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INTERNATIONAL STANDARD

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Semiconductor devices – Micro-electromechanical devices – Part 35: Test method of electrical characteristics under bending deformation for flexible electromechanical devices

Dispositifs à semiconducteurs – Dispositifs microélectromécaniques – Partie 35: Méthode d’essai des caractéristiques électriques sous déformation par courbure de dispositifs électromécaniques souples

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

FDIS	Report on voting
47F/344/FDIS	47F/352/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 62047 series, published 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 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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

In the recent trend toward ubiquitous sensor society and the world of internet of things, demand and thus the market for softer electronic devices are quickly expanding. That is what flexible micro-electromechanical devices are for, some of which are already released into the market. Even a so-called foldable device is under development and will soon appear in the market. However, to operate trillions of such devices for the comfort and safety of human beings, the reliability of the individual devices is a critical concern. Especially in the case of flexible devices, robustness against bending deformation is an important issue which is shared among all the producers and users of such devices. In order to understand how safe a situation is, critical conditions for possible dangers should be thoroughly determined so that the potential risk can be for the first time managed. In this context, flexible devices should be folded in two at least once so that every possible critical failure actually appears. This standard procedure of testing is designed with the emphasis on such a point and with the applicability not only to already emerging flexible devices but also to so-called foldable devices which still function even when the device is folded.

SEMICONDUCTOR DEVICES –
MICRO-ELECTROMECHANICAL DEVICES –
Part 35: Test method of electrical characteristics under bending deformation for flexible electromechanical devices

1 Scope

This part of IEC 62047 specifies the test method of electrical characteristics under bending deformation for flexible electromechanical devices. These devices include passive micro components and/or active micro components on the flexible film or embedded in the flexible film. The desired in-plane dimensions of the device for the test method ranges typically from 1 mm to 300 mm and the thickness ranges from 10 µm to 1 mm, but these are not limiting values. The test method is so designed as to bend devices in a quasi-static manner monotonically up to the maximum possible curvature, i.e. until the device is completely folded, so that the entire degradation behaviour of the electric property under bending deformation is obtained. This document is essential to estimate the safety margin under a certain bending deformation and indispensable for reliable design of the product employing these devices.

2 Normative references

There are no normative references in this document.

3 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 General

3.1.1
flexible micro-electromechanical system
flexible MEMS
device with structured semiconductor and/or mechanical components electrically connected to each other, being assembled onto or embedded into flexible substrate and operated without unacceptable loss of its functions under bending deformation

EXAMPLE Organic transistors, thermistors, smart diapers with wet sensors and smart epidermal patches for health care, etc.

Note 1 to entry: This note applies to the French language only.

3.2 Loading configurations

3.2.1
bending axis
line on a device around which the device is bent with the minimum radius of curvature

Note 1 to entry: Due to the characteristics of this document, the bending axis can be and should be placed at arbitrary positions in arbitrary directions in accordance with the requirements of the evaluation. The actual positions and directions shall be intentionally determined according to the structures on the test piece.

3.2.2

bending direction

direction in which the device is bent

3.3 Measure of loading levels

3.3.1

d

folding distance

distance between two loading walls, representing the load level applied to the device

Note 1 to entry: The degree of bending given to the device is here represented by the distance between two walls approaching close to each other to bend the device, which is denoted as the folding distance.

Note 2 to entry: This measure may be optionally converted to the radius of curvature given around a bending axis but it may not be uniform between the two walls especially when the rigidity distribution around the bending axis is not homogeneous due to the heterogeneity of structures. More details are given in Annex D.

3.3.2

d_l

distance at defined operation limit

folding distance(s) corresponding to unacceptable deterioration(s) in the electrical performance of the test piece

Note 1 to entry: More details can be found in Annex A.

4 Test piece

4.1 General

A flexible MEMS device, which is bent in use, can in principle be a test piece as it is and subjected to the evaluation of this document. In principle, this test method is applicable without restriction as to the size and shape of the devices. However, for ease of a load application, it may be cut into a rectangular shape with target parts to be loaded at the center as mentioned in 4.2. More methods for test piece preparation are suggested in Annex B.

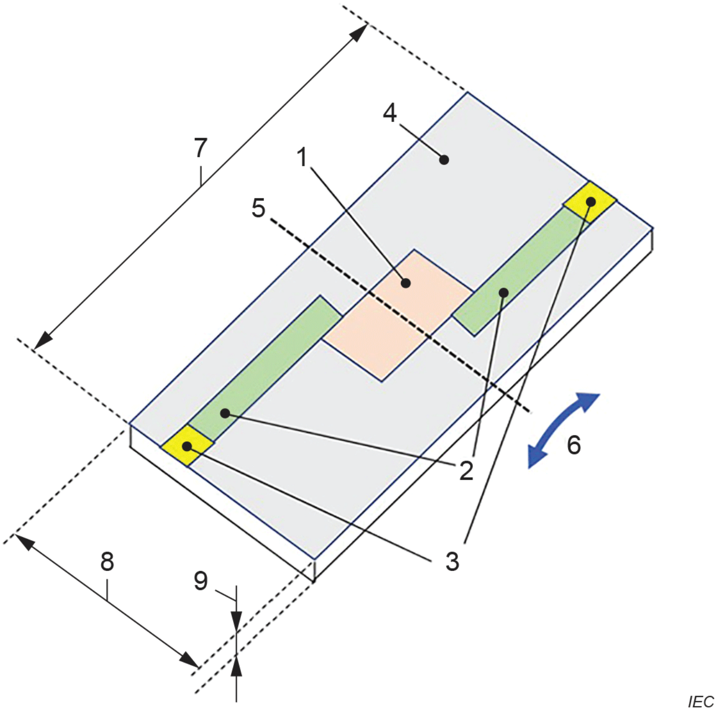
4.2 Shape of a test piece

A rectangular shape of the test piece should be used for the ease of experiment as shown in Figure 1. It may be necessary to cut out a part of the devices for the test, especially when the target part to be tested, which determines its own functional feature, is not located in the center of the device. In this case, the test piece shall be prepared in a rectangular form by cutting a part out of the entire device with the target part located at the center of two parallel edges which should also be parallel to the bending axis. This is because the point to be loaded to the end is limited in this test method only along the bending axis likely coming out at the center due to the loading scheme explained in 5.1.

In this document, the length l and the width w of test piece are the dimensions of the test piece in the perpendicular and parallel direction to the bending axis, respectively. Because of the structures assembled on or embedded in the flexible substrate, the thickness may not be uniform over the entire device and hence depends on the location.

As a number of target parts can be arranged on a substrate, especially for testing purposes in accordance with this document, some recommendations are given in Annex B.

NOTE The length and width can be interchangeable when the bending axis is rotated by 90°, which is symbolically illustrated in Figure 3.



Key

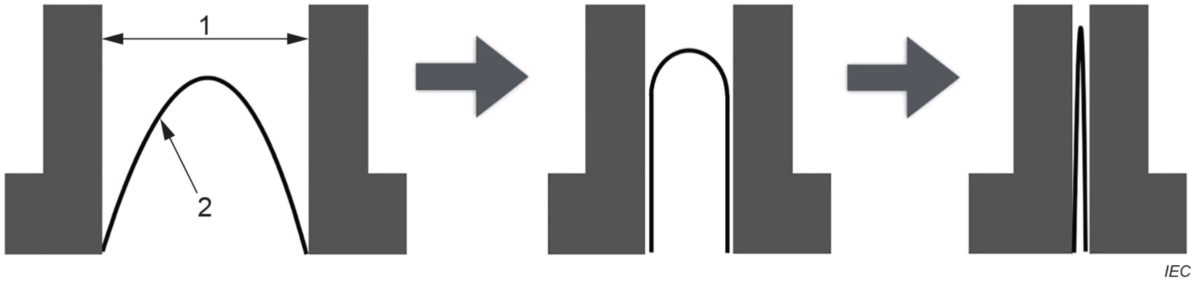
1 target part
2 interconnects
3 electrodes
4 flexible substrate
5 bending axis
6 bending direction
7 length
8 width
9 thickness

Figure 1 – Schematic illustration of a flexible MEMS test piece

5 Test method

5.1 Principle

The principles of loading to the test piece are illustrated in Figure 2. The device shall be inserted between two walls sliding closer to each other as illustrated in Figure 2 a). Then let the distance between two walls, i.e. folding distance d, be gradually shortened as shown in Figure 2 b) until finally touching each other with the folded test piece in between as in Figure 2 c). While the device is folded gradually tighter and tighter, its functions should be evaluated to find which portion of the performance could be maintained while the folding distance is applied.



a) **Initial stage** b) **Middle stage** c) **Final stage**

Key

1 folding distance d

2 test piece

Figure 2 – Principle of folding test

5.2 Test apparatus

There is no special requirement for the configuration of the test apparatus in this document, as long the device can be folded tighter and tighter until the end of the test. However, the width and height of the walls shall be longer, preferably at least by 5 %, than the width and half the length of the test piece, respectively, so that the whole test piece is firmly pressed by the walls. The surface flatness and parallelism of the walls are carefully prepared so that they do not to touch each other before the end of the test. The variance of the gap between the walls shall be smaller than the thickness of the test piece. The surface roughness and flatness of the walls are recommended to be less than 1/10 of the thickness of the test piece so as not to distort the test piece by bumps of the wall except for the intended bending deformation. Either wall or both walls are shifted by a motor drive system, or a manually-actuated linear stage. A number of recommendations for the convenience of experiment can be found in Annex B and Annex C.

The folding distance shall be measured to an accuracy of less than 5 % relative to the folding distance itself. Therefore, it may be suggested to use a number of tools, for example a scale for the millimeter range, a micrometer gauge for the submillimeter range, or a laser displacement meter or microscopy for the micron and sub-micron range.

NOTE Not an absolute error for full range measurement but a relative error on the folding distance is of importance to maintain the reproducibility in the bending deformation, especially around the end of the test, because the nominal curvature can be approximated by $2/d$ under the bending deformation as shown in Figure 2b). In addition, the value of d ranges from l, for example more than 100 mm, to $2t$, for example values less than a millimeter. The dimension with such a wide range is difficult to measure with an accuracy of less than 1 % by a ready-made apparatus. That is why the accuracy of the folding distance is noted in terms of the relative value with an accuracy of 5 % for the ease of experiment in this document.

5.3 Procedure

5.3.1 Testing conditions

Since the aim of this document is to see the deterioration behaviour of a device's performance by bending to the end of possible curvature, it may not always be easy to find the testing speed adequately corresponding to the conditions of the actual device operation. Therefore, the evaluation of time-dependent deformation behaviour such as visco-elasticity is regarded here as out of the scope, and thus the holding time between two loading steps before starting the instrumentation as well as the loading speed itself are not specified here. It is here simply suggested to keep the holding time for measurement the same for all the steps and be aware of any drift after increasing the folding distance. The test speed and holding time determined by the user shall be included in the test report, for example l per minute of the wall moving speed and 1-min holding time per each measurement. Since substrates for flexible MEMS may often be made of polymeric materials, the deformation behaviour should be in principle more or less time-dependent. Non-elastic time-dependent behaviour should be mentioned in the test report, if any is noticed.

Other conditions for testing, such as temperature and humidity, etc., shall be so far as possible the same as those where the devices are operated in actual use.

NOTE 1 Since the aim of this document is to see the deterioration behaviour of the device's performance against monotonic bending to the end of possible curvature, it may not be always easy to find testing conditions (especially speed) which adequately correspond to those of the actual device operation. In such cases, the users are responsible for determining the conditions and report them appropriately as mentioned in 6.6.

NOTE 2 When the length of the test piece l is 20 mm, the candidates for wall speed are 20 mm/min, 50 mm/min, 100 mm/min, 200 mm/min, etc. If a real-time monitoring system is available for measurement, the holding time can possibly be zero.

5.3.2 Selection of bending direction

Set the test piece on the test apparatus, with the side to be loaded in a convex way facing upward. Choice of this side, the bending direction in which the test piece is loaded, should follow in principle the condition in which the device is actually bent during its service. However, in order to explore possible failure modes, the two bending directions may be examined regardless of how the device is actually used.

NOTE When a test piece as shown in Figure 1 is set on the test apparatus with the target part facing upward, the test piece is loaded in a convex way and the target part is strained. On the other hand, for the test under the opposite bending direction, the test piece is set with the target part facing downward and the target part is compressed. In the test report, the curvilinear arrow is denoted in a concave form.

5.3.3 Determination of bending axes

Select a characteristic axis of individual devices to be tested. In addition, at least another direction of 90° to this axis should also be tested as shown in Figure 3. The actual selection of the directions is left to the suppliers and users. It is noted here that the actual bending axes appearing at the end of the test may somehow not be exactly at the position expected, likely because of a possible error in the test piece preparation and inhomogeneous stiffness distribution over the device. Therefore, a fine adjustment of the bending axis location may be necessary during the loading process. Possible methods for the precise control for this adjustment are available in Annex B.

5.3.4 Measurement of test piece dimensions

The length and width of the test piece shall be measured and recorded for each test piece. Measurement of the length of the device is critical because of the loading scheme explained in 5.2. It shall be measured to an accuracy of 1 % relative to the length itself. Dimensions in the direction parallel to the bending axis are not important but may also be measured in the same way. Thickness may vary among different points over the test piece due to its inhomogeneous structures. Therefore it shall also be measured at a number of typical points, for example both the substrate part and the target part. A profilometer can measure the local thickness of test piece with sufficient accuracy.

NOTE 1 As the preferable methods and accuracy in the measurement strongly depend on the individual devices, nothing is normatively specified in this document. Instead, users of this procedure are responsible for choosing adequate methods for their devices and reporting accuracy in the test report as described later.

NOTE 2 Since the distribution of thickness strongly depends on the structure of individual devices subjected to the test, selection of measuring points is left to the users.

NOTE 3 It is optional to report the dimensions except for length because the width and the thickness are just a supporting information for the design of the test apparatus for this document.