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Dispositifs à semiconducteurs – Dispositifs à semiconducteurs souples et extensibles – Partie 4: Evaluation de la fatigue pour les couches minces conductrices souples sur les substrats pour dispositifs à semiconducteurs souples

IEC 62951-4:2019-02(en-fr)

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SEMICONDUCTOR DEVICES –
FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

Part 4: Fatigue evaluation for flexible conductive thin film on the substrate for flexible semiconductor devices

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

FDIS	Report on voting
47/2531/FDIS	47/2549/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.

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The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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SEMICONDUCTOR DEVICES – FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

Part 4: Fatigue evaluation for flexible conductive thin film on the substrate for flexible semiconductor devices

1 Scope

This part of IEC 62951 specifies an evaluation method of the bending fatigue properties of conductive thin film and flexible substrate for the application at flexible semiconductor devices. The 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 used for flexible semiconductor devices. The electrical and mechanical behaviours of films on the substrate are evaluated. The fatigue test methods include dynamic bending fatigue test and static bending fatigue 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.

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

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3.1
bending radius
radius of arc corresponding to the curvature of the central line between innermost and outermost surfaces of flexible electronic devices during a bending test

[SOURCE: IEC 62715-1-1:2013, 2.5.1, modified – The words "a flexible display device" have been replaced by "flexible electronic devices".]

3.2
critical bending radius
bending radius at which the failure of the flexible semiconductor devices occurs

Note 1 to entry: For the conductive films, the electrical resistance starts to exceed a predefined limit, and/or fracture of the film or caused by delamination or initiation of the cracks occurs, or by damage of the substrate.

3.3
flexible substrate
substrate with flexibility onto which conductive thin films will be deposited, bonded or attached

[SOURCE: IEC 62951-1:2017, 3.1.4.]

3.4
outer bending test
test, where the test piece is bent into a convex shape (∩)

Note 1 to entry: Outer bending test induces tensile stress on the film.

Note 2 to entry: There are different names of outer bending test such as outward, face-out, or convex bending test.

3.5
inner bending test
test, where the test piece is bent into a concave shape (∪)

Note 1 to entry: Inner bending test induces compressive stress on the film.

Note 2 to entry: There are different names of inner bending test such as inward, face-in, or concave bending test.

3.6
dynamic bending fatigue test
test designed for determining the bending properties of flexible semiconductor device to withstand the repeated strain for a certain period of time

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3.7
static bending fatigue test
test designed for determining the bending properties of flexible semiconductor device to withstand the same strain for a certain period of time

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Note 1 to entry: Test piece is bent at fixed bending radius for any length of time.

3.8
***S*-*N* curve**
plot of stress (S) against the number of cycles to failure

[SOURCE: IEC 62047-12:2011, 3.3, modified – The expression "plot of stress or strain" has been replaced by "plot of stress".]

3.9
ε-*N* curve
plot of strain (ε) against the number of cycles to failure

[SOURCE: IEC 62047-12:2011, 3.3, modified – The term has been modified and the expression "plot of stress or strain (S)" has been replaced by "plot of strain (ε).]

4 Test piece

4.1 Design of test piece

In order to minimize the influence of size, the test piece should have dimensions of the same order as that of the objective device component as much as possible. The shape of a test piece is based on 4.2 of IEC 62047-22:2014. 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. For uniform strain distribution, the shape of the test piece is a rectangular 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. 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 thickness and width of the test piece shall be specified within the maximum error of ± 1% for the thickness and ± 5% for the width. 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

Care should be taken on the storage environment, because for thin films and flexible substrates there is a great risk to affect the electromechanical properties of the film by the storage environment. For example, oxidation on the test piece surface will deteriorate the electrical and mechanical properties of the test piece. If there is a longer duration 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.

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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 or compressive load shall be uniform in a pre-defined gauge section in the elastic region of the substrate and the thin 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.

5.2 Test apparatus

The cyclic bending test equipment includes the clamp to hold a bending test sample, the moving part to shuttle, and control system which regulates cyclic bending number, moving distance, and moving speed while testing. Specimen should be securely clamped with gripping part during the test. Several cyclic bending test equipments are available and described in Annex A. It is not necessary that a certain type of bending test equipment be preferred. During the test, however, the test apparatus shall not cause any unintended damage to the test piece such as scratches and other defects.

5.3 Method of gripping

It is recommended that the test piece be tightly clamped. However, this should be carefully done in order to prevent local stress concentration in the clamped region. The stress concentration in the clamped region could generate some cracks or any damage on the film, resulting in failure of the film or substrate.

5.4 Bending test

The bending test of the test piece is recommended before the cyclic fatigue testing in order to determine the testing conditions such as critical bending radius and prevent too early failure of the test piece during the cyclic loading for the bending fatigue tests. For example, if the critical bending radius of the test piece is found to be 5 mm from the bending test, the use of a larger bending radius shall be recommended for the dynamic bending fatigue test.

5.5 Dynamic bending fatigue test

This test is to provide a standard procedure for determining the cyclic bending fatigue properties of flexible semiconductor devices to withstand the repeated strain for a certain period of time. This test can be performed in an outer bending mode or inner bending mode depending on the application of the films and devices.

5.6 Static bending fatigue test

This test is to provide a standard procedure for determining the bending fatigue properties of flexible semiconductor devices to withstand the same strain for a certain period of time. Each specimen is bent at fixed bending radius for a certain period of time. There are several types of bending test equipments to measure the static bending fatigue property of the semiconductor device. It is not necessary that a certain type of bending test method be preferred. Mandrel or round bar with a certain radius can be used. In order to make sure that the specimen is bent at a fixed bending radius, the specimen should be safely clamped with pressing tool or securely adhere to the test equipment.

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5.7 Bending fatigue test of flexible substrate

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The bending fatigue properties of the conductive thin films or semiconductor devices deposited on flexible substrates are influenced by the fatigue properties of flexible substrates. Therefore, the dynamic or static bending fatigue testing of the substrate itself is recommended prior to fatigue testing of the conductive thin films or semiconductor devices. Any damages, deformation, or cracks of the substrate should be carefully monitored during the bending fatigue test.

5.8 Speed of bending fatigue test

The frequency of the bending cycle will depend upon the testing environment, the type of testing machine employed, and the stiffness of the test piece. Generally, the frequency should be chosen properly depending on the application of flexible semiconductor devices. In addition, the frequency shall not heat the test piece during the application of cyclic loading due to the rapid dissipation of strain energy in the test piece. It is recommended that the frequency of the cyclic motion should be within the range from around 0,1 Hz to 1 Hz. This practice does not apply to fatigue testing of the viscoelastic films.

6 Test

6.1 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 properties such as 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. For the conductive films, change in electrical resistance should be measured in situ during test.

d) Unload the test piece when electrical failure occurs in the test piece or fracture/damage of the film or the substrate occurs.

6.2 Failure criterion (test termination)

Fatigue testing shall continue until the test piece is cracked or failed, or until a predetermined number of cycles have been applied to the test piece depending on the application of flexible semiconductor. The termination criterion (test piece fracture or predetermined number of cycles) shall be described in the test report.

6.3 Test environments

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; thus, the change in relative humidity (RH) in the testing laboratory shall be controlled to be less than ± 5 % RH for such materials. When the tests are completed, the environmental conditions should be recorded.

6.4 Recorded data

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The failure of the specimen shall be recorded. *S*-*N* curve is generally used for fatigue life prediction. However, for the bending fatigue test of flexible semiconductor devices, ε (strain)-*N* curve or critical bending radius-*N* curve can be more appropriate for the bending fatigue test.

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7 Test report

The test report shall contain the following information.

a) Mandatory
   1) Test piece material and substrate material
   2) Test piece preparation procedures
   3) Test piece dimensions and their measurement method
   4) Description of the testing apparatus;
   5) Fatigue test conditions
      – bending radius
      – speed of the test
      – testing environments (temperature and relative humidity)
      – bending mode (outer or inner bending)
   6) Fatigue test result
      – Fatigue life (S-N, or ε-N, and critical bending radius-N) curve. If the test piece is not fractured during a predetermined number of cycles, the number of cycles and the description “no failure” should be noted.
      – Change of electrical resistance

b) Optional
   1) Internal residual stress of the film
   2) Surface roughness of test piece
   3) Failure mechanism of the test piece

Annex A
(informative)

Various bending fatigue testers

There are several equipments for the bending fatigue test which were suggested by several researchers. Bending fatigue equipment in Figure A.1 used a curved mandrel with a fixed radius [3] [1]. The mandrel produces the concave and convex shapes for a cyclic bending, producing the concave and convex shapes. The rollers eliminate the vibration caused by the movement of the balance weight, which ensures smooth bending. Fatigue equipment in Figure A.2 also uses a mandrel and shaft which repeatedly rotates clockwise and counter clockwise [5]. One end of the sample is firmly fastened to the mandrel by a metal plate screwed on to the curved mandrel surface. The other end of the sample is clamped between a pair of thin metal plates, which, in turn, are held in place by a low-tension spring. The bending fatigue tester in Figure A.3 is known as a collapsing radius tester. The sample is mounted between the plates in a curved shape of some relatively large radius and it is subsequently squeezed between the plates. The bending radius is approximately the half of the distance between the plates. In the X-Y-θ system [6] as shown Figure A.4, the test piece is clamped in a flat position between a fixed plate and a co-planar plate mounted on top of a stack of two linear and one rotary motorized actuator. These actuators control the spatial coordinates of the specimen end in X-Y-θ space in such a way that the specimen end is positioned on the coordinates of a circumference. The details on the test method can be found in [6]. The angle θ is defined as the angle between the tangent to the test piece end and the X-axis. The bending tester shown in Figure A.5 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. The calculation of the bending radius is described in [7].

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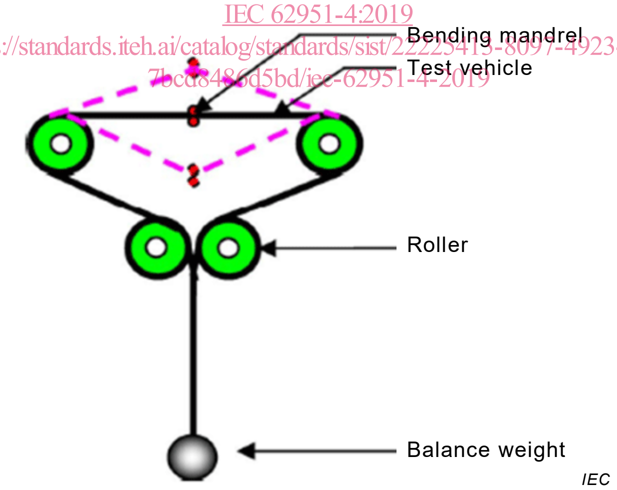

Figure A.1 – Bending fatigue tester using curved mandrel and roller

1 Numbers in square brackets refer to the Bibliography.