# IEC 62951-1

Edition 1.0 2017-04

# INTERNATIONAL STANDARD

colour inside

## Semiconductor devices – Flexible and stretchable semiconductor devices – Part 1: Bending test method for conductive thin films on flexible substrates



IEC 62951-1:2017-04(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.080.99

ISBN 978-2-8322-3896-7

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

| FDIS | Report on voting |
|---|---|
| 47/2369/FDIS | 47/2384/RVD |

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62951 series, published under the general title *Semiconductor devices – Flexible and stretchable semiconductor devices*, can be found on the IEC website.

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# SEMICONDUCTOR DEVICES – FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

# Part 1: Bending test method for conductive thin films on flexible substrates

## 1 Scope

This part of IEC 62951 specifies a bending test method to measure the electromechanical properties or flexibility of conductive thin films deposited or bonded on flexible non-conductive substrates. Conductive thin films on flexible substrates are extensively used in flexible electronic devices and flexible semiconductors. Conductive thin films include any films deposited or bonded onto a non-conductive flexible substrate such as thin metal film, transparent conducting electrode, and thin silicon film. The electrical and mechanical behaviours of thin films on flexible substrates differ from those of freestanding films and substrates due to their interfacial interactions and adhesion between the film and substrate. The object of this standard is to establish simple and repeatable test methods for evaluating the electromechanical properties or flexibility of conductive thin films on flexible substrate. The bending test methods include outer bending test and inner bending test.

## 2 Normative references



The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 62047-2:2006, *Semiconductor devices – Micro-electromechanical devices – Part 2: Tensile testing method of thin film materials*

IEC 62047-22:2014, *Semiconductor devices – Micro-electromechanical devices – Part 22: Electromechanical tensile test method for conductive thin films on flexible substrates*

## 3 Terms, definitions and symbols

### 3.1 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

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

**3.1.1**
**bending radius of curvature**
$r$
radius of curvature that the test piece shows in bending test

**3.1.2**
**critical bending radius**
bending radius at which the electrical resistance starts to exceed a predefined limit, and/or fracture of the film caused by delamination or initiation of the cracks occurs

Note 1 to entry: It is the minimum bending radius that conductive thin films can tolerate.

**3.1.3**
**nominal bending strain**
$e$
strain in the center of the bent test piece in the bending direction

Note 1 to entry: Generally it is referred to the strain at the top of the bent film on flexible substrate.

**3.1.4**
**flexible substrate**
substrate with flexibility onto which conductive thin films will be deposited, bonded or attached

**3.1.5**
**gauge factor**
$G_F$
ratio of the change in electrical resistance divided by the original resistance ($R_O$, resistance in the undeformed configuration) to nominal bending strain ($e$)

Note 1 to entry: Gauge factor is expressed as $G_F = (R - R_O)/ R_O e$, where $R$ is the electrical resistance in the deformed configuration.



[SOURCE: IEC 62047-22: 2014, 3.1.1, modified – The word "engineering" has been replaced by "nominal bending" in the definition.]



**3.1.6**
**outer bending test**
outward bending test
face-out bending test
convex bending test
test, where the test piece is bent into a convex shape (∩) which may also be considered as an outward bending test, face-out bending test or convex bending-test

**3.1.7**
**inner bending test**
inward bending test
face-in bending test
concave bending test
test, where the test piece is bent into a concave shape (∪) which may also be considered as an inward bending test, face-in bending test or concave bending-test

## 3.2 Symbols and designations

The shape of the test piece and symbols are presented in Figure 1 and Table 1, respectively. The overall shape of the test piece is similar to the shape shown in 3.2 of IEC 62047-22:2014 for tensile tests. But the shape of the test piece can be rectangular or square. The test pieces has a flexible substrate and the conductive thin film deposited on the flexible substrate.

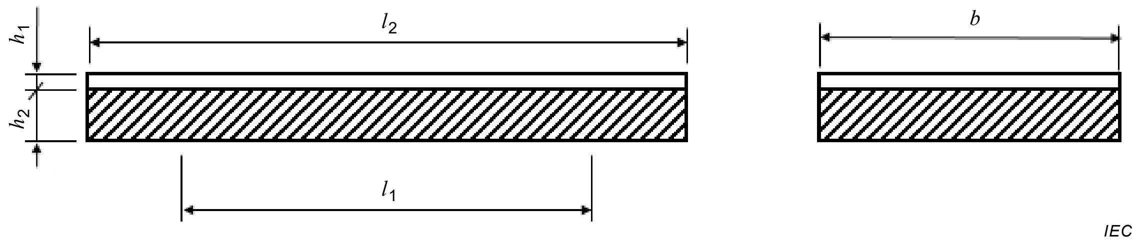


**Figure 1 – Shape of a test piece**

**Table 1 – Symbols and designations of a test piece**

| Symbol | Unit | Designation |
|---|---|---|
| $l_1$ | mm | Gauge length for strain and resistance change measurements |
| $l_2$ | mm | Overall length |
| $h_1$ | µm | Thickness of the conductive thin film |
| $h_2$ | µm | Thickness of the flexible substrate |
| $b$ | mm | Width |

## 4 Test piece



### 4.1 Design of test piece

In order to minimize the influence of geometric size the test piece shall be reasonably similar to the final product. In particular, the size effect of the thin brittle films on failure is substantial due to the randomly distributed cracks or defects on the test piece. Therefore, the dimension of the test piece should be as much as possible of the same order as that of the objective device component. The shape of a test piece is shown in Figure 1. For uniform strain distribution, the shape of the test piece is a rectangular or square strip.



### 4.2 Preparation of a test piece

The test piece shall be prepared using the same fabrication process as the real device fabricated for flexible electronics and flexible semiconductor devices, because the mechanical and electrical properties depend on the fabrication processes. Both the film thickness and substrate thickness should be uniform and small compared with the lateral dimensions. The flexible substrate and film have also the uniform material properties. Thin conductive film shall be carefully prepared to prevent formation of cracks or flaws and delamination from the substrate.

### 4.3 Measurement of dimensions

The thickness and width of the conductive thin film and flexible substrate shall be accurately measured respectively, because the dimensions are used to determine the mechanical and electrical properties of test materials. Each test piece should be measured directly. Both the dimension of the test piece shall be specified within the maximum error of ± 1 % for the thickness and ± 5 % for the width, respectively. Thickness measurement shall be performed according to Clause 4 and Annex C of IEC 62047-2:2006. There can be some combinations of thin film and substrate where it is difficult to fulfil the tolerance of thickness measurement. In this case, the average and the standard deviation of the thickness measurement should be reported.

### 4.4 Storage prior to testing

In the case of conductive thin films, the storage environment can affect the electromechanical properties of the film. For example, oxidation on the test piece surface will deteriorate the electrical and mechanical properties of the test piece. If there is an interval between final preparation and testing, particular care should be taken in storing the test pieces, and the specimens should be examined by appropriate means to ensure that the surface has not deteriorated during the storage period. If any deterioration is observed that was not present after the specimens were prepared, testing shall not be performed. However, if the damage was introduced during the preparation processes, the test shall be performed.

## 5 Testing method and test apparatus

### 5.1 General

The test is performed by bending a test piece. The bending strain induced by the tensile load shall be uniform in a pre-defined gauge section in the elastic region of the substrate or the thin conductive film. To measure the change in electrical resistance along with the change in mechanical strain, carefully select the gauge section. The gauge section for measuring mechanical strain shall be coincident with or scalable to that for measuring electrical resistance. There are several types of bending test equipments to measure the electromechanical property of conductive thin films. It is not necessary that a certain type of bending test method be preferred. As an example, X-Y-θ bending test equipment is described in Annex A.



### 5.2 Test apparatus

As shown in Figure 2, the bending tester includes the test piece holder to place a test piece, and control system in which separation distance is controlled by an actuator or motor. Use of an optical microscope is recommended to observe the existence of cracks on surface of the test piece during the test. The control system regulates the moving distance and moving speed while testing. One holder is fixed, and other holder is free to move using an actuator. For a material sensitive to stress concentration and local plastic deformation such as brittle films of inorganic and thin silicon film, it is recommended that the film should not be tightly clamped in order to prevent the local stress concentration in the clamped region. The stress concentration in the clamped region will generate the cracks or any damage on the film, resulting in film failure.



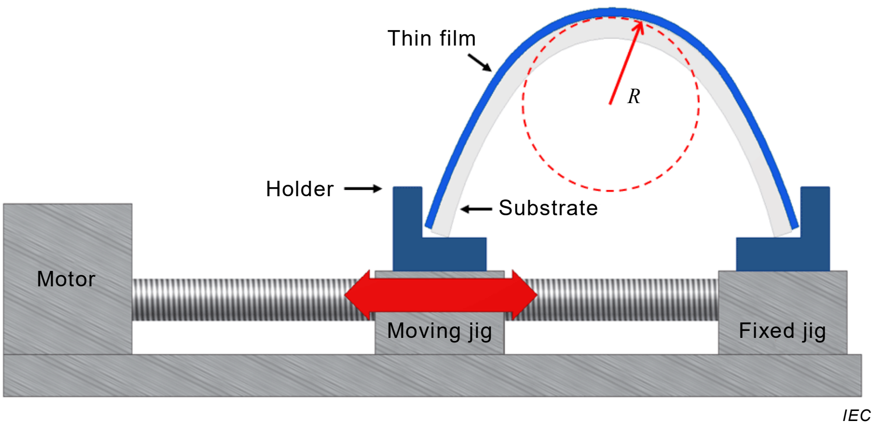


**Figure 2 – Bending test apparatus**

### 5.3 Measurement of electrical resistance

Since the change in electrical resistance is related to strain or stress, the electrical resistance shall be measured in a region of nearly uniform strain. To measure electrical resistance, attach lead wires to the conductive thin film of the test piece. The electrical measurement circuit can be a 2-wire or 4-wire method depending on the magnitude of the electrical resistance of the test piece. For a test piece with an electrical resistance greater than 1 kΩ, a 2-wire method can be utilized for ease of measurement. For a test piece with an electrical resistance less than 1 kΩ, the 4-wire method (Kelvin method) shall be utilized to eliminate contact and lead wire resistance. In a bending tester to measure the electromechanical property of conductive thin film, change rate of electrical resistance during/after the bending test is more important than the absolute value of the resistance. Therefore, 2-wire method is acceptable if the contact and lead wire resistance do not significantly influence the test results.

## 5.4 Test procedure

The test procedure is as follows:

a) Place the test piece into the holder. 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 5°. In case of outer bending test, the sample is facing upward to apply tensile stress, and in case of inner bending test, the sample is facing downward to apply the compressive stress.

b) Measure the electrical resistance of the test piece.

c) The test piece is bent with a decreasing bending radius by controlling the moving distance from flat surface to a designated bending radius. The test is performed under a constant bending stroke speed depending on the material system of the test piece and the actual usage condition of the customer. Change in electrical resistance should be measured in real time at different bending radii.



d) Unload the test piece when electrical failure occurs in the test piece or when fracture of the film caused by initiation of the cracks or delamination occurs.

NOTE In conductive thin film on flexible substrate, electromechanical property of outer bending test is generally different from that of inner bending test. That is, the critical outer bending radius is different from the critical inner bending radius for the same test piece. The difference is attributed to the internal residual stress, microstructure, and adhesion property of the film. Therefore, the outer bending test and inner bending test will be performed separately to determine the electromechanical property of the film.



## 5.5 Observation of cracks in test piece

It is recommended that the existence of cracks in the surface of test piece shall be monitored in real time or periodically with an optical microscope. Observation of the cracking on the surface during the test is important. In some cases, cracking of the film during the bending test do not lead to the electrical failure of the film. The difference between the points of cracking and electrical failure is attributed to existence of the conduction path when film debris and overlapping film due to the fracture of the film form the conduction path in the film. Therefore, the electromechanical property of the film should be evaluated not only by the electrical resistance change but also by actual occurrence of cracking, because any mechanical failure of the film can significantly deteriorate the real device performance.

## 5.6 Data analysis

To obtain the bending radius and bending strain, several compensations may be required depending on the bending test apparatus. As an example, the calculation of bending radius and bending strain for this bending test method are described in Annex B. The actual bending radius also can be measured by fitting circles to images taken using an optical camera mounted.

## 5.7 Test environment

It is recommended to perform a test under constant temperature and humidity. As the environmental conditions such as temperature and humidity affect the electrical and mechanical properties of thin films, the testing temperature and humidity shall be monitored during testing. Fluctuations in temperature during the test shall be controlled to be less than ± 2 °C. Flexible substrates made of certain polymeric materials can be sensitive to humidity;