IEC 62624

Edition 1.0 2009-08

INTERNATIONAL STANDARD

IEEE Std 1650™

Test methods for measurement of electrical properties of carbon nanotubes

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE Q

ICS 07.030; 17.220.20

ISBN 978-2-88910-775-9

CONTENTS

Foreword iii
IEEE Introduction vi

1. Overview 1

1.1 Scope 1
1.2 Purpose 1
1.3 Electrical characterization overview 1

2. Definitions, acronyms, and abbreviations 6

2.1 Definitions 6
2.2 Acronyms and abbreviations 7

3. Nanotube properties 7

3.1 Single-walled nanotube 8
3.2 Multi-walled nanotube 9

4. Electrodes 9

4.1 Materials 9
4.2 Method for electrode fabrication 9
4.3 Dimensions 10

5. Device characterization 10

5.1 Architecture design 10
5.2 Method for processing and fabrication 10
5.3 Standard characterization procedures 11
5.4 Environmental control and standards 14

Annex A (informative) Bibliography 15
Annex B (informative) List of Participants 16

Published by IEC under licence from IEEE. © 2009 IEEE. All rights reserved.

INTERNATIONAL ELECTROTECHNICAL COMMISSION

TEST METHODS FOR MEASUREMENT OF ELECTRICAL PROPERTIES OF CARBON NANOTUBES

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 provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
6) 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.

International Standard IEC 62624/IEEE Std 1650 has been processed through IEC technical committee 113: *Nanotechnology standardization for electrical and electronic products and systems*.

The text of this standard is based on the following documents:

IEEE Std	FDIS	Report on voting
1650 (2005)	113/58A/FDIS	113/63/RVD

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

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

Published by IEC under licence from IEEE. © 2009 IEEE. All rights reserved.

IEC/IEEE Dual Logo International Standards

This Dual Logo International Standard is the result of an agreement between the IEC and the Institute of Electrical and Electronics Engineers, Inc. (IEEE). The original IEEE Standard was submitted to the IEC for consideration under the agreement, and the resulting IEC/IEEE Dual Logo International Standard has been published in accordance with the ISO/IEC Directives.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

Use of an IEC/IEEE Dual Logo International Standard is wholly voluntary. The IEC and IEEE disclaim liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEC or IEEE Standard document.

The IEC and IEEE do not warrant or represent the accuracy or content of the material contained herein, and expressly disclaim any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEC/IEEE Dual Logo International Standards documents are supplied “AS IS”.

The existence of an IEC/IEEE Dual Logo International Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEC/IEEE Dual Logo International Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEC and IEEE are not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Neither the IEC nor IEEE is undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEC/IEEE Dual Logo International Standards or IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations – Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments for revision of IEC/IEEE Dual Logo International Standards are welcome from any interested party, regardless of membership affiliation with the IEC or IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA and/or General Secretary, IEC, 3, rue de Varembé, PO Box 131, 1211 Geneva 20, Switzerland.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

NOTE – Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

IEEE Standard Test Methods for Measurement of Electrical Properties of Carbon Nanotubes

Sponsor

Nanotechnology Council Standards Committee
of the
IEEE Nanotechnology Council

Approved 8 December 2005

IEEE-SA Standards Board

Abstract: Recommended methods and standardized reporting practices for electrical characterization of carbon nanotubes (CNTs) are covered. Due to the nature of CNTs, significant measurement errors can be introduced if the electrical characterization design-of-experiment is not properly addressed. The most common sources of measurement error, particularly for high-impedance electrical measurements commonly required for CNTs, are described. Recommended practices in order to minimize and/or characterize the effect of measurement artifacts and other sources of error encountered while measuring CNTs are given.

Keywords: carbon nanotube, electrical characterization, high-impedance measurement, nanotechnology

Published by IEC under licence from IEEE. © 2009 IEEE. All rights reserved.

IEEE Introduction

This standard covers recommended methods and standardized reporting practices for electrical characterization of carbon nanotubes (CNTs). Due to the nature of CNTs, 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 error.

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 scientists and engineers from the CNT field. These practices were based on standard operating procedures utilized in facilities worldwide. This standard was initiated in 2003 to assist in the diffusion of CNT technology from the laboratory into the marketplace. Standardized characterization methods and reporting practices creates a means of effective comparison of information and a foundation for manufacturing readiness.

Notice to users

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: http://standards.ieee.org/reading/ieee/updates/errata/index.html. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: http://standards.ieee.org/reading/ieee/interp/index.html.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents or patent applications for which a license may be required to implement an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Published by IEC under licence from IEEE. © 2009 IEEE. All rights reserved.

TEST METHODS FOR MEASUREMENT OF ELECTRICAL PROPERTIES OF CARBON NANOTUBES

1. Overview

1.1 Scope

This standard provides methods for the electrical characterization of carbon nanotubes (CNTs). The methods will be independent of processing routes used to fabricate the CNTs.

Published by IEC under licence from IEEE. © 2009 IEEE. All rights reserved.