

TECHNICAL SPECIFICATION



**Nanomanufacturing – Key control characteristics –
Part 6-14: Graphene-based material – Defect level: Raman spectroscopy**



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

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

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CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	8
2 Normative references	8
3 Terms and definitions	8
3.1 General terms	8
3.2 Key control characteristics measured in accordance with this document	11
4 General	11
4.1 Measurement principle.....	11
4.2 Sample preparation method	12
4.3 Description of measurement equipment/apparatus	12
4.4 Supporting materials	12
4.5 Ambient conditions during measurement.....	12
5 Measurement procedure	13
5.1 Calibration of measurement equipment	13
5.2 Detailed protocol of the measurement procedure	13
5.3 Measurement accuracy	13
5.4 Measurement uncertainty source	13
6 Sampling plan.....	13
7 Data analysis / interpretation of results	13
8 Results to be reported	14
8.1 General.....	14
8.2 Product/sample identification	14
8.3 Test conditions	14
8.4 Measurement specific information.....	14
8.5 Test results	14
Annex A (informative) Recommended format of the test report.....	15
Annex B (informative) Sampling plan	17
Annex C (informative) Case study: measurement and data analysis.....	18
C.1 Step 1: sample preparation	18
C.2 Step 2: Raman test	18
C.3 Step 3: Raman spectra processing.....	18
C.4 Step 4: Data analysis	19
Annex D (informative) Why use the intensity ratio $I_{D+D'}/I_{2D}$ for defect level characterization of graphene powder?	22
D.1 Interpretation of characteristic bands in the Raman spectrum of graphene and Raman scattering mechanism	22
D.2 Example – Influence of edges in the Raman spectrum of graphene.....	22
D.3 Example – Influence of defect in the Raman spectrum of single layer graphene	24
D.4 Example – Raman characteristics of reduced graphene sheet.....	26
D.5 Conclusion.....	27
Bibliography.....	28

Figure 1 – Schematic diagram of Raman scattering processes in realistic graphene material	6
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Figure 2 – Different packing configurations of graphene flakes in film (left) and powder (right).....	6
Figure 3 – Schematic drawing of Raman spectra of defective graphene (upper) and pristine graphene (bottom).....	12
Figure 4 – Schematic drawing of sample preparation method.....	12
Figure B.1 – Schematic drawing of five-point-sampling method.....	17
Figure B.2 – Location of measurement points	17
Figure C.1 – The field view of graphene sample beneath Raman microscope	18
Figure C.2 – The procedure of Raman spectrum processing	19
Figure C.3 – Typical Raman spectrum after processing	20
Figure C.4 – The overall defect level of one test sample	21
Figure C.5 – Measurement results of different testing organizations	21
Figure D.1 – Characteristic bands in the Raman spectrum of graphene and Raman processes [6]	22
Figure D.2 – Raman spectra from the edges of a monolayer graphene sample [9]	23
Figure D.3 – Raman spectra obtained from monolayer graphene samples with hexagonal and circular holes [10].....	23
Figure D.4 – Raman spectra for four different ion doses in graphene [1]	24
Figure D.5 – $E_L^4 [I_D/I_G]$ as a function of L_D [2]	24
Figure D.6 – (a) Definition of the activated A-region (green) and structurally-disordered S-region (red). (b-e) Snapshots of the structural evolution of the graphene sheet for different defect concentrations [1]	25
Figure D.7 – Evolution of 2D and other second-order bands with increasing ion doses [5]	25
Figure D.8 – Raman characteristics of as-made graphene sheet and different types of reduced graphene sheet film samples: (a) Raman spectra; (b) D/G intensity ratios; (c) S3/2D intensity ratios [7].....	26
Figure D.9 – Resistivity of as-made graphene sheet and different types of reduced graphene sheet [7].....	26
Table A.1 – Product identification (in accordance with IEC 62565-3-1).....	15
Table A.2 – General material description (in accordance with IEC 62565-3-1).....	15
Table A.3 – Information related with test	16
Table A.4 – Measurement results.....	16
Table C.1 – Average $I_{D+D'}/I_{2D}$ of each test point	20

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

IEC TS 62607-6-14, 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:

Enquiry draft	Report on voting
113/495/DTS	113/536/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 document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of 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 document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

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INTRODUCTION

Graphene has been intensively studied by researchers from both academic and industrial communities due to its unique properties, which include exceptional thermal conductivity, great strength and excellent transparency. Defects in graphene influence its optical and magnetic performance, electronic structure and thermal conductivity, thus influencing its applications. Therefore, defect is a key control characteristic for the fabrication of high-quality graphene for desired applications.

One of the most useful methods to evaluate defect level in graphene is Raman spectroscopy, which is sensitive to the structure of samples. This method is efficient, non-contact and well-understood. The defect states and boundary states of realistic graphene material will induce a series of Raman scattering processes (Figure 1). Some of scattering processes are only associated with defective states, which are used in this document to analyse defect level in graphene powder.

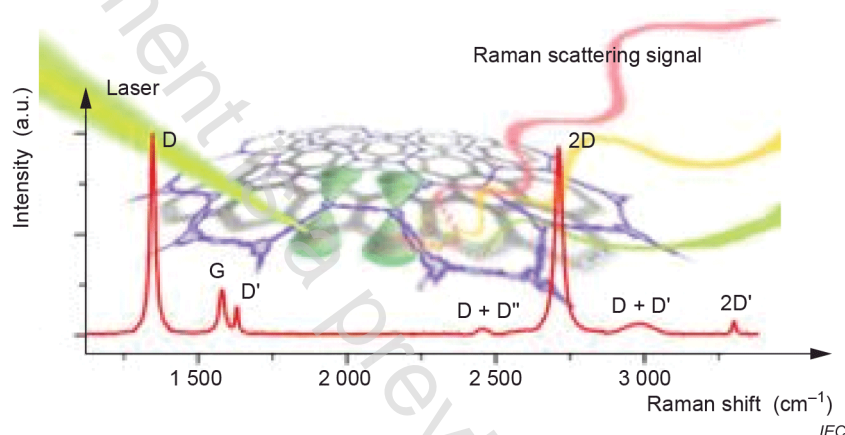


Figure 1 – Schematic diagram of Raman scattering processes in realistic graphene material

Commercialized graphene samples can be classified by their physical forms as graphene film, graphene powder and graphene solution. Figure 2 shows the schematic packing configurations of graphene flakes in graphene film (left side of Figure 2) and graphene powder (right side of Figure 2) and their corresponding SEM images.

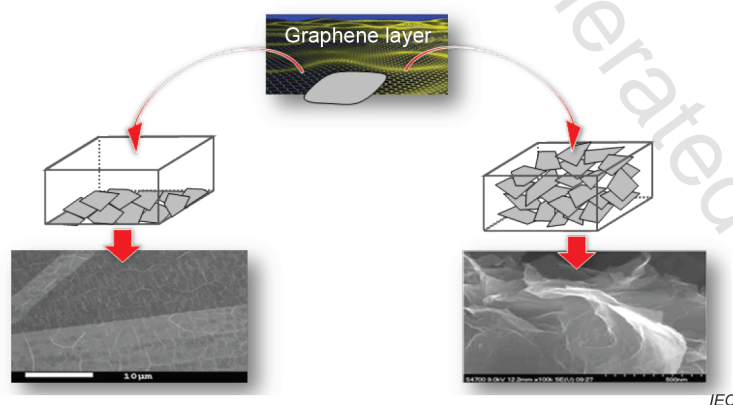


Figure 2 – Different packing configurations of graphene flakes in film (left) and powder (right)

Usually, defects in graphene films are characterized by the intensity ratio of two principle bands – D band and G band – in Raman spectra (symbolized by I_D/I_G) [1],[2]. However, in graphene powders consisting of flakes with sizes below 10 μm there are numerous edges and boundary states, which all contribute to the D-band signal and make its correlation to various defects problematic. The D-band intensity could result from the contribution of edges, boundary states or defects, so it is not appropriate to determine the defect level of graphene powder with the parameter I_D/I_G .

D+D' band is only relevant with defects in graphene powder, but not with edges and boundary states. Therefore, in order to characterize defect level in graphene powder, the intensity ratio of D+D' and 2D bands (symbolized by $I_{D+D'}/I_{2D}$) is proposed as a more relevant parameter in this document. Detailed information can be found in Annex D.

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-14: Graphene-based material – Defect level: Raman spectroscopy

1 Scope

This part of IEC TS 62607 establishes a standardized method to determine the structural key control characteristic

- defect level
for powders consisting of graphene-based material by

- Raman spectroscopy.

The defect level is derived by the intensity ratio of the D+D' band and 2D band in Raman spectrum, $I_{D+D'}/I_{2D}$.

- The defect level determined in accordance with this document will be listed as a key control characteristic in the blank detail specification for graphene IEC 62565-3-1 for graphene powder.
- The method is applicable for graphene powder or graphene-based material, e.g. reduced graphene oxide (rGO), bilayer graphene, trilayer graphene and few-layer graphene.
- Typical application areas are quality control and classification for graphene manufacturers, and product selection for downstream users.
- The method described in this document is appropriate if the physical form of graphene is powder.

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 General terms

3.1.1

two-dimensional material

2D material

material, consisting of one or several layers with the atoms in each layer strongly bonded to neighbouring atoms in the same layer, which has one dimension, its thickness, in the nanoscale or smaller and the other two dimensions generally at larger scales

Note 1 to entry: The number of layers when a two-dimensional material becomes a bulk material varies depending on both the material being measured and its properties. In the case of graphene layers, it is a two-dimensional material up to 10 layers thick for electrical measurements, beyond which the electrical properties of the material are not distinct from those for the bulk (also known as graphite).

Note 2 to entry: Interlayer bonding is distinct from and weaker than intralayer bonding.