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Edition 1.0 2019-04

INTERNATIONAL STANDARD

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Semiconductor devices – Flexible and stretchable semiconductor devices – Part 2: Evaluation method for electron mobility, sub-threshold swing, and threshold voltage of flexible devices

Dispositifs à semiconducteurs – Dispositifs à semiconducteurs souples et extensibles –
Partie 2: Méthode d'évaluation pour la mobilité des électrons, la pente en régime de sous-seuil et la tension de seuil des dispositifs souples

IEC 62951-2:2019-04(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES – FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

Part 2: Evaluation method for electron mobility, sub-threshold swing, and threshold voltage of flexible devices

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

FDIS	Report on voting
47/2541/FDIS	47/2564/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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- withdrawn,
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SEMICONDUCTOR DEVICES – FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

Part 2: Evaluation method for electron mobility, sub-threshold swing, and threshold voltage of flexible devices

1 Scope

This part of IEC 62951 specifies terms, definitions, symbols, configurations and evaluation methods that can be used to evaluate and determine the performance characteristics of flexible thin-film transistor (TFT) devices. This document specifies test methods and characteristic parameters for accurately evaluating the performance and reliability in practical use of flexible TFT devices under the bending status.

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.

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

3.1
flexible thin-film transistor
flexible TFT
thin-film transistor fabricated on mechanically flexible substrates such as polymers and metal foils

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

3.2
mobility
<of an electron> quantity equal to the quotient of the modulus of the mean velocity of a charge carrier (electron) in the direction of an electric field by the modulus of the field strength

[SOURCE: IEC 60050-521:2002, 521-02-58, modified — "electron" has been added.]

3.3
sub-threshold swing
S
parameter for quantifying how sharply the transistor is turned off by the gate voltage, defined by the following formula

$$s = \ln(10)\frac{kT}{q}\left(1+\frac{C_d}{C_{ox}}\right)$$

where C_d and C_{ox} represent depletion layer capacitance and gate-oxide capacitance, respectively

3.4
threshold voltage
gate-source voltage at which the magnitude of the drain current reaches a specified low value

[SOURCE: IEC 60050-521:2002, 521-07-24]

3.5
gate voltage
V_{GS}
voltage between gate and source

3.6
drain voltage
V_{DS}
voltage between drain and source

3.7
drain current
I_{DS}
current between drain and source

3.8
transconductance
g_m
ratio of the increment in the drain current to a corresponding incremental change of the gate-source voltage with the drain-source voltage held constant

[SOURCE: IEC 60050-521:2002, 521-07-25]

4 Test method

4.1 General

To investigate the reliability of the flexible TFTs, bending tests are performed as follows (see Figure 1):

a) prior to any bending, the electrical characteristics of the TFTs are measured;
b) under the mechanical bending state, the electrical characteristics of the TFTs are re-measured as shown in Figure 3.

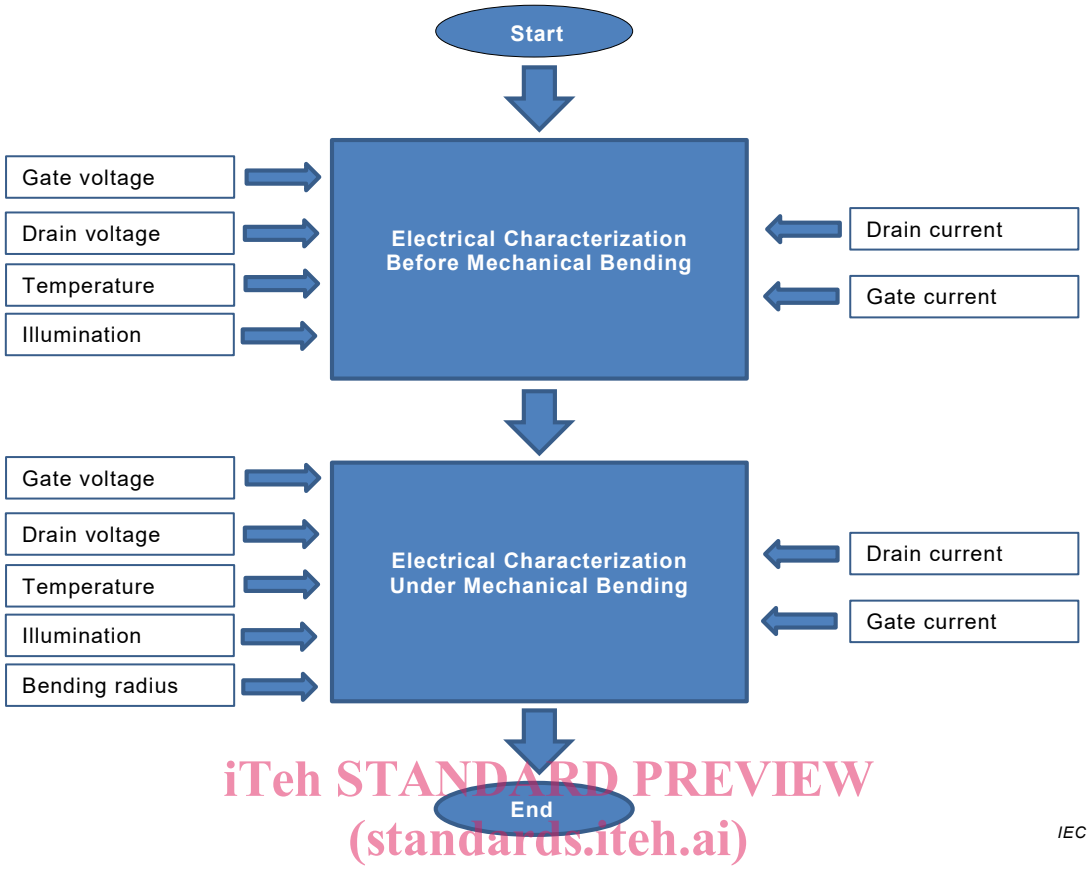

Figure 1 – Procedure for measurement of flexible thin-film transistor

4.2 Test of electrical characteristics before bending

The stability test of a flexible TFT is carried out using four kinds of biased evaluation. The negative-bias-stress (NBS) test is carried out with a V_{GS} of −20 V at a fixed V_{DS} of 10 V under dark and the substrate temperature is maintained at 20 °C and 60 °C. The negative-bias-illumination-stress (NBIS) test is carried out with a V_{GS} of −20 V at a fixed V_{DS} of 10 V under illumination with a white light-emitting diode of 300 cd/m^2 brightness and the substrate temperature is maintained at 20 °C and 60 °C. The positive-bias-stress (PBS) test is carried out with a V_{GS} of +20 V at a fixed V_{DS} of 0,1 V under dark and the substrate temperature is maintained at 20 °C and 60 °C. The positive-bias-illumination-stress (PBIS) test is carried out with a V_{GS} of +20 V at a fixed V_{DS} of 0,1 V under illumination with a white light-emitting diode of 300 cd/m^2 brightness and the substrate temperature is maintained at 20 °C and 60 °C.

In the test procedure, the drain current is measured at room temperature by sweeping the gate voltage from −30 V to 30 V, at a fixed drain voltage of 0,1 V. Afterwards, the device stability tests are performed for 3 h. The field-effect mobility shall be calculated using Formula (1). The mobility is extracted from the linear-regime transconductance g_m at the low drain voltage of 0,1 V as follows:

$$\mu_{FE} = \frac{g_m}{C_{ox}(W/L)V_{DS}} \quad (1)$$

where, L and W are the channel length and width, respectively. The sub-threshold swing shall be obtained using the slope of transfer curves in the sub-threshold regime by application of Formula (2).

$$S = \left(\frac{\partial \log I_{DS}}{\partial V_{GS}}\right)^{-1} \quad (2)$$

Threshold voltage shall also be determined by plotting $(I_{DS})^{1/2}$ versus V_{GS} and extrapolating the curve to zero drain current. The on/off ratio is estimated from the transfer curves by calculating the ratio between the maximal on-current (at V_{GS} = 30 V) and the minimal off-current. Finally the gate leakage current shall be obtained measuring the gate-to-source current at 30 V of the gate voltage applied. A schematic circuit diagram is shown in Figure 2.

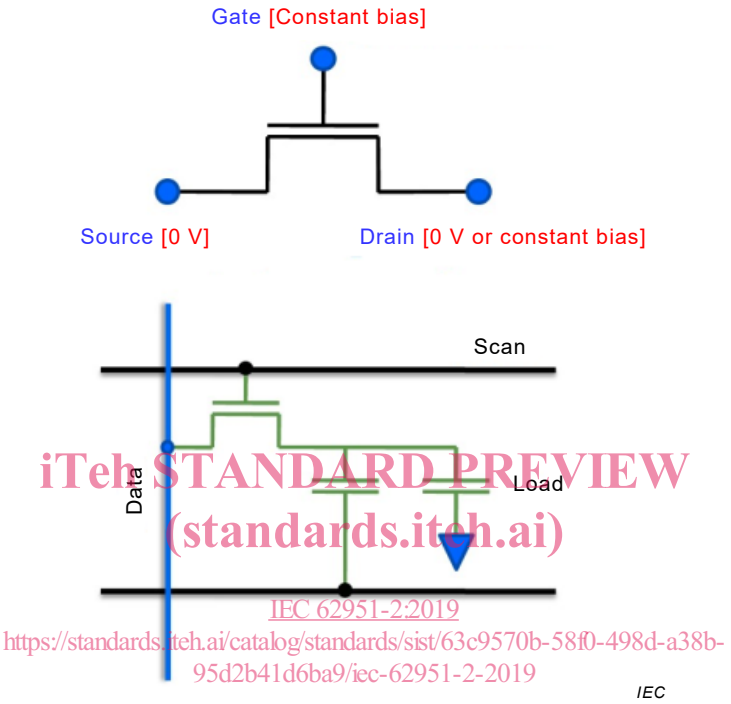

Figure 2 – Schematic circuit diagram of the test

4.3 Test of electrical characteristics under bending

To characterize the effects of mechanical stress on flexible TFTs, strain is applied on the TFTs by bending the device convexly (i.e., inducing a tensile strain on the active devices) or concavely (i.e., inducing a compressive strain on the active devices) with varied radius of curvature R as shown in Figure 3. The bending direction is parallel or perpendicular to the drain-to-source current path. The TFTs are first bent to the maximum R for 1 min and then released to the flat state and are measured. This test cycle is repeated at decreasing R down to the minimum R. After each mechanical bending, the TFT on-current, the off-current and the gate leakage current are monitored.

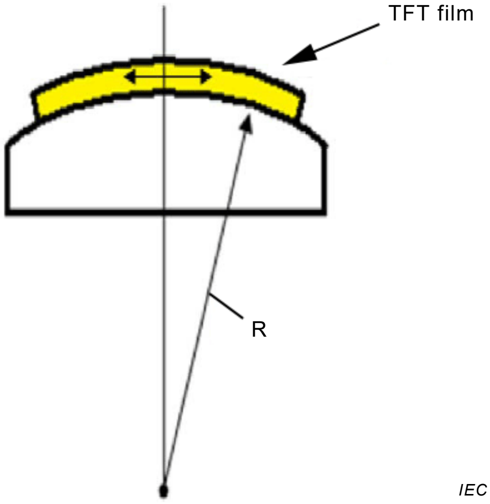

Figure 3 – Configuration for the TFT bending test

In the bended state, all bending radii (R) are converted to percent strain (ε) using Formula (3)

$$\varepsilon = \frac{d_T + d_S}{2 \times R} \tag{3}$$

Where, d_T and d_S are the corresponding thicknesses of the TFT stack and the flexible substrate. Simple mechanical fatigue testing is performed by putting the flexible TFTs through repeated bending (i.e., at constant R) and flattening up to 50 000 times. The substrate temperature is maintained at 20 °C and 60 °C. The TFTs are periodically measured while flat without removal from the bending apparatus.

The four kinds of test shall proceed under the bending state. To obtain the results of negative-bias-stress under the bending state (i.e., at different R), the NBS stability test is carried out with a V_{GS} of −20 V at a fixed V_{DS} of 10 V under dark, and the substrate temperature is maintained at 20 °C and 60 °C. The test of negative-bias-illumination-stress under the bending state is carried out with a V_{GS} of −20 V at a fixed V_{DS} of 10 V under illumination with a white light-emitting diode of 300 cd/m^2 brightness, and the substrate temperature is maintained at 20 °C and 60 °C. Under the mechanical bending state, the positive-bias-stress stability test is carried out with a V_{GS} of +20 V at a fixed V_{DS} of 0,1 V under dark and the substrate temperature is maintained at 20 °C and 60 °C. The value of positive-bias-illumination-stress under the bending state stability test is also carried out with a V_{GS} of +20 V at a fixed V_{DS} of 0,1 V under illumination with a white light-emitting diode of 300 cd/m^2 brightness, and the substrate temperature is maintained at 20 °C and 60 °C.

4.4 Test report

The test report shall include the following elements:

a) reference to IEC 62951-2;

b) the layer materials including gate, insulator, active, source and drain of the tested device;

c) test conditions:

- illumination, in test case of NBIS and PBIS;
- gate and drain voltage;
- drain current;
- time under bending state;
- bending radius of the tested device;
- ambient temperature.

d) test results:

- threshold voltage;
- sub-threshold swing.