IEC TS 62607-5-1

Edition 1.0 2014-09

TECHNICAL SPECIFICATION

colour inside

Nanomanufacturing – Key control characteristics – Part 5-1: Thin-film organic/nano electronic devices – Carrier transport measurements

IEC TS 62607-5-1:2014-09(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue
The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in 14 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
More than 55 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

IEC TS 62607-5-1

Edition 1.0 2014-09

TECHNICAL SPECIFICATION

colour inside

Nanomanufacturing – Key control characteristics – Part 5-1: Thin-film organic/nano electronic devices – Carrier transport measurements

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRICE CODE **P**

ICS 07.030
ISBN 978-2-8322-1812-9

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 5-1: Thin-film organic/nano electronic devices – Carrier transport measurements

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62607-5-1, which is a technical specification, has been prepared by IEC technical committee 113: Nanotechnology standardization for electrical and electronic products and systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
113/212/DTS	113/221/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62607 series, published under the general title *Nanomanufacturing key control characteristics*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Organic/nano thin-film devices have many attractive features such as being light-weight and flexible, and having a low-cost, low-temperature fabrication process. Organic/nano electronic devices have been widely researched by academic institutions, research institutes, and materials and device industries. One of their possible applications is therefore expected to be in flexible and rollable devices. Many thin-film transistors based on organic semiconductor materials, called organic thin-film transistors (OTFTs), are expected to be mounted on organic electroluminescence display to drive each organic light-emitting diode pixel circuit. These OTFTs are also promising candidates for molecular nanoelectronics.

OTFTs show a relatively smaller carrier mobility (thin-film mobility: at most 10 cm^2/Vs, but usually less than 1 cm^2/Vs) compared with other thin-film transistors based on inorganic semiconductors (silicon, III-V compounds, metal oxides). Carrier transport properties such as thin-film mobility and thin-film carrier concentration in OTFTs are usually measured by simply applying the device physics of silicon metal-oxide-semiconductor transistors to OTFTs. Both the intrinsic bulk mobility of organic semiconductors and extrinsic effects such as contact resistance, carrier trap, interface, and surface state can limit thin-film mobility in OTFTs. Therefore, reliable methods of evaluating carrier transport properties for nanometer-scale thin-film materials have not yet been established and urgently need to be developed.

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 5-1: Thin-film organic/nano electronic devices – Carrier transport measurements

1 Scope

This part of IEC 62607, which is a Technical Specification, provides a standardized sample structure for characterizing charge transport properties in thin-film organic/nano electronic devices and a format to report details of the structure which shall be provided with the measurement results. The standardized OTFT testing structure with a contact-area-limited doping can mitigate contact resistance and enable reliable measurement of the charge carrier mobility. The purpose of this Technical Specification is to provide test sample structures for determining the intrinsic charge transport properties of organic thin-film devices. The intention is to provide reliable materials information for OTFTs and to set guidelines for making test sample structures so that materials information is clear and consistent throughout the research community and industry.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at http://www.electropedia.org/)

IEC 62860, *Test methods for the characterization of organic transistors and materials*

3 Terms, definitions and abbreviations

For the purposes of this document, the terms and definitions given in IEC 60050-521 as well as the following apply.

3.1 Terms and definitions

3.1.1
organic thin-film transistor
OTFT
field-effect transistor that has a conduction channel made of thin films consisting of organic compounds

3.1.2
thin-film mobility
charge carrier mobility of the conduction channel (the semiconductor layer) in an OTFT

3.1.3
contact-area-limited doping
doping at around interface regions between the source and drain electrodes and the conduction channel in an OTFT

3.1.4
channel resistance
electrical resistance which comes from the conduction channel induced by applying gate voltages in a field-effect transistor

3.1.5
contact resistance
electrical resistance obtained by subtracting the channel resistance from the total electrical resistance between the source and drain electrodes in a field-effect transistor

Note 1 to entry: Main components of the contact resistance are electrical leads and carrier injection barriers at the interface between the source electrode and the semiconductor layer.

3.1.6
bottom-gate, bottom-contact device
field-effect transistor with the following structures:

– the gate electrode is located between the gate dielectric and the substrate;
– the source and drain electrodes are located directly on top of the substrate, and adjacent to the conduction channel-gate dielectric interface

3.1.7
bottom-gate, top-contact device
field-effect transistor with the following structures:

– the gate electrode is located between the gate dielectric and the substrate;
– the source and drain electrodes are located on top of the semiconductor layer

3.1.8
top-gate, bottom-contact device
field-effect transistor with the following structures:

– the gate electrode is located farthest away from the substrate;
– the gate dielectric is located between the gate electrode and the semiconductor layer;
– the source and drain electrodes are located directly on top of the substrate, and adjacent to the conduction channel-gate dielectric interface

3.1.9
top-gate, top-contact device
field-effect transistor with the following structures:

– the gate electrode is located farthest away from the substrate;
– the gate dielectric is located between the gate electrode and the semiconductor layer;
– the source and drain electrodes are located on top of the semiconductor layer

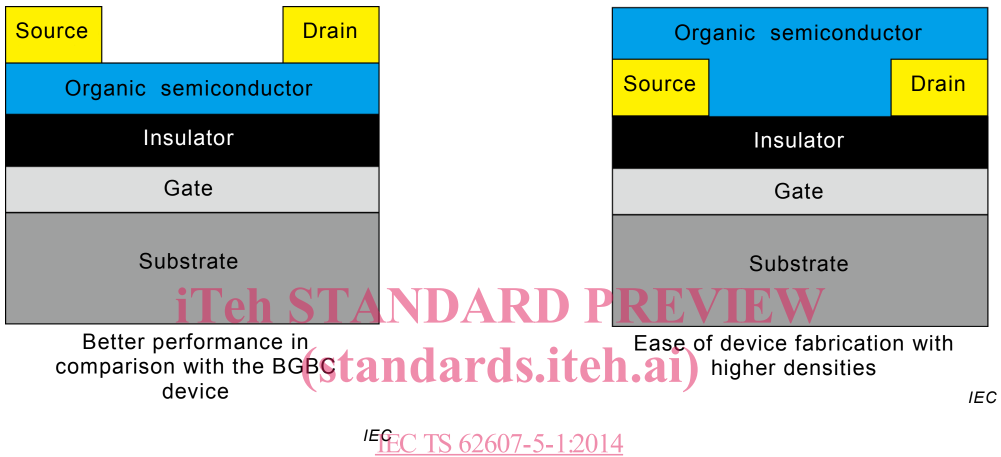
3.2 Symbols and abbreviated terms

OTFT	organic thin-film transistor
BGBC	bottom-gate, bottom-contact
BGTC	bottom-gate, top-contact
TGBC	top-gate, bottom-contact
TGTC	top-gate, top-contact
F4TCNQ	2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane

4 Sample structures of OTFTs

4.1 Typical device structures of OTFTs

Several different device structures on OTFTs are possible, depending on the position of the source-drain and gate electrodes. Figure 1 illustrates two typical device structures: a bottom-gate, top-contact (BGTC) structure and a bottom-gate, bottom-contact (BGBC) structure. BGTC devices usually show better performance in comparison with BGBC devices. In comparison, the BGBC structure is more suitable for high-density device integration. However, high contact resistance is a common and serious problem in OTFTs regardless of the device structure, because the high contact resistance leads to the underestimation of the intrinsic field-effect channel mobility in OTFTs [1],[2][1].



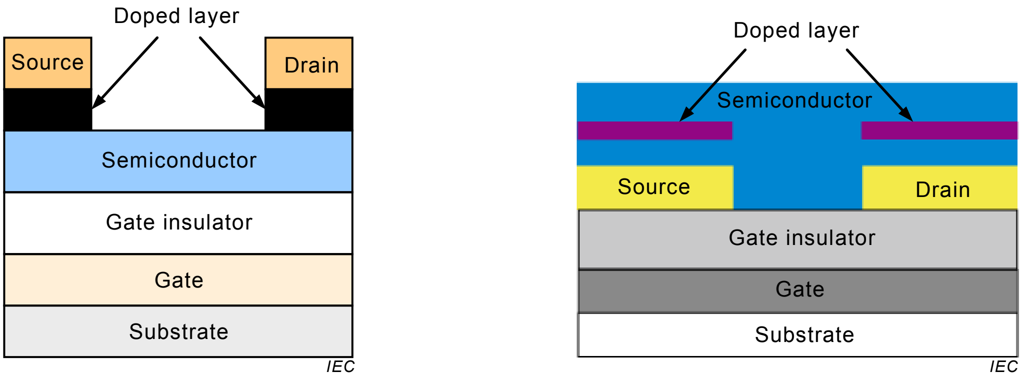
a) Bottom-gate, top-contact (BGTC) b) Bottom-gate, bottom-contact (BGBC)

Figure 1 – Typical device structures of OTFTs

4.2 Contact-area-limited doping in OTFTs

Contact-area-limited doping is effective for increasing the drain current in OTFTs [2], [3], [4], [5], [6], [7]. In this type of doping, as shown in Figure 2, acceptor (or donor) doped layers are formed at the interface regions between the active semiconductor layer and the contact electrode. These doped layers cause a decrease in the contact resistance, resulting in an increase in the drain current.

1 Figures in square brackets refer to the Bibliography.



a) BGTC transistor **b) BGBC transistor**

Figure 2 – Contact-area-limited doping in OTFTs

Contact-area-limited doping is a versatile method for improving the device performance of OTFTs. In other words, the effective thin-film mobility in the channel regions of OTFTs greatly depends on extrinsic effects such as structure and the electronic properties of the contact electrode area. Therefore, materials information on organic semiconductor films is not consistent throughout the research community and industry at present. This fact has led to this technical specification proposal for standard test sample structures. Namely, highly doped layers around contact electrodes are indispensable for reliably evaluating carrier mobility and concentration in organic semiconductor devices (see Figure 3).

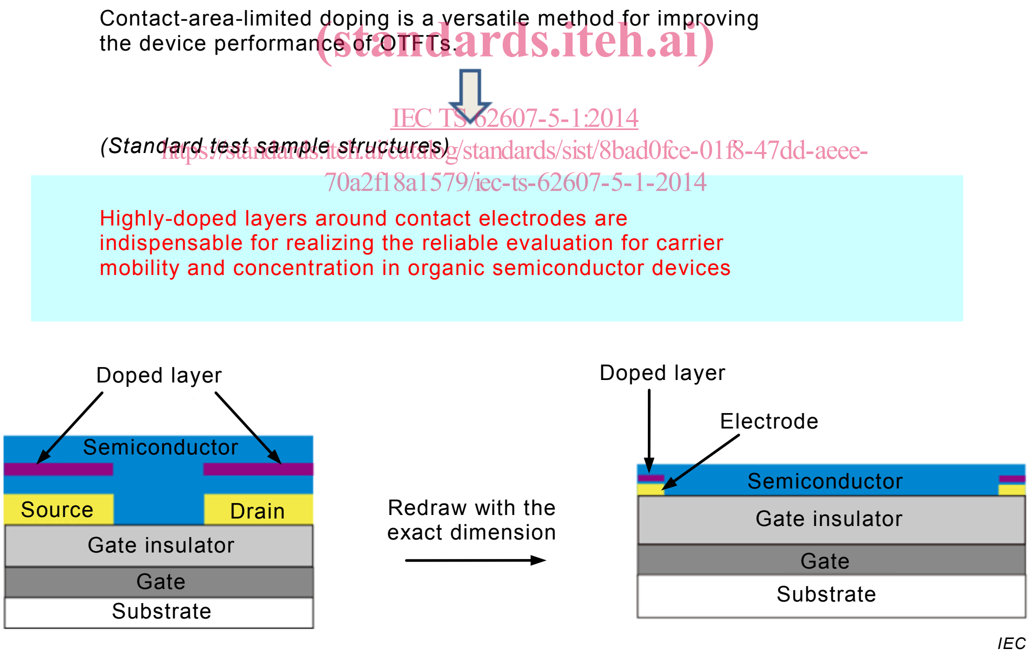


Figure 3 – Summary of this Technical Specification

5 Appropriate data format

A blank detail specification for OTFT test samples is an appropriate form for this Technical Specification (see Table 1). Items such as contact structure and contact electrode materials should be included in this Technical Specification.