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INTERNATIONAL STANDARD

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Semiconductor devices – Flexible and stretchable semiconductor devices – Part 8: Test method for stretchability, flexibility, and stability of flexible resistive memory

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SEMICONDUCTOR DEVICES – FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

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Draft	Report on voting
47/2786/FDIS	47/2793/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.

The language used for the development of International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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- withdrawn,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

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SEMICONDUCTOR DEVICES – FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

Part 8: Test method for stretchability, flexibility, and stability of flexible resistive memory

1 Scope

This part of IEC 62951 defines terms and specifies the test method for evaluating the stretchability, flexibility, and stability of flexible resistive memory. The test method descriptions include experimental procedures and the equipment to be used. It also includes general requirements for test conditions such as the temperature and relative humidity of the testing environment. The test method described in this document focuses on stability evaluation rather than reliability.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purpose 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 https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
flexible resistive memory
flexible device that works by changing the resistance between dielectric materials

3.2
bending radius
measured to the inside curvature, is the minimum radius one can bend a pipe, tube, sheet, cable or hose

3.3
resistance of low resistance state
LRS
one of stable resistance states induced by applying higher voltage (unipolar switching) or positive bias (bipolar switching)

3.4
resistance of high resistance state
HRS
one of stable resistance states induced by applying lower voltage (unipolar switching) or negative bias (bipolar switching)

3.5
set voltage
V_{set}
voltage for switching to low resistance state

3.6
reset voltage
V_{reset}
voltage for switching to high resistance state

4 Test method

4.1 General

This document applies to flexible resistive memory in order to evaluate its stretchability, flexibility, and stability. This type of semiconductor device is used mostly in products related to flexible or wearable electronics, which are often stretched or bent when used. Hence, it is critical that the main performance parameters of the device be maintained under mechanical deformation. Detailed performance parameters and characterisation procedures are described in IEC 62951-1, and Table 1 in this document summarises them as applicable to resistive memory. This document focuses on experimental methods for testing stretchability, flexibility and stability, and includes a description of the experimental setup.

One of the most problematic issues in the reliability of resistive memory is its increased performance degradation rate under mechanical deformation. This deterioration is caused by cracks in electrodes and the resistive materials used in these types of semiconductor devices. In particular, degradation is accelerated when cracks occur in the encapsulation layer due to the stress caused by bending. Therefore, this evaluation suggests an experimental method for observing the deterioration of an organic semiconductor while flat and bent and while held at a specified humidity and temperature higher than room temperature.

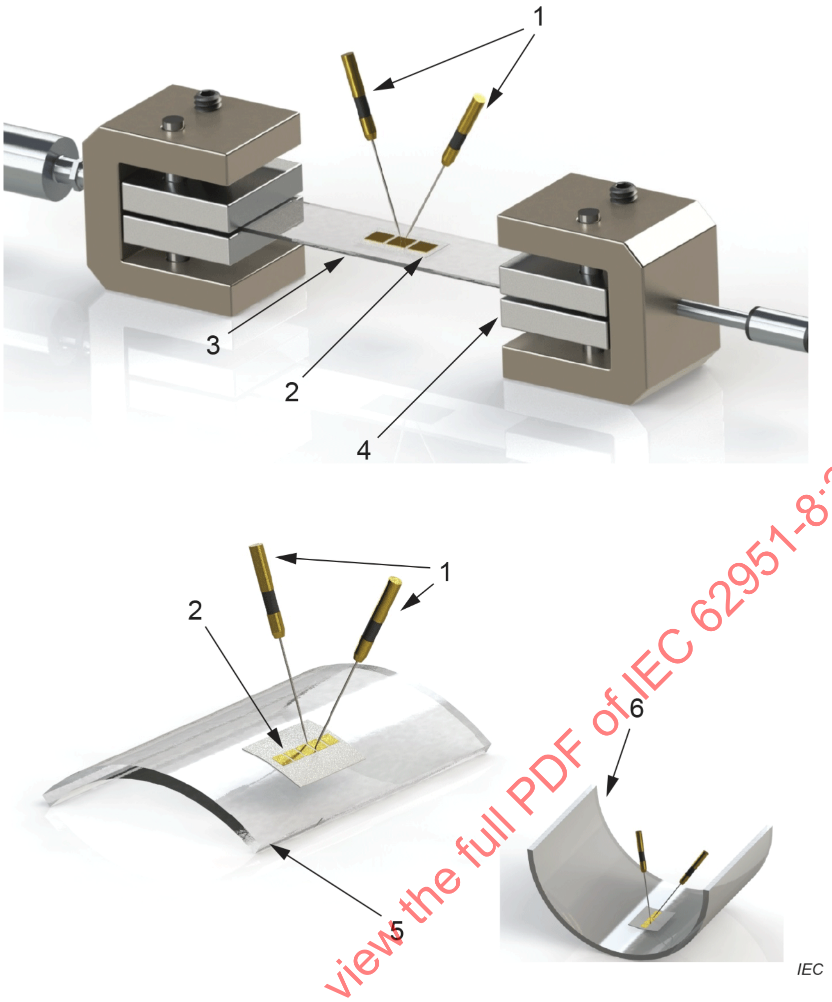
In order to evaluate the performance and its change or degradation, below performance parameters need to be evaluated before and after bending and stretching.

Table 1 – Performance parameters of resistive type memory

Characteristics	Performance parameters
I-V characteristics (switching behaviour)	V_{set}, V_{reset}
Switching endurance	Resistance change as a function of cycle time
Retention test	Current change as a function of time

4.2 Test equipment and tools

A variety of experimental approaches have been employed to test the stretchability and flexibility of flexible devices. Each has advantages and disadvantages, requiring a user to decide which type is appropriate to their application. If a setup from a similar application is considered, care should still be taken to consider the device size or material used to make it. In this evaluation of resistive memory, the experimental setup shown in Figure 1 should be used. Details of each experimental setup and test procedure are explained in 4.3.



Key

1 Probe for characterisation;

2 Specimen (resistive memory);

3 Substrate used in device fabrication;

4 Jig for stretchability test;

5 Jig for flexibility test (tensile stress);

6 Jig for flexibility test (compressive stress).

Figure 1 – Examples experimental setup for testing stretchability (top) and flexibility (bottom)

For stability tests, an environmental chamber shall be used in order to maintain a test environment at a suggested temperature and relative humidity such as those listed in Table 2 of 4.3.3.

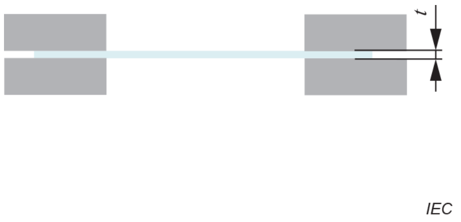
4.3 Test procedures

4.3.1 Stretchability test

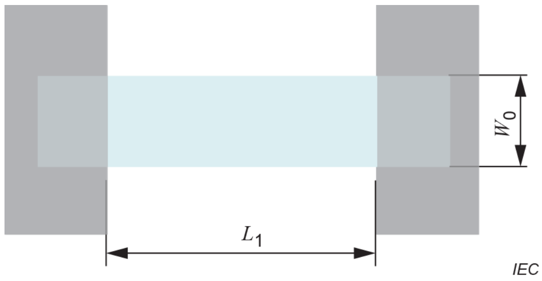
Stretchability testing is carried out in order to investigate whether the performance of resistive memory is maintained while under the tensile stress induced by stretching. In particular, tensile stress in resistive memory can induce changes in resistivity, voltage, mobility and drain current. Figure 2 shows schematics of stretchability testing and denotes key parameters that should be reported following a test. Note that the grip shall be longer than the substrate, as explained in Annex A. The amount of stretching can be determined based on strain, stress or force, but of these, strain is the only geometry-dependent parameter and is independent of other factors such as the dimension of the substrate or material type. Moreover, strain is easy to measure without additional equipment. The strain (ε) induced by stretching is determined by

$$\varepsilon = \frac{L_0 - L_1}{L_0} \times 100 \text{ (\%)} \tag{1}$$

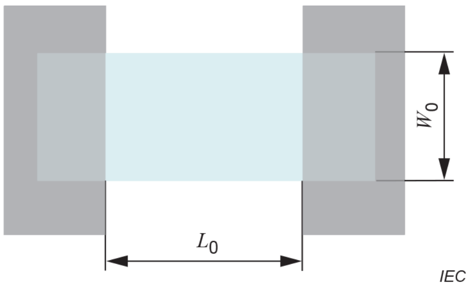
where L_0 and L_1 are the substrate length prior to stretching and after stretching, respectively. W_0 and W_m are the length prior to stretching and after stretching, respectively, measured from the middle of the sample.



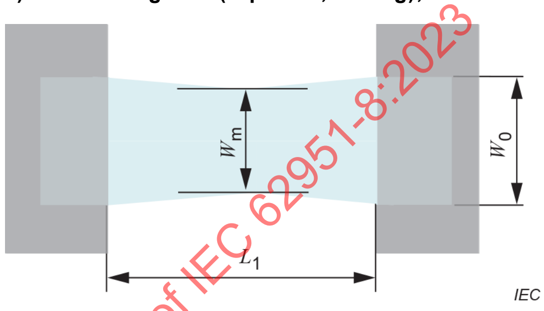
a) **Stretching test (side view)**



b) **Stretching test (top view, during); ideal case**



c) **Stretching test (top view, before)**



d) **Stretching test (top view, during); actual case**

Key

1 Thickness of substrate (t)

2 Length of substrate before stretching (L_0);

3 Length of substrate after stretching (L_1);

4 Width of substrate before stretching (W_0);

5 Width of substrate after stretching, at the middle point of the sample (W_m).

Figure 2 – Schematic for stretchability test denoting parameters before and during testing

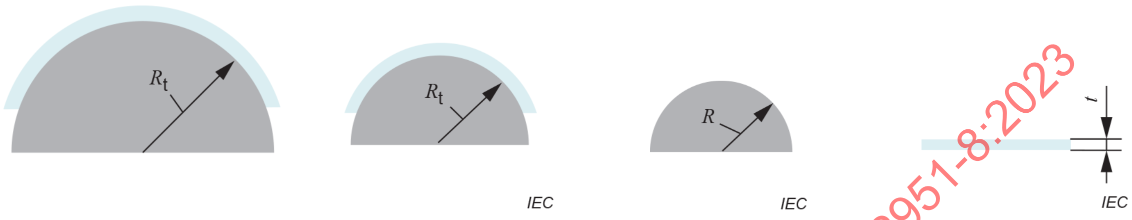
4.3.2 Flexibility test

Flexibility testing is performed to investigate how the performance of resistive memory is maintained under a tensile stress induced by bending and includes tensile and compressive components. Similar to the stretchability tests, tensile or compressive stress imposed on a device can induce changes in resistivity, voltage, mobility, and drain current. In general, a bending test shall include tensile and compressive aspects because their impact on the material and device may differ. Figure 3 shows schematics for flexibility testing including the key parameters which should be reported after testing. The amount of bending can be determined based on strain, stress or force, but of these, strain is the only geometry-dependent parameter and is independent of other factors such as the dimension of the substrate or material type. Strain is also easy to measure without additional equipment. The strain (ε) induced by bending is determined by

$$\varepsilon = \frac{t/2}{R_t} \times 100\ (\%) \tag{2}$$

$$\varepsilon = \frac{t/2}{R_c} \times 100\ (\%) \qquad (3)$$

A detailed description of Formulae (2) and (3) for tensile and compressive, respectively, can be found in Annex A.



a) Bending test (for tensile stress) **b) Bending jig** **c) Resistive memory on the substrate**

d) Bending test (for compressive stress)

Key

1 Bending radius of curvature under tensile stress (R_t);

2. Bending radius of curvature under compressive stress (R_c);

3 Substrate thickness (t).

Figure 3 – Schematic for flexibility test denoting parameters before and during testing

4.3.3 Stability testing

One measurement of performance parameters under mechanical deformation (stretched or bent) is insufficient to ensure that resistive memory maintains its critical performance. Instead, it is necessary to investigate how long device performance is maintained under mechanical deformation given constant environmental conditions. Hence, a stability test should be carried out in a controlled environmental chamber, because the performance degradation in resistive memory significantly depends on environmental conditions. In particular, temperature and relative humidity should be set at specified, application-dependent values and maintained during the test period. This document does not specify the temperature and relative humidity required during a test period, but

Table 2 lists typical test conditions as an example. Any combination of temperature and relative humidity can be applied during stability testing, because thermal properties such as the transition and melting temperatures of organic materials used to fabricate resistive memory differ. The reader should set the environmental conditions and record them in the test report.

After determination of environmental conditions such as temperature and relative humidity, the duration of stability testing shall be determined. This shall be determined according to the materials used in device, applications of device and environmental conditions. The performance parameters before and after stability test should be investigated and reported including the duration of stability test as described in 4.4. Typical performance parameters for flexible resistive memory are described in IEC 62951-9.

Table 2 – Example temperature and relative humidity conditions

Relative Humidity (%)	**Temperature** (°C)				
	55	**65**	**75**	**85**	**95**
55	√	√	√	√	√
65	√	√	√	√	√
75	√	√	√	√	√
85	√	√	√	√	√
95	√	√	√	√	√

4.4 Test report

The report shall include the following items:

a) test apparatus;

b) specimen identification (types of resistive memory);

c) date of test;

d) sample dimension;

e) experimentally determined performance parameters (flat and under mechanical deformation) such as I-V characteristics (set and reset voltages), switching endurance and retention time;

f) stretched length or induced strain of resistive memory;

g) bending radius or induced strain of resistive memory;

h) atmospheric (or laboratory, environmental chamber) conditions of test;

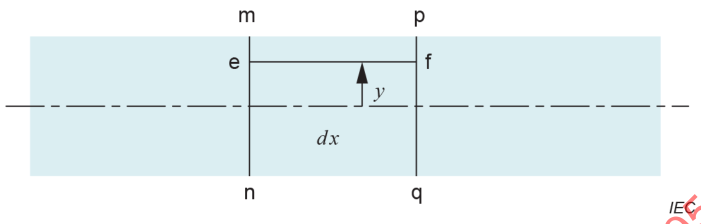
i) duration of stability test.

Annex A
(informative)

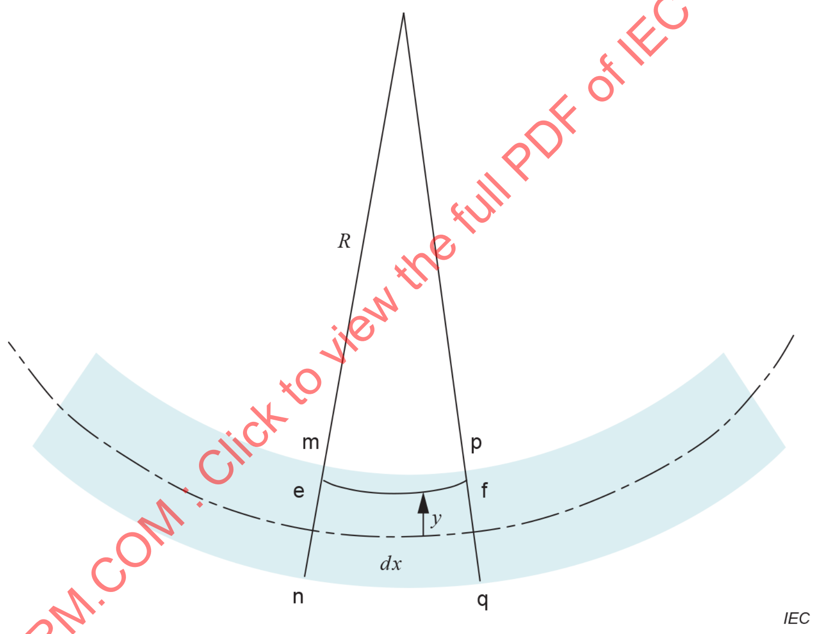
Induced strain on a substrate due to bending

A.1 Detailed derivation of the strain formula by bending[1]

Figure A.1 schematically shows the deformation of a substrate under pure bending.



a) Side view of substrate before bending



b) Side view of substrate after bending

Figure A.1 – Deformation of a substrate induced strain by bending

Formula (2) of 4.3.2 may be derived as follows, referencing Figure A.1. The initial length of ef is dx, while its length after bending is

$L_1 = (\rho - y)d\theta$

$= (\rho - y)dx/\rho$

$= dx - ydx/\rho$.

[1] See Formula (2) in 4.3.2.