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INTERNATIONAL STANDARD

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Semiconductor devices – Flexible and stretchable semiconductor devices – Part 6: Test method for sheet resistance of flexible conducting films

Dispositifs à semiconducteurs – Dispositifs à semiconducteurs souples et extensibles – Partie 6: Méthode d'essai pour la résistance de couche des couches conductrices souples

IEC 62951-6:2019-05(en-fr)

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SEMICONDUCTOR DEVICES – FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

Part 6: Test method for sheet resistance of flexible conducting films

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

FDIS	Report on voting
47/2547/FDIS	47/2566/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.

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 6: Test method for sheet resistance of flexible conducting films

1 Scope

This part of IEC 62951 specifies terms, as well as the test method and report of sheet resistance of the flexible conducting film under bending and folding tests. The measurement methods include the 2-point probe, 4-point probe and Montgomery method, which can be applied to in-situ and ex-situ measurement and the measurements of anisotropic sheet resistance.

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.

ISO 291:2008, *Plastics – Standard atmospheres for conditioning and testing*

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

3.1
resistivity
inverse of the conductivity when this inverse exists

[SOURCE: IEC 60050-121:1998, 121-12-04]

3.2
R_s
sheet resistance
resistance of thin films that are nominally uniform in thickness, which is the resistivity divided by the thickness of conducting film

3.3
resistance
for a resistive two-terminal element or two-terminal circuit with terminals A and B, quotient of the voltage (IEC 60050-131:2008, 131-11-56) u_{AB} between the terminals by the electric current i in the element or circuit

$$R = \frac{u_{AB}}{i}$$

where the electric current is taken positive if its direction is from A to B and negative if its direction is from B to A

Note 1 to entry: A resistance cannot be negative.

Note 2 to entry: The term "resistance" is also a short term for “resistance to alternating current” (IEC 60050-131:2013, 131-12-45).

Note 3 to entry: In French, the term "résistance" also denotes a device, in English "resistor" (see IEC 60050-151:2001, 151-13-19).

Note 4 to entry: The coherent SI unit of resistance is ohm, Ω.

[SOURCE: IEC 60050-131:2013, 131-12-04]

3.4
contact resistance
resistance between the surface of a material and the electric contact made to the surface

3.5
radius
distance from the centre of a circle to the circumference

Note 1 to entry: The radius of a sphere is the radius of a great circle.

[SOURCE: IEC 60050-113:2011, 113-01-25]

3.6
radius of curvature
at a point of a curve, radius of the osculating circle

Note 1 to entry: The osculating circle is the circle tangent to a curve at a point that approaches at best the curve in the vicinity of the point.

[SOURCE: IEC 60050-113:2011, 113-01-30]

3.7
2-point probe method
method for measuring the resistivity of a material, using two electric contacts to the material

Note 1 to entry: The measured value is dependent on the probe resistance.

3.8
4-point probe method
method for measuring the resistivity of a material, using four electric contacts to the material

Note 1 to entry: This avoids many contact resistance problems.

3.9
Montgomery method
technique used to measure the resistivity of two-dimensional sample by placing the electrodes on its perimeter

4 Atmospheric conditions for evaluation and conditioning

The standard atmosphere for evaluation (test and measurement) and storage of the specimen shall be a temperature of 23°C ± 2°C and relative humidity of (50 ± 10) %, conforming to standard atmosphere class 2 specified in ISO 291:2008. If a polymer substrate is used for a test piece coated with a conductive layer, the standard atmosphere for evaluation shall be a temperature of 23°C ± 1°C and relative humidity of (50 ± 5) %, conforming to standard atmosphere class 1 specified in ISO 291:2008.

If conditioning is necessary, the same standard atmosphere as specified above shall apply.

5 In situ measurements using 2-point probe method

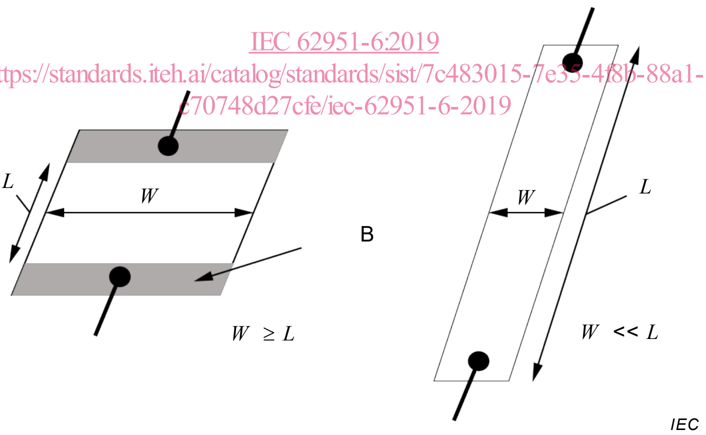
5.1 General

The 2-point probe method for measuring the sheet resistance of a conductive film uses two electric contacts. It is well known that the measured value includes the error caused by the probe resistance and the contact resistance. However, other methods (i.e. 4-point probe and Montgomery method) are not convenient or impossible to use for in-situ measurement during the bending or folding test. Consequently, the 2-point probe method is often necessary for in-situ measurements.

5.2 Sample preparation

To minimize the error caused by the probe resistance and the contact resistance, the following should be satisfied.

- The sample resistance should be 20 times larger than the probe resistance to guarantee the error within 5 % (e.g. if the sheet resistance is about 50 ohms/square and the probe resistance is about 5 Ω, the ratio of length to width, L/W can be larger than 2).
- The probe electric contact should be made securely using highly conductive adhesive, such as silver paste.
- When the width W is comparable or larger than the length L, of the sample, the conducting bar (using highly conductive adhesive, such as silver paste) should be securely attached to the sample to minimize the spreading resistance in the width direction. (see Figure 1)



Key

W width of the sample

L length of the sample

B conductive bar

Figure 1 – Possible electric connection of 2-point probe measurement

5.3 Test methods

5.3.1 Test apparatus

The appropriate evaluation for flexible electronics is bending the sample to a given radius. For this, either the collapsing radius test (see IEC 62951-1) or the $X–Y–\theta$ test can be used (refer to Annex A). It is noted that the gauge section (where the bending radius r is observed) should be measured in the collapsing radius test.

It is noted that the folding test is also similar to the bending test. The difference is the fact that the permanent deformation occurs in folding due to the relatively small radius of curvature.

5.3.2 Measurement and data analysis

Acquisition of temporal resistance data requires digital multimeter, whose reading rate should be 10 times faster than the bending frequency to measure the resistance change during one cyclic bending. It is noted that the applied current can cause heating of the material, which can change its resistivity. To avoid this problem, make sure the measured resistance is constant with time (the average resistance should not drift more than 10 % in a few minutes).

For the 2-point probe method, the sheet resistance, R_s can be calculated from the measured resistance, R, as shown by Formula (1):

$$R_s = R\frac{W}{L} \tag{1}$$

In addition, the bending radius should be measured by fitting circles to optical images of curvature (especially when collapsing radius test is used). When the whole area of sample does not experience the same bending radius (Figure 2), the sheet resistance at the gauge section can be obtained from the initial resistance, R_i as shown by Formula (2):

$$R_s = \left(R - R_i\frac{L - L_{bend}}{L}\right)\frac{W}{L_{bend}} \tag{2}$$

After the bending test, it is recommended to measure the sheet resistance of the sample using a 4-point probe. The comparison of measurements between the 2-point and 4-point probe can ascertain the secure electrical connection of the 2-point probe after the bending test and can further reduce the measurement error by the 2-point probe. For the same reason, it is also recommended to measure the sheet resistance using a 4-point probe before the bending test.

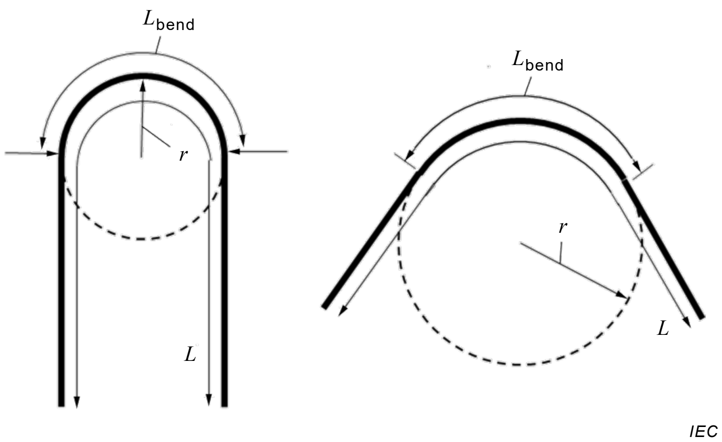


Figure 2 – Gauge section of bending test

5.4 Report of results

The report shall include the following items:

a) specimen identification;

b) date of test;

c) atmospheric conditions of test;

d) bending radius;

e) sample dimension and the actual bending area (gauge section);

f) frequency of bending;

g) temporal sheet resistance curve (or equivalent sheet resistance over bending area);

h) optical observation permanent deformation;

i) (optional) 4-point probe measurement before and after the bending test.

6 Uniformity measurement using 4-point probe method

6.1 General

The 4-point probe method is an electrical measuring technique that uses separate pairs of current-carrying and voltage-sensing electrodes to make more accurate measurements than the simpler 2-point probe sensing. Separation of current and voltage electrodes eliminates the lead and contact resistance from the measurement. 4-point probes can accurately measure a resistance below 100 Ω, and therefore it is a suitable technique to evaluate the sheet resistance uniformity of thin films.

6.2 Test methods

6.2.1 Test apparatus

The sheet resistances are measured by pressing collinear 4-point probes against the surface of the film. A current is applied between the outer two points, while the voltage is measured across the inner two points.

For the soft conducting film on flexible substrate, the use of the special collinear probe with a finite contact area equipped with internal springs is recommended. An example of this probe pin is shown in Figure B.6.

6.2.2 Measurement and data analysis

From the induced current, I and the measured voltage, V, the sheet resistance is calculated as:

$$R_s = \frac{\pi}{\ln 2}\frac{V}{I}f = 4{,}5324\frac{V}{I}f \qquad (3)$$

Here, f is the correction factor considering the finite size of the sample and the finite size of the probe contact area and is detailed in Annex B. See Figure B.1 and Figure B.7.

To evaluate the uniformity of the sheet resistance of the conductive film, many measurement points are required. There is not a preferred map for measuring positions, but it is recommended that the positions are located 10 % inside from the edge. An example of measuring positions is shown in Figure 3.

In the case of a long roll of flexible conductive film, it is recommended to acquire the samples from both ends, but not the extremities of the roll and to evaluate the uniformity.

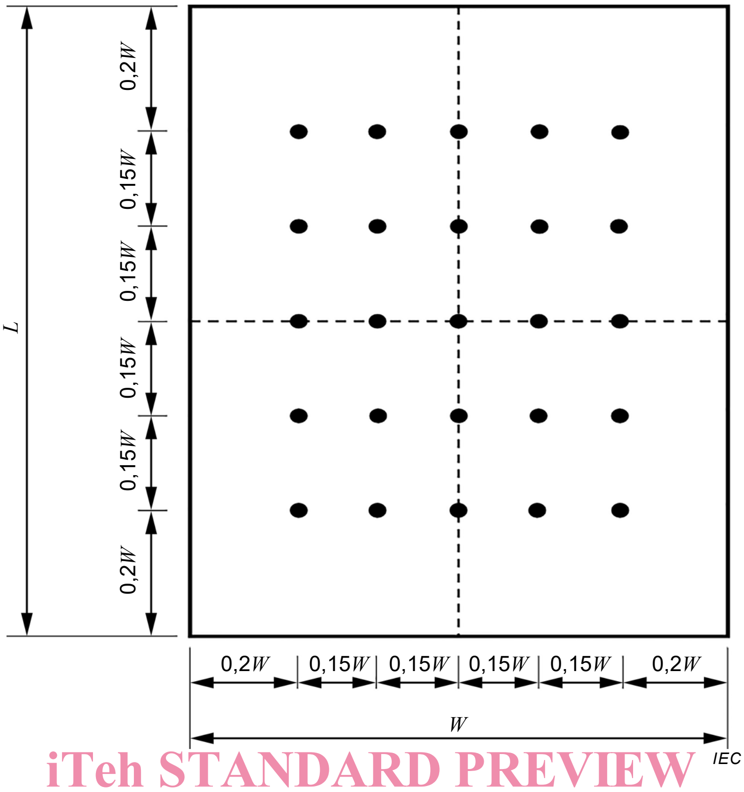
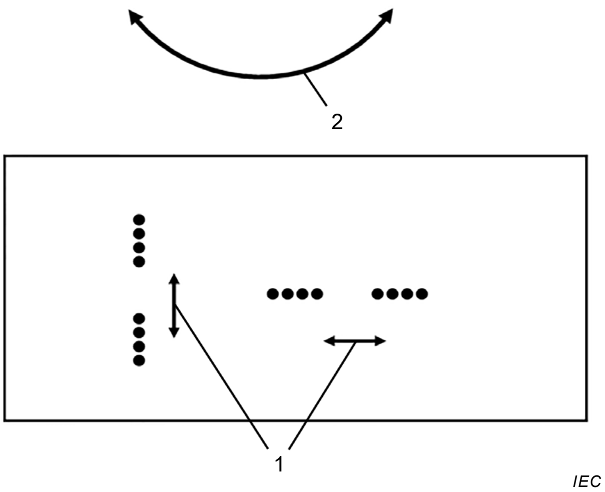


Figure 3 – Example of measuring positions

In the case of a sample after the bending test, anisotropic resistivity may appear. Therefore, it is recommended that the sheet resistance is measured with the collinear probe placed in both directions, parallel and perpendicular to the bending direction, as depicted in Figure 4.



Key

1 direction of collinear probes

2 bending direction

Figure 4 – Direction of bending and collinear probes

6.3 Report of results

The report shall include the following items:

a) specimen identification;

b) date of test;
c) atmospheric conditions of test;
d) sample history;
e) sample dimension and measuring positons;
f) direction of collinear probes;
g) sheet resistance data and its statistical uniformity information;
h) (optional) data of correction factor.

7 Anisotropic measurement using the Montgomery method

7.1 General

The Montgomery method is a technique used to measure the sheet resistance of a sample. Its advantage lies in its ability to accurately measure the sheet resistance of a sample and to measure an anisotropic resistivity as well. However, for this method, electrodes should be placed on the perimeter of the sample, so that it only provides the average value. See Annex C.

7.2 Test methods

7.2.1 Test apparatus

An electric equipment similar to that used for the 4-point probe method can be used. Since the current source and voltmeter shall be switched to all terminals of the sample, equipment with switching matrix to automate measurements is recommended. The electric contacts should be made on the four corners of the rectangular sample and the size of contact should be 10 times smaller than the sample dimension to guarantee an error within 1 %.

7.2.2 Measurement and data analysis

To make a measurement, a current should flow along one edge of the sample (for instance, I_{12} and I_{23}) and the voltage across the opposite edge (in this case, V_{34} and V_{41}, respectively) is measured (refer to Figure 5). From these values, a resistance (for this example, $R_{12,34}$ and $R_{23,41}$) can be found using Ohm's law:

$$R_{12,34} = \frac{V_{34}}{I_{12}} \quad (4)$$

$$R_{23,41} = \frac{V_{41}}{I_{23}} \quad (5)$$

These measurements are repeated to improve the accuracy of the resistance values and the vertical and horizontal resistance can be obtained as follows:

$$R_{\text{vertical}} = \frac{R_{12,34} + R_{21,43} + R_{34,12} + R_{43,21}}{4} \quad (6)$$

$$R_{\text{horizontal}} = \frac{R_{23,41} + R_{32,14} + R_{41,23} + R_{14,32}}{4} \quad (7)$$

If any of the reversed polarity measurements do not agree, to a sufficient degree of accuracy (usually within 3 %), with the corresponding standard polarity measurement, then there is probably a source of error somewhere in the setup, which should be investigated before continuing. The same principle applies to the reciprocal measurements.

In the case of an anisotropic sample, both the respective sheet resistances for both vertical and horizontal directions can be calculated as follows:

$$R_{\mathrm{s,vertical}} = \frac{\pi}{8}\frac{L_{23}}{L_{12}} R_{\mathrm{horizontal}} F \sinh(\pi F) \tag{8}$$

$$R_{\mathrm{s,horizontal}} = \frac{\pi}{8}\frac{L_{23}}{L_{12}} R_{\mathrm{horizontal}} \frac{\sinh(\pi F)}{F} \tag{9}$$

where

$$F \approx \frac{1}{2}\left[\frac{1}{\pi}\ln\frac{R_{\mathrm{vertical}}}{R_{\mathrm{horizontal}}} + \sqrt{\left(\frac{1}{\pi}\ln\frac{R_{\mathrm{vertical}}}{R_{\mathrm{horizontal}}}\right)^2 + 4}\right] \tag{10}$$

L_{12} and L_{23} are vertical and horizontal lengths of the sample, respectively.

$R_{12,34} = V_{43}/I_{12}$ $R_{23,41} = V_{41}/I_{23}$

Figure 5 – Resistance measurement with the Montgomery method

7.3 Report of results

The report shall include the following items:

a) specimen identification;

b) date of test;

c) atmospheric conditions of test;

d) sample dimension;

e) directional sheet resistance data;

f) (optional) data of correction factor;

g) (optional) sample history (direction of bending).