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TEST METHODS FOR THE CHARACTERIZATION OF ORGANIC TRANSISTORS AND MATERIALS

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IEEE Std	FDIS	Report on voting
1620™-2008	113/184/FDIS	113/194/RVD

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IEEE Standard for Test Methods for the Characterization of Organic Transistors and Materials

Sponsor

Microprocessor Standards Committee
of the
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Approved 26 September 2008

IEEE-SA Standards Board

Abstract: Recommended methods and standardized reporting practices for electrical characterization of printed and organic transistors are covered. Due to the nature of printed and organic electronics, significant measurement errors can be introduced if the electrical characterization design-of-experiment is not properly addressed. This standard describes the most common sources of measurement error, particularly for high-impedance electrical measurements commonly required for printed and organic transistors. This standard also gives recommended practices in order to minimize and/or characterize the effect of measurement artifacts and other sources of error encountered while measuring printed and organic transistors.
Keywords: electrical characterization, FET, flexible electronics, high impedance, nanocomposite, nanotechnology, OFET, organic electronics, organic transistor, printed electronics, printing, transistor

IEEE Introduction

This introduction is not part of IEEE Std 1620-2008, IEEE Standard for Test Methods for the Characterization of Organic Transistors and Materials.

This standard covers recommended methods and standardized reporting practices for electrical characterization of organic transistors. Due to the nature of organic transistors, significant measurement errors can be introduced if not properly addressed. This standard describes the most common sources of measurement error and gives recommended practices in order to minimize and/or characterize the effect of each.

Standard reporting practices are included in order to minimize confusion in analyzing reported data. Disclosure of environmental conditions and sample size are included so that results can be appropriately assessed by the research community. These reporting practices also support repeatability of results so that new discoveries may be confirmed more efficiently.

The practices in this standard were compiled from research and industry organizations developing organic transistor devices, materials, and manufacturing techniques. These practices were based on standard operating procedures utilized in laboratories worldwide.

This standard was initiated in 2002 to facilitate the evolution of organic transistors from the laboratory into a sustainable industry. Standardized characterization methods and reporting practices create a means of effective comparison of information and a foundation for manufacturing readiness.

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Test Methods for the Characterization of Organic Transistors and Materials

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1. Overview

1.1 Scope

This standard describes a method for characterizing organic electronic devices, including measurement techniques, methods of reporting data, and the testing conditions during characterization.

1.2 Purpose

The purpose of this standard is to provide a method for systematically characterizing organic transistors. These standards are intended to maximize reproducibility of published results by providing a framework for testing organic devices, whose unique properties cause measurement issues not typically encountered with inorganic devices. This standard stresses disclosure of the procedures used to measure data and extract parameters so that data quality may be easily assessed. This standard also sets guidelines for reporting data, so that information is clear and consistent throughout the research community and industry.

1.3 Electrical characterization overview

1.3.1 Testing apparatus

Testing is performed using an electronic device test system with measurement sensitivity sufficient to give an accuracy of at least ±0.1% (minimum sensitivity at or better than three orders of magnitude below expected signal level). For example, the smallest current through an organic transistor is often the gate leakage current. If gate leakage is approximately 1 pA (10^{-12} A), the instrument shall have a resolution of 1 fA (10^{-15} A) or smaller. Additionally, due to the large (>1 GΩ) impedances encountered in organic devices, the input impedance of all elements of the test system shall be at least three orders of magnitude greater than the highest impedance in the device. Commercial semiconductor systems with the capability to characterize organic devices typically have input impedance values of 10^{16} Ω, which is a recommended minimum value.

This test method requires that the instrumentation be calibrated against a known and appropriate set of standards (e.g., National Institute of Standards and Technology, NIST). These calibrations may be performed by the equipment user or as a service by the equipment vendor. Calibration is not performed against a known organic field-effect transistor (OFET) or other FET-type device; the basic instrument operations (e.g., voltage, current, and resistance) are calibrated against some method traceable to a NIST (or similar internationally recognized standards organization) physical standard. Re-calibration is required according to the instrument manufacturer's recommendations or when the instrument is moved or when the testing conditions change significantly (e.g., temperature change greater than 10 °C, relative humidity change greater than 30%).

1.3.2 Measurement techniques

1.3.2.1 Required measurements

Characterization of the organic transistor requires at minimum the following two primary sets of measurements:

— The transfer (I_{DS} vs. V_{GS}) curves, which allow for preliminary determination of field-effect mobility, μ, and threshold voltage, V_T.

— The *I* versus *V* output (I_{DS} vs. V_{DS}) curves that provide saturation and general electrical performance information. This curve is used to determine whether the device exhibits FET-like behavior.

— The gate leakage (I_{GS} vs. V_{GS}) curves that characterize the gate dielectric quality and quantify leakage current from the gate to the channel. Leakage measurements are carried out prior to transfer or *I* versus *V* measurements to ensure gate dielectric integrity before subsequent measurements are performed. Gate leakage characterization is necessary to ensure that its magnitude is negligible to the magnitude of the drain current, so that reliable and useful device characteristics may be measured and key parameters extracted.

1.3.2.2 Recommended measurements

The following additional measurement is strongly recommended:

— The stray capacitance values C_{GD} and C_{GS}. Stray capacitance values have a negative effect on device switching speed and may affect device electrical characterization.

1.3.3 Repeatability and reporting sample size

Sample performance between different devices may vary due to variations in the fabrication process. Additionally, it is critical to determine how repeatable the reported results are. Therefore, sample size is to be reported thus:

— If no sample size is reported, it is assumed that the data represents a sample size of a single device (i.e., may not represent repeatable results).

— For sample sizes larger than one, the sample size is reported with the method of sampling (whether all devices were characterized, a randomly-chosen fraction of the total sample set, etc.).

A description of what the reported data demonstrates (average values, worst-case, etc.) is also required.

1.3.4 Application of low-noise techniques

Generally, lower absolute gate bias voltages cause smaller stress effects, such as shifts in the threshold voltage, than higher absolute gate biases. Depending on the device structure, this shifting may be reduced by ensuring that the device under test is properly grounded. This issue may be further improved if this grounding is through a low-impedance path to system ground.

In order for comparability between different device structures and eventual compatibility to nanoelectronics, voltages should be referenced to the corresponding film thickness (V_{GS}) and channel length (V_{DS}). Sufficient information is to be given so that electrical fields (V/cm) may be determined. Preferably, electrical field values are specified.

Due to optical sensitivity of some organic semiconducting materials, all measurements should be conducted inside a light-insulating enclosure that is preferably earth (safety) grounded. Optical isolation is recommended if exposure to ambient light causes a change of more than 1% from values obtained in the dark.

Due to the high impedances and extremely low current values being measured, proximity of personnel, heavy machinery, or other potential electromagnetic/radiofrequency interference (EMI/RFI) sources should be maintained as far away from the measurement system while in operation. This is of particular concern when measured voltages are below 1 mV or when current values are less than 1 μA.