



TECHNICAL SPECIFICATION



Nanomanufacturing – Key control characteristics – Part 2-1: Carbon nanotube materials – Film resistance

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE

P

ICS 07.030

ISBN 978-2-83220-114-5

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

CONTENTS

FOREWORD.....	3
INTRODUCTION.....	5
1 Scope.....	6
2 Terms, definitions, acronyms and abbreviations	6
2.1 Terms and definitions	6
2.2 Acronyms and abbreviations.....	7
3 Sample preparation methods	8
3.1 General.....	8
3.2 Reagents.....	8
3.2.1 Carbon nanotubes	8
3.2.2 Dispersants	8
3.3 Preparation of SWCNT or MWCNT films.....	8
3.4 Preparation of SWCNT or MWCNT ribbons.....	9
4 Measurement of sheet resistance of SWCNT or MWCNT films	9
4.1 4-point measurement.....	9
4.1.1 Demarcation of method.....	9
4.1.2 Experimental procedures and measurement conditions	9
4.2 4-wire measurement.....	10
4.2.1 Demarcation of method.....	10
4.2.2 Experimental procedures and measurement conditions	11
5 Data analysis / Interpretation of results.....	11
5.1 Sheet resistance of SWCNTs or MWCNTs using 4-point measurements	11
5.2 Sheet resistance of SWCNTs or MWCNTs using 4-wire measurements	11
Annex A (informative) Case study.....	13
Bibliography.....	16
Figure 1 – Preparation of SWCNT and MWCNT films.....	9
Figure 2 – 4-point probe.....	10
Figure 3 – Photo of typical 4-point measurement apparatus.....	10
Figure 4 – Diagram for 4-wire measurement apparatus	11
Figure A.1 – FE-SEM images of CNT ribbons	14
Figure A.2 – Photos of fabricated CNT specimens	14
Table A.1 – Properties of dispersants used to prepare thin-film samples.....	13
Table A.2 – Resistance and sheet resistance of MWCNTs and SWCNTs ribbons.....	15
Table A.3 – Results of 4-point measurements of CNT films and 4-wire measurements of CNT ribbons using the same sample preparation	15

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**NANOMANUFACTURING –
KEY CONTROL CHARACTERISTICS –****Part 2-1: Carbon nanotube materials –
Film resistance**

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

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 62607-2-1, 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
113/118/DTS	113/131/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 of 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.

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

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

There are two major trends in the fabrication of new materials incorporating carbon nanotubes (CNTs) for next generation of industrial applications:

- a) conducting composites in field-emission displays (FEDs), flexible displays, or printed electronics; and
- b) nano-composites for mechanical applications, by taking advantage of their attractive mechanical properties such as high Young's modulus, elastic behaviour and high tensile strength.

This IEC technical specification is related to a), the conducting composites application. As conducting composites using CNTs are increasingly being used in the electronics industry, it is essential to establish a standard method to evaluate their electrical properties.

Characterization of the electrical properties of CNTs used in conducting composites is important to both manufacturers and users. This IEC technical specification describes simple methods to characterize the electrical properties of CNT materials that are to be used in conducting composites.

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 2-1: Carbon nanotube materials – Film resistance

1 Scope

This part of IEC 62607 provides a standardized method for categorizing a grade of commercial CNTs in terms of their electrical properties to enable a user to select a CNT material suitable for their application. The method is intended to assess whether the delivered materials from different production batches of the same production process are comparable regarding electrical properties of the final product which are related to electrical conductivity. The correlation between the measured parameters by the proposed method and a relevant product performance parameter has to be established for every application. This specification includes

- a) definitions of terminology used in this document,
- b) recommendations for sample preparation,
- c) outlines of the experimental procedures to measure sheet resistance of CNTs in thin films,
- d) methods of interpretation of results and discussion of data analysis,
- e) case studies and,
- f) references.