



TECHNICAL SPECIFICATION



Nanomanufacturing – Key control characteristics – Part 6-6: Graphene – Strain uniformity: Raman spectroscopy

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 07.120

ISBN 978-2-8322-4305-3

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

CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	7
2 Normative references	7
3 Terms and definitions	7
3.1 General terms	8
3.2 Key control characteristics	8
3.3 Measurement related terms	9
4 General introduction	9
4.1 Measurement principle.....	9
4.2 Sample preparation method	10
4.3 Test equipment.....	11
4.4 Calibration standards	11
5 Measurement procedure	12
5.1 Calibration of test equipment	12
5.2 Description of the measurement procedure	12
5.3 Measurement accuracy	12
6 Data analysis/interpretation of results.....	12
7 Sampling plan.....	14
8 Test report.....	14
Annex A (informative) Format of the test report.....	15
Annex B (normative) Sampling plan	17
B.1 General.....	17
B.2 Sampling plan for circular substrates	17
B.3 Sampling plan for square substrates	18
B.4 Sampling plan for irregular substrates.....	19
Annex C (informative) Recommendations for wavelengths depending on substrate.....	20
Annex D (informative) Examples of Raman spectra of single-layer graphene on different substrates	21
D.1 Example 1: FWHM(2D) = 16,6 cm ⁻¹ – Graphene encapsulated in hexagonal boron nitride	21
D.2 Example 2: FWHM(2D) = 22,3 cm ⁻¹ – Graphene on SiO ₂ covered with hBN	21
D.3 Example 3: FWHM(2D) = 25,3 cm ⁻¹ – Graphene on SiO ₂	22
D.4 Example 4: FWHM(2D) = 34,8 cm ⁻¹ – Graphene on SiO ₂ substrate covered with hBN	23
D.5 Example 5: FWHM(2D) = 40,3 cm ⁻¹ – Graphene on SiO ₂ covered with very thin hBN.....	23
Annex E (informative) Relation between observed Raman 2D linewidth and carrier mobility.....	25
Bibliography.....	27
Figure 1 – Typical Raman spectra of an exfoliated graphene flake adopted from [6]	10
Figure 2 – Schematic illustration of a confocal Raman setup.....	11
Figure 3 – Example FWHM(2D) Raman map.....	13
Figure 4 – Example FWHM(2D) histogram obtained from the Raman map in Figure 3.....	13

Figure B.1 – Sampling plan for circular substrates of diameter a	17
Figure B.2 – Sampling plan for square substrates with edge length a	18
Figure B.3 – Sampling plan for irregular substrates	19
Figure D.1 – Spectrum of graphene encapsulated in hBN	21
Figure D.2 – Spectrum of graphene on SiO ₂ covered with hBN	22
Figure D.3 – Spectrum of graphene on SiO ₂	22
Figure D.4 – Spectrum of graphene on SiO ₂ covered with hBN	23
Figure D.5 – Spectrum of graphene on SiO ₂ covered with hBN	24
Figure E.1 – Relation of the inverse mobility and the average full width at half maximum FWHM(2D) of the Raman 2D-peak	26
Table A.1 – Sample identification	15
Table A.2 – General material information	15
Table A.3 – Test related information	16
Table A.4 – Schematic of sample geometry/structure	16
Table A.5 – Measured key control characteristic	16
Table B.1 – Sampling plan for circular substrates	18
Table B.2 – Sampling plan for square substrates	18
Table C.1 – Laser wavelength recommendations	20

INTERNATIONAL ELECTROTECHNICAL COMMISSION

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-6: Graphene – Strain uniformity: 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) 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.

IEC TS 62607-6-6 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
113/579/DTS	113/605/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/standardsdev/publications.

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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

IMPORTANT – The "colour inside" logo on the cover page of this document 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

Graphene, a single layer of carbon atoms arranged in a honeycomb lattice, has a high potential for future nanoelectronic applications thanks to the excellent conductivity and high flexibility of the material. As there is a strong connection between nanoscale lattice deformations and carrier mobility, the uniformity of strain and flatness of the graphene lattice is a key control characteristic for the fabrication of high-quality graphene layers for electronic devices.

One of the most useful methods to evaluate the structural properties of graphene is Raman spectroscopy (see, for example, [1]¹). The method is simple, fast, non-destructive and well understood so that the Raman spectrum can be used as a fingerprint for graphene especially if the sample under evaluation consists of single-layer graphene not too far away from perfection. Things become more complicated if the sample consists of more than one layer, perhaps with different stacking angles and many lattice defects. As this document is intended to support the fabrication of nearly defect-free high-quality single-layer graphene, the interpretation of the Raman spectrum remains relatively simple.

As recently reported [2], nanometre-scale strain variations in graphene give rise to a pseudo-vector disorder potential which allows the pseudo-spin in graphene to flip and thus enables intra-valley backscattering. This scattering mechanism has been identified to be the responsible mechanism for limiting the carrier mobility in high-quality graphene [2]. Interestingly these nanometre-scale strain variations are directly connected to the experimentally observed linewidth of the Raman 2D-peak [3], making this quantity a very interesting measure for estimating the possibility of getting very high mobility graphene devices.

It is important to note that although graphene is a truly two-dimensional material, consisting exclusively of surface atoms, it is embedded in our three-dimensional world. This has the consequence that the properties of graphene are in all cases intrinsically influenced by its intimate surrounding. Thus, substrates or contact gases (in the case of suspended graphene) play a very crucial role when fabricating, transferring and characterizing graphene. Most crucially, substrates, contact gases and moisture are actually becoming part of the graphene system under investigation and there is no way (in practice) of eliminating their influence on the two-dimensional graphene layer.

¹ Numbers in square brackets refer to the Bibliography.

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-6: Graphene – Strain uniformity: Raman spectroscopy

1 Scope

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

- strain uniformity

for single-layer graphene by

- Raman spectroscopy.

The width of the 2D-peak in the Raman spectrum is analysed to calculate the strain uniformity parameter which is a figure of merit to quantify the influence of nano-scale strain variations on the electronic properties of the layer. The classification will help manufacturers to classify their material quality to provide an upper limit of the electronic performance of the characterized graphene, to decide whether or not the graphene material quality is potentially suitable for various applications.

- The uniformity of strain measured by this method is applicable for nearly defect free, high-quality single-layer graphene, e.g. synthesized by chemical vapour deposition or graphene integrated into 2D-material heterostructures.
- The method is used if the Raman spectrum shows a visible D-peak with an integrated intensity ratio $A(D)/A(G) < 0,1$.
- Confocal Raman spectroscopy is used to consistently evaluate the graphene layer according to strain variations on the nanoscale.

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 TS 62607-6-11, *Nanomanufacturing – Key control characteristics – Part 6-11: Graphene film – Defect density: Raman spectroscopy*²

² Under preparation. Stage at the time of publication: IEC DTS 62607-6-11.