IEC TS 62607-6-28

Edition 1.0 2025-09

TECHNICAL SPECIFICATION

Nanomanufacturing - Key control characteristics -
Part 6-28: Graphene-related products - Number of layers for graphene films on a substrate: Raman spectroscopy

ICS 07.120

ISBN 978-2-8327-0740-1

IEC TS 62607-6-28:2025-09(en)

THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2025 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

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

Tel.: +41 22 919 02 11
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 corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
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 It also gives information on projects, replaced and withdrawn publications.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 once a month by email.

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: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews, graphical symbols and the glossary. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 500 terminological entries in English and French, with equivalent terms in 25 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

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

CONTENTS

FOREWORD 3
INTRODUCTION 5
1 Scope 6
2 Normative references 6
3 Terms, definitions and abbreviated terms 6
3.1 General terms 7
3.2 Key control characteristics measured according to this standard 8
3.3 Terms related to the measurement method 9
3.4 Abbreviated terms 10
4 Method A 11
4.1 General 11
4.1.1 Measurement principle 11
4.1.2 Sample preparation method 12
4.1.3 Description of measurement equipment and apparatus 12
4.1.4 Ambient conditions during measurement 12
4.2 Measurement procedure 13
4.2.1 Calibration of measurement equipment 13
4.2.2 Detailed description of the measurement procedure 13
4.3 Data analysis and interpretation of results 13
5 Method B 14
5.1 General 14
5.1.1 Measurement principle 14
5.1.2 Sample preparation method 15
5.1.3 Description of measurement equipment 15
5.1.4 Ambient conditions during measurement 15
5.2 Measurement procedure 15
5.2.1 Calibration of measurement equipment 15
5.2.2 Detailed description of the measurement procedure 16
5.3 Data analysis and interpretation of results 16
6 Test report 17
6.1 Cover sheet 17
6.2 Measurement information 17
6.3 Sample information 17
6.4 Test results 17
Annex A (informative) Comparison of Method A and Method B 18
Annex B (informative) Spectral characteristics of a typical Raman peak 19
Annex C (informative) Calculation of I_G(Si) and I_0(Si) 20
C.1 Optical interference model for the Raman intensity from the multi-layered structures 20
C.2 Calculation of I_G(Si) 22
C.3 Calculation of I_0(Si) 24
Annex D (informative) Theoretical values of I_G(Si)/I_0(Si) in Method B excited by 532 nm 25
Annex E (informative) Test report 26
Annex F (informative) Application example 27

F.1 Application example 1 27
F.2 Application example 2 28
Bibliography 31

Figure 1 – The schematic crystal structures 8
Figure 2 – Raman spectra of G and 2D-peak of 1LG to 5LG and HOPG 12
Figure 3 – Schematic diagram of I_G(Si)and I_0(Si) on SiO_2/Si substrate 14
Figure 4 – The relationship of I_G(Si)/I_0(Si) and N (1 to 10) under 532 nm excitation 15
Figure B.1 – Schematic diagram of the spectral characteristics of a typical Raman peak 19
Figure C.1 – Multiple reflection and optical interference in the multilayer structures 20

Table 1 – I_G(Si)/I_0(Si) of N (1 to 10) under 532 nm laser with h_{SiO_2} = 90nm, NA = 0,50 16
Table A.1 – Comparison of Method A and Method B 18
Table D.1 – Theoretical values of I_G(Si)/I_0(Si) in Method B excited by 532 nm 25
Table E.1 – Test report 26
Table F.1 – Test report by Method A 27
Table F.2 – Test report by Method B 29

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

Nanomanufacturing - Key control characteristics - Part 6-28: Graphene-related products - Number of layers for graphene films on a substrate: Raman spectroscopy

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) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TS 62607-6-28 has been prepared by IEC technical committee 113: Nanotechnology for electrotechnical products and systems. It is a Technical Specification.

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

Draft	Report on voting
113/897/DTS	113/923/RVDTS

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

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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 document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

– reconfirmed,

– withdrawn, or

– revised.

INTRODUCTION

Graphene-related products have appealing performance in electrical, optical, mechanical and thermal properties, which have aroused widespread interests in both academic and industrial communities. The number of layers of graphene-related products is one of the key control characteristics (KCCs) affecting their performance. Therefore, the accurate measurement of the number of layers is a critical issue in related research and applications. Raman spectroscopy is a fast, non-destructive and highly sensitive characterization tool used in graphene-related research. The most prominent Raman peaks in graphene layers are the D-peak (~1 350 cm^{-1}), the G-peak (~1 580 cm^{-1}), and the 2D-peak (also known as the G'-peak, ~ 2 700 cm^{-1}, which depends on the excitation energy and number of layers). Their peak positions, peak intensities and peak shapes can be used to determine the number of layers [1][1]. For example, the intensity ratio of 2D-peak and G-peak (I_{2D}/I_G) of roughly 2 or higher provides a good identification of monolayer graphene. As the number of graphene layers increasing, the I_{2D}/I_G ratio decreases rapidly.

As for multilayer graphene layers with Bernal stacking (AB stacking) and rhombohedral stacking (ABC stacking) prepared by mechanical exfoliation, the spectral characteristics of their Raman peaks show certain relationships with the number of layers. For example, the 2D-peak of graphene-related products with AB stacking less than 5 layers has a distinctive peak shape that is related to the number of layers but independent of the substrate. The Raman peak intensity of the silicon substrate underneath the graphene-related products with AB and ABC stacking is also related to the number of layers. The $I_G(Si)/I_0(Si)$ intensity ratio declines linearly with the number of layers, where $I_G(Si)$ is the Raman peak intensity of silicon substrate underneath the graphene layers while $I_0(Si)$ is that of the bare silicon substrate [2] [3]. Therefore, the number of graphene layers up to 10 can be precisely determined using only Raman spectroscopy based on these two criteria.

Both methods employ Raman spectroscopy to characterize the number of layers of graphene-related products. Method A is based on the Raman shape of 2D-peak and is suitable for mechanical exfoliated graphene-related products with AB stacking and less than 5 layers. Method B is based on the intensity ratio of the $I_G(Si)/I_0(Si)$ and is applicable to mechanical exfoliated and chemical vapor deposition grown graphene-related products with AB and ABC stacking and the number of layers up to 10. The purpose of this document is to provide scientific and reliable technical guidance for the electronic products and research of graphene-related products.

Since the crystallinity and structure of graphene-related products prepared by different processes can vary greatly, no existing characterization method is general. In practical applications, it is important to select or combine multiple characterization methods based on the crystallinity and structure of the graphene-related products under study that best meets the specific needs.

---

[1] Numbers in square brackets refer to the Bibliography.

1 Scope

This part of IEC 62607 establishes two standardized methods to determine the key control characteristic

- number of layers

for graphene layers by

- Raman spectroscopy.

This document presents two complementary methods for determining the number of layers in graphene-related products: Method A, which analyzes the lineshape of the 2D-peak in the Raman spectrum, and Method B, which measures the Raman intensity from the underlying silicon substrate. The two methods can be employed individually but combining both methods enhances accuracy and extends the detection range for the number of layers and stacking configurations.

– The method is intended to be used for graphene layers prepared by mechanical exfoliation, but also can be used with care for other high quality graphene layers, such as graphene layers prepared by chemical vapor deposition.

– The method can be used for graphene layers with AB and ABC stacking on a substrate. Its lateral size should be at least 2 μm.

– Method A is effective for AB stacked graphene up to 4 layers but becomes less reliable with more layers due to peak overlap.

– Method B can detect up to 10 layers in AB and ABC stacking but oxidized silicon substrate (SiO_2 on silicon substrate) is required.

– The comparison of Method A and Method B can be found in Annex A.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC TR 63258, *Nanotechnologies - A guideline for ellipsometry application to evaluate the thickness of nanoscale films*