

# INTERNATIONAL STANDARD



Printed electronics –  
Part 503-1: Quality assessment – Test method of displacement current  
measurement for printed thin-film transistor

IEC 62899-503-1:2020  
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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## PRINTED ELECTRONICS –

**Part 503-1: Quality assessment –  
Test method of displacement current  
measurement for printed thin-film transistor**

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FDIS	Report on voting
119/303/FDIS	119/307/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.

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## INTRODUCTION

There has been a need for a method to measure and evaluate performance and reliability that is appropriate for printed thin-film transistors (TFTs). In the case of printed TFTs, there is much larger parasitic capacitance than dielectric capacitance in the channel. Accordingly, there has been a need for a method to measure and evaluate the properties for printed TFTs. Carrier behavior is one such property, and mobility and threshold voltage ( $V_{th}$ ) for TFTs are other properties. In the case of inorganic TFTs, for example complementary metal-oxide semiconductor (CMOS) TFTs, carriers are induced by the strong inversion at the semiconductor/dielectric interface. But in the case of organic or printed TFTs, carrier generation takes place in the accumulation mode. The total number of carriers in the organic semiconductor layer can often be insufficient to enrich the carrier concentration at the channel. There exists a carrier injection. The carrier injection occurs at the interface of the organic semiconductors' source/drain electrodes. There are three methods to investigate the carrier injection property, that is, Kelvin probe microscopy, four-terminal measurement, and displacement current measurement (DCM). Both Kelvin probe microscopy and four-terminal measurement are indirect methods, but DCM is a direct method to detect charge motion in semiconductors, molecular thin films, and nanoparticles. In this document, the DCM-based channel charge trapping and channel capacitance measurement method is proposed as a measuring method for the carrier properties of organic or printed TFTs.

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## PRINTED ELECTRONICS –

### Part 503-1: Quality assessment – Test method of displacement current measurement for printed thin-film transistor

## 1 Scope

This part of IEC 62899 specifies a test method for displacement current measurement (DCM) for printed thin-film transistors (TFTs) or organic thin-film transistors (OTFTs).

## 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, *Plastics – Standard atmospheres for conditioning and testing*

## 3 Terms and definitions (standards.iteh.ai)

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

#### printed thin-film transistor

#### printed TFT

device of a field effect transistor whose components, that is, source-drain electrodes, semiconductor, gate electrode, and insulator, are formed by any kind of printing technologies

### 3.2

#### saturation region

operating region of a TFT in which, when the drain voltage with a magnitude greater than the difference in the applied drain-to-source voltages is applied, the drain current stays constant despite the increase in drain voltage

### 3.3

#### displacement current measurement

#### DCM

measurement method to measure carrier motion between the source/channel/drain and gate electrodes

### 3.4

#### charge trapping

phenomenon where the charge is trapped within (active layer and insulator layer) due to external and internal causes, when passing from the printed TFT's gate voltage through the forward scan (injection) and reverse scan (ejection)



### 3.5

#### channel capacitance

total capacitance generated in the boundary between the active and insulator layers due to the injection of electrons (or electron holes) into the active layer

### 3.6

#### turn-on voltage

magnitude of the gate voltage that needs to be applied to a printed transistor to cause the drain current to rise above the background (off) current

## 4 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

DCM displacement current measurement

FET field effect transistor

OTFT organic thin-film transistor

TFT thin-film transistor

## 5 Symbols and units

The information that is reported with all the symbols is shown in Table 1.

**Table 1 – List of symbols**

No	Name of quantity	Symbol	Unit	Remarks
1	Gate electrode	G	-	Refer to Figure 1
2	Drain electrode	D	-	Refer to Figure 1
3	Source electrode	S	-	Refer to Figure 1
4	Drain current	$I_D$	A	Refer to Figure 1 Refer to Figure 2
5	Source current	$I_S$	A	Refer to Figure 1 Refer to Figure 2
6	Voltage measured between the gate electrode and the source electrode	$U_{GS}$	V	Refer to Figure 1 Refer to Figure 2 Refer to Figure 3
7	Voltage measured between the drain electrode and the source electrode	$U_{DS}$	V	Refer to Figure 1
8	Current flow calculated as the sum of each measured value of $I_S$ versus $U_{GS}$ and $I_D$ versus $U_{GS}$	$I_{dis}$	A	Refer to Figure 3
9	Ammeter	$\textcircled{A}$	A	Refer to Figure 1
10	Oscilloscope	$\textcircled{V}$	V	Refer to Figure 1
11	Trapped charge	$Q_{trap}$	C	Refer to Table 3
12	Value difference between the first and second trap charge	$\Delta Q_{trap}$	C	Refer to Table 3
13	Injected carrier charge	$Q_{injected}$	C	Refer to Table 3
14	Ejected carrier charge	$Q_{ejected}$	C	Refer to Table 3

No	Name of quantity	Symbol	Unit	Remarks
15	First swing trapped charge	$Q_{\text{trap},1}$	C	Refer to Table 3
16	Second swing trapped charge	$Q_{\text{trap},2}$	C	Refer to Table 3
17	Channel capacitance	$C$	F	Refer to Table 3

## 6 Measuring method of DCM

### 6.1 Guidelines on measurements of printed TFT channel properties

The standard atmosphere for evaluation (test and measurement) and storage of the specimen shall be a temperature of  $(23 \pm 2) ^\circ\text{C}$  and relative humidity of  $(50 \pm 10) \%$ , conforming to standard atmosphere class 2 specified in ISO 291. For a test piece which is a plastic substrate with printed patterns, the standard atmosphere for evaluation (test and measurement) and storage of the specimen shall be a temperature of  $(23 \pm 1) ^\circ\text{C}$  and relative humidity of  $(50 \pm 5) \%$ , conforming to standard atmosphere class 1 specified in ISO 291.

### 6.2 Procedure for DCM

#### 6.2.1 Measuring apparatus

A function generator, an amplifier, an oscilloscope, and a battery shall be prepared as shown in Figure 1.

#### 6.2.2 Measuring procedure

- 1) Set a printed TFT as a specimen according to Figure 1.
- 2) Apply a triangle wave with constant frequency and amplitude to a gate terminal of the specimen, using the function generator and the amplifier.
- 3) Measure  $I_S$  versus  $U_{GS}$  (current flowing in the source electrode in accordance with changes in the signal applied to the gate) and  $I_D$  versus  $U_{GS}$  (current flowing in the drain in accordance with changes in the signal applied to the gate) using the oscilloscope.
- 4) Calculate  $I_{\text{dis}}$  (refer to Formula (A.1) and Formula (A.2) in Clause A.1).
- 5) Calculate  $Q_{\text{trap}}$  and  $\Delta Q_{\text{trap}}$  (refer to Formula (A.3) and Formula (A.4) in Clause A.1).

As a triangular wave with constant frequency and amplitude is applied to the gate voltage,  $I_S$  versus  $U_{GS}$  (current flowing in the source electrode in accordance with changes in the signal applied to the gate) and  $I_D$  versus  $U_{GS}$  (current flowing in the drain in accordance with changes in the signal applied to the gate) are measured.

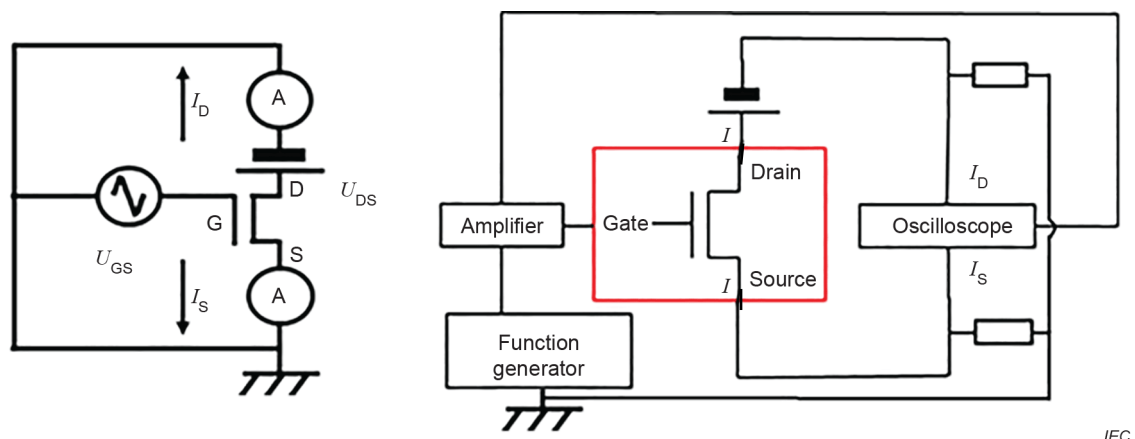


Figure 1 – Example of structure (left) and schema (right) of a measuring device

Because the probe station, passive probe, and measuring cable can cause distortion (delay) in the signal due to its internal capacitor, the electronic kit for measurement should be used in this document for the connection of the printed TFT and to minimize the effect of external capacitance. In DCM, the current flowing in the transistor cannot be measured directly, so commercial resistors should be connected.

An amplifier should be used for the application of gate voltage in the form of a triangular wave, for the saturation region of the printed TFT. The ability of the amplifier to distinguish signals depends on its type. When using a general-purpose, high-voltage amplifier, the increase in noise reduces the distinguishing capability, so a single-supply amplifier should be used, which has an amplification factor of 5. For a precise DCM, a unijunction transistor shall be used to measure separation, and for the connection of drain and source electrodes, an Ag paste ink, which does not require additional heat treatment processes or have parasitic capacitance, is recommended.

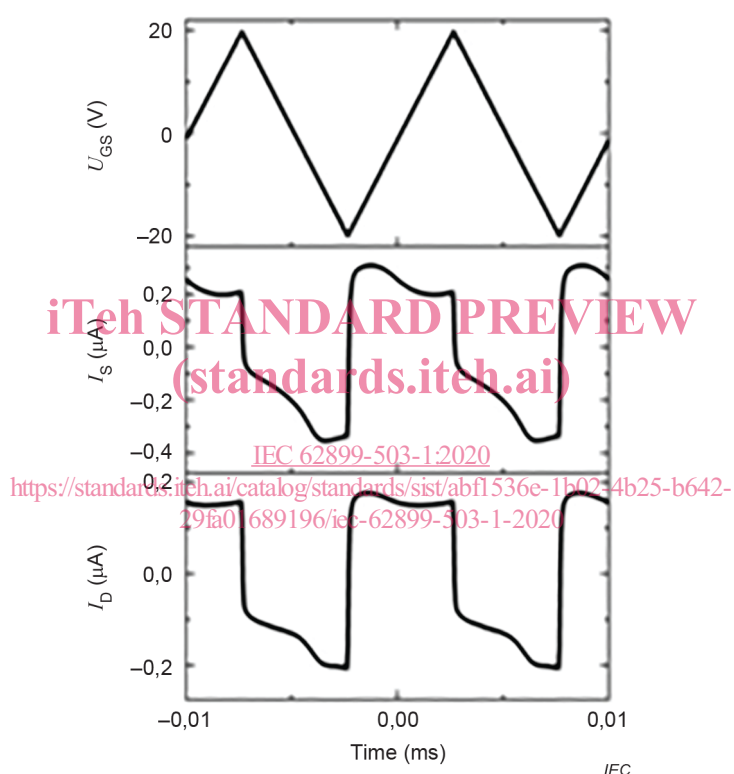


Figure 2 – Plots of the printed TFT's  $U_{GS}$ ,  $I_S$ ,  $I_D$  at  $U_{DS} = -20V$  with respect to time