resolution of less than 0,1 % in full scale is very important for an accurate measurement.

5.3 Test environment

It is recommended to perform a test under constant temperature and humidity. Temperature change can induce thermal drift during deflection measurement. Temperature change during the test should be less than 2 °C.

6 Specimen

6.1 General

The film materials used in the specimen shall be prepared by using the same fabrication process as the actual device or materials fabrication.

There are many fabrication methods of the test piece depending on the applications. As an example, the fabrication of the specimen with a frame is described in Annex B.

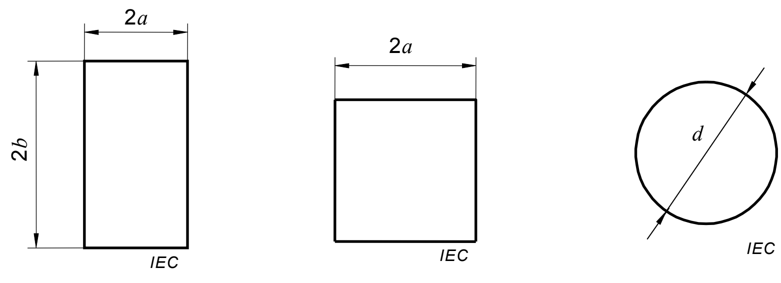
The film specimen without a frame can be prepared from the electroplating process.

6.2 Shape and dimension of specimen

The shapes of membrane windows can be rectangle, square and circle as shown in Figure 4. Membrane window is surrounded with a thick substrate frame or frame jig which is not deformed by pressure.

It is recommended that the half-width, a, of the rectangular and square membrane window and the diameter, d, of the circular membrane be in the range from 0,5 mm to 4 mm.

In the case of rectangular window, the aspect ratio of length to width in a rectangular membrane window is recommended to be equal to or greater than 4 due to plane strain condition.



a) rectangular b) square c) circle

Figure 4 – Bulge membrane window shapes

6.3 Measurement of test piece dimension

To analyze the test results, the accurate measurement of the test piece dimension and pressure is required since the dimensions are used to extract mechanical properties of test materials. The thickness (t) and dimension of the window (width and length or diameter) should be measured with very high accuracy with less than ±1 %. Special cares should be taken to measure the window size by clearly dividing the window boundary.

The methods for measuring film thickness and accuracy given in Clause C.3 of IEC 62047-2:2006 apply.

Special care should be taken to avoid damage on the specimen during the measurement.

7 Test procedure and analysis

7.1 Test procedure

The test procedure is as follows:

a) The bulge specimen should be attached to the bulge chamber in an appropriate method, such as mechanical clamping or epoxy gluing method etc., not to cause unwanted stress, such as bending, shear or combined stress, or in-plane distortion on the membrane.

   It is desired to test considering clamping effect on the change in the bulge height. Hard clamping on the specimen often causes residual stress on a membrane window. However, to avoid pressure leakage in the bulge chamber, proper sealing method is required for the test.

   The specimen can be mechanically clamped to the chamber with screws. In general, specimen holder to which the specimen would be attached is screwed tightly on to the chamber. To prevent any leakages, an O-ring between the specimen holder (or specimen) and the chamber can be used. Special care is required to be taken in positioning the O-ring on the chamber to avoid offset of bulge height.

   NOTE 1 The specimen or specimen holder can be also attached to the chamber using epoxy with sufficient adhesive strength.

b) To obtain quasi-static deformation of the film, pressure should be carefully controlled to increase or decrease monotonically. The strain rate imposed on the test should be ranged from 10^{-7}/s to 10^{-2}/s.

c) The test should be performed within the appropriate deformation of the bulge specimen; it is recommended that the deformation should not be over 0,5 % and 2 % of strain for linear elastic and elastic-plastic materials, respectively. The pressure-height curve obtained from the test can be plotted as shown in Figure 5(a).

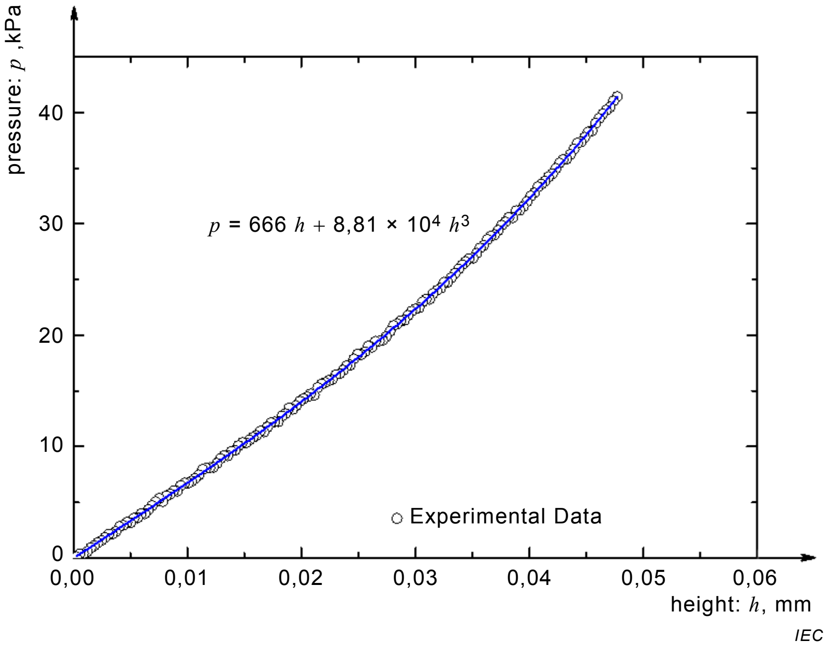
d) In case the elastic modulus would be determined from stress-strain curve, some de-pressurizing steps during pressurizing can be applied. The de-pressurizing steps should be provided at the well-timed instants and preferably at even intervals during pressurizing process, as shown in Figure 5(b). It is recommended that the minimum pressure at each de-pressuring step be greater than 50 % of the pressure level at the instant the de-pressuring step starts.

   The slope shall be determined from the linear stress-strain response obtained during de-pressurizing step. Here, the slope means the biaxial elastic modulus of the film, M. See Annex A.2.

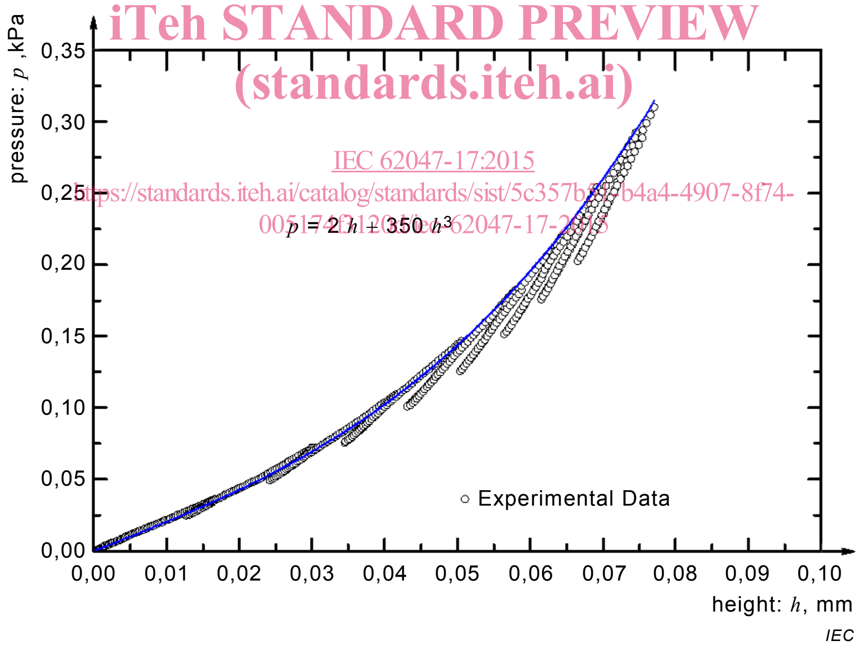
   Special care should be taken to avoid cyclic effect on the mechanical property of the film with excessively repeating the de-pressurizing steps.

   NOTE 2 Average values in modulus can be determined by reasonably repeating pressuring and depressurizing steps.

e) During test, the pressure and deformation in the window should be precisely measured simultaneously.



a) for elastic film



b) for elastic-plastic material

Figure 5 – Example of typical pressure-height curve obtained from bulge test

7.2 Data analysis

The mechanical properties are determined according to two methods.

– Fitting method in pressure and height curve;

– Calculation in stress and strain curve.

Detailed analysis procedures are described in Annex A.

8 Test report

The test report should contain at least the following information:

a) references to this International Standard;
b) identification number of the specimen;
c) fabrication procedures of the specimen;
d) specimen material;
e) shape and dimension of the specimen and window;
f) measurement method;
g) description of testing apparatus;
h) pressure-deflection relationship;
i) measured properties and results: elastic modulus and residual stress, pressure-deflection curve (if used).