PD IEC TS 62607-5-3:2020

BSI Standards Publication

Nanomanufacturing — Key control characteristics

Part 5-3: Thin-film organic/nano electronic devices — Measurements of charge carrier concentration

bsi.

National foreword

This Published Document is the UK implementation of IEC TS 62607-5-3:2020.

The UK participation in its preparation was entrusted to Technical Committee NTI/1, Nanotechnologies.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2020
Published by BSI Standards Limited 2020

ISBN 978 0 580 99198 1

ICS 07.030; 07.120

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 April 2020.

Amendments/corrigenda issued since publication

Date	Text affected

IEC TS 62607-5-3

Edition 1.0 2020-04

TECHNICAL SPECIFICATION

Nanomanufacturing – Key control characteristics – Part 5-3: Thin-film organic/nano electronic devices – Measurements of charge carrier concentration

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 07.030; 07.120

ISBN 978-2-8322-8073-7

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

® Registered trademark of the International Electrotechnical Commission

CONTENTS

FOREWORD ... 3
INTRODUCTION ... 5
1 Scope ... 6
2 Normative references ... 6
3 Terms and definitions ... 6
4 Sample structures ... 6
4.1 Metal/insulator/semiconductor (MIS) structure ... 6
4.2 Thin-film specimens with the van der Pauw configuration ... 7
5 Criteria for choosing a method for measuring carrier concentration in organic semiconductor layers ... 8
6 Appropriate data formats ... 8
Annex A (informative) Case study of carrier concentration measurements of organic materials ... 10
A.1 Procedure of capacitance-voltage (C-V) measurement ... 10
A.2 Capacitance-voltage measurement for unoptimized pentacene MIS structures ... 11
A.3 Influences of semiconductor layer thickness and electrode contact conditions on C-V measurements ... 13
A.4 Capacitance-voltage measurement for a pentacene MIS structure with an ultrathin insulator ... 14
A.5 Procedure of Hall-effect measurement ... 17
A.6 Hall-effect measurement for organic semiconductor single-crystalline layers ... 18
Bibliography ... 20

Figure 1 – Typical metal/insulator/semiconductor (MIS) structures ... 7
Figure 2 – An organic MIS structure favourable for capacitance-voltage measurements ... 7
Figure 3 – Sample structures for Hall-effect measurement with the van der Pauw configuration ... 8
Figure A.1 – Equivalent circuit model for capacitance-voltage measurement with MIS structure ... 10
Figure A.2 – Typical capacitance-voltage curves observed for MIS structures with organic semiconductor films ... 11
Figure A.3 – Capacitance-voltage curves obtained for the MIS structure with 70-nm-thick-pentacene film ... 12
Figure A.5 – Capacitance-voltage curves obtained for a pentacene MIS structure with an ultrathin SAM-modified AlOx insulator ... 16
Figure A.6 – Hall-effect measurement results for rubrene single-crystalline layer doped with ferric chloride ... 19

Table 1 – Possible data format to be given together with carrier concentrations obtained with capacitance-voltage measurements ... 9
Table 2 – Possible data format to be given together with carrier concentrations obtained with the Hall-effect measurements ... 9

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

**NANOMANUFACTURING –
KEY CONTROL CHARACTERISTICS –**

**Part 5-3: Thin-film organic/nano electronic devices –
Measurements of charge carrier concentration**

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 62607-5-3, which is a Technical Specification, has been prepared by IEC technical committee 113: Nanotechnology for electrotechnical products and systems.

The text of this Technical Specification is based on the following documents:

Draft TS	Report on voting
113/477/DTS	113/523/RVDTS

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 TS 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 website 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.

INTRODUCTION

Organic/nano thin-film devices are attracting much attention as promising candidates for light, low cost, flexible, and printable devices in large-area electronics applications. Recently, charge carrier doping techniques have been intensely studied and developed, in the same way as the mature silicon technologies. In organic light-emitting diodes (OLEDs) and organic thin-film transistors (OTFTs), which are typical organic/nano thin-film devices, carrier doping around contact electrode regions with molecular donor/acceptor dopants are often utilized to make ohmic-like contacts for the purpose of increasing electric current in the devices. While the great importance of carrier doping in organic/nano layers is well recognized, the carrier doping mechanisms have not been fully understood yet, and the evaluation method of charge carrier concentration in these materials has not been established.

Conventional representative methods for evaluating charge carrier concentrations (or dopant concentrations) and the type of charge carrier (electron or hole) in inorganic semiconductor materials are Hall-effect measurements and capacitance-voltage measurements. For example, the Hall-effect measurement based on the van der Pauw configuration enables one to get the above-mentioned physical parameters of the charge carrier in specimens with arbitrary shapes including thin-film structures. However, this versatile method cannot be utilized for higher resistance materials such as low-mobility organic semiconductors because of lower currents and sensitivities in the Hall effect. At the present time, the capacitance-voltage measurement based on metal/insulator/semiconductor structures is not applicable to highly-doped organic semiconductors that show some level of metallic behaviour. Therefore, standard methods and guidelines for measuring charge carrier concentration in organic semiconductor layers need to be developed.

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 5-3: Thin-film organic/nano electronic devices – Measurements of charge carrier concentration

1 Scope

This part of IEC TS 62607, which is a Technical Specification, specifies sample structures for evaluating a wide range of charge carrier concentration in organic/nano materials. This specification is provided for both capacitance-voltage (C-V) measurements in metal/insulator/semiconductor stacking structures and Hall-effect measurements with the van der Pauw configuration. Criteria for choosing measurement methods of charge carrier concentration in organic semiconductor layers are also given in this document.

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.

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
doping
addition of impurities to a semiconductor to control hole or electron concentrations

Note 1 to entry: For organic semiconductors, not only atomic, but also molecular impurities are utilized.

Note 2 to entry: The added impurities are called "dopants".

3.2
bottom-contact electrode
contact electrode located underneath the semiconductor layer to be tested

3.3
top-contact electrode
contact electrode located on top of the semiconductor layer to be tested

4 Sample structures

4.1 Metal/insulator/semiconductor (MIS) structure

Fabrication of a metal/insulator/semiconductor (MIS) structure as shown in Figure 1 is necessary for measuring a capacitance-voltage (C-V) curve in organic/nano semiconductor layers. This structure consists of a series capacitor of the insulator and a depletion region in the semiconductor layer.