

This is a preview of "PD IEC TS 62607-6-1:...". [Click here to purchase the full version from the ANSI store.](#)



**BSI Standards Publication**

## **Nanomanufacturing — Key control characteristics**

---

Part 6-1: Graphene-based material — Volume resistivity: four probe method

This is a preview of "PD IEC TS 62607-6-1:...". [Click here to purchase the full version from the ANSI store.](#)

## National foreword

This Published Document is the UK implementation of IEC TS 62607-6-1:2020.

The UK participation in its preparation was entrusted to Technical Committee NTI/1, Nanotechnologies.

A list of organizations represented on this committee can be obtained on request to its committee manager.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2020  
Published by BSI Standards Limited 2020

ISBN 978 0 580 97331 4

ICS 07.120

**Compliance with a British Standard cannot confer immunity from legal obligations.**

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 July 2020.

### Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

---

This is a preview of "PD IEC TS 62607-6-1:...". [Click here to purchase the full version from the ANSI store.](#)



Edition 1.0 2020-07

# TECHNICAL SPECIFICATION



---

**Nanomanufacturing – Key control characteristics –  
Part 6-1: Graphene-based material – Volume resistivity: four probe method**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

---

ICS 07.120

ISBN 978-2-8322-8561-9

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

This is a preview of "PD IEC TS 62607-6-1:...". Click here to purchase the full version from the ANSI store.

## 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 Terms related to measurements.....	8
4 Sample preparation .....	10
5 Measurement of volume resistivity of graphene pellet.....	10
5.1 Description of the measurement apparatus .....	10
5.2 Determination of sample amount.....	12
5.3 The measurement procedures.....	12
6 Data analysis and interpretation of results .....	12
6.1 General.....	12
6.2 Analysis of volume resistivity as a function of the applied pressures .....	13
6.3 Calculation of volume conductivity of a pellet.....	13
6.4 Analysis of volume resistivity (or volume conductivity) as a function of the volume density of graphene pellet.....	13
7 Report .....	14
Annex A (informative) Case studies .....	15
A.1 Graphene (reduced graphene oxide (rGO) and graphene nanopowder (GNP)).....	15
A.2 Morphology change of rGO flakes before and after pressurization.....	15
A.3 Raman spectroscopy measurement of graphene powder before and after pressurization up to 52 MPa.....	16
A.4 Results on powder resistivity measurements.....	17
A.4.1 Powder resistivity measurement of rGO-A (company 1) with various amounts .....	17
A.4.2 Powder resistivity measurement of 1,0 g of rGO-B (company 2).....	19
A.4.3 Powder resistivity measurement of GNP .....	22
A.4.4 Powder resistivity measurement of graphene oxides with different amounts of oxygen .....	26
Bibliography.....	32
Figure 1 – Measurement system .....	11
Figure A.1 – FE-SEM images of rGO flakes of (A) Company 1 (rGO-A), (B) Company 2 (rGO-B) and (C) graphene nanopowder (GNP) before (left) and after (right) pressurization .....	15
Figure A.2 – Raman spectra of (A) rGO-A, (B) rGO-B and (C) GNP before (black line) and after (red line) pressurization .....	16
Figure A.3 – Comparison data for $I_D/I_G$ of rGO-A (short-dash line), rGO-B (solid line) and GNP (long-dash line) before and after pressurization .....	16
Figure A.4 – Correlation plots of (A) thickness, (B) volume resistivity ( $\rho_V$ ), and (C) volume conductivity ( $\sigma_V$ ) as a function of the applied pressure: (1) 0,1 g and (2) 0,2 g of rGO-A.....	18

This is a preview of "PD IEC TS 62607-6-1:...". [Click here to purchase the full version from the ANSI store.](#)

Figure A.5 – Correlation plots of (A) volume resistivity ( $\rho_V$ ) and (B) volume conductivity ( $\sigma_V$ ) as a function of the volume density ( $d_V$ ) of a graphene pellet: 0,1 g (filled symbol) and 0,2 g (unfilled symbol) of rGO-A .....	19
Figure A.6 – Correlation plots of (A) thickness ( $t$ ), (B) volume resistivity ( $\rho_V$ ), and (C) volume conductivity ( $\sigma_V$ ) of rGO-B (1,0 g) as a function of the applied pressure .....	19
Figure A.7 – Correlation plots of (A) volume resistivity ( $\rho_V$ ) and (B) volume conductivity ( $\sigma_V$ ) of rGO-B (1,0 g) as a function of the volume density ( $d_V$ ) of the graphene pellet .....	20
Figure A.8 – Correlation plots of (A) volume resistivity ( $\rho_V$ ) and (B) volume conductivity ( $\sigma_V$ ) as a function of the volume density ( $d_V$ ) of graphene pellets: 0,1 g (filled symbol), 0,2 g (unfilled symbol) of rGO-A and 1,0 g (lined symbol) of rGO-B .....	20
Figure A.9 – Correlation plots of (A) thickness ( $t$ ), (B) volume resistivity ( $\rho_V$ ), and (C) volume conductivity ( $\sigma_V$ ) as a function of the applied pressure: (1) 0,1 g and (2) 0,2 g of GNP.....	22
Figure A.10 – Correlation plots of (A) volume resistivity ( $\rho_V$ ) and (B) volume conductivity ( $\sigma_V$ ) as a function of the volume density ( $d_V$ ) of a graphene pellet: 0,1 g (filled symbol) and 0,2 g (unfilled symbol) of GNP .....	23
Figure A.11 – Comparison plots of (A) volume resistivity ( $\rho_V$ ) and (B) volume conductivity ( $\sigma_V$ ) as a function of the volume density ( $d_V$ ) of graphene pellets: rGO-A (filled symbol) and GNP (unfilled symbol).....	23
Figure A.12 – XPS survey spectra of as-received (A) rGO-A, (B) rGO-B and (C) GNP .....	24
Figure A.13 – Correlation plots of thickness ( $t$ ) as a function of the applied pressure: 0,3 g samples of four types of graphene oxide (G-a, G-b, G-c, and G-d) .....	26
Figure A.14 – Correlation plots of volume resistivity ( $\rho_V$ ) as a function of the applied pressure: 0,3 g samples of four types of graphene oxide (G-a, G-b, G-c, and G-d) .....	27
Figure A.15 – Correlation plots of volume conductivity ( $\sigma_V$ ) as a function of the applied pressure: 0,3 g samples of four types of graphene oxide (G-a, G-b, G-c, and G-d) .....	28
Figure A.16 – Correlation plots of volume resistivity ( $\rho_V$ ) as a function of the volume density ( $d_V$ ) of graphene oxide pellet (G-a, G-b, G-c, and G-d).....	29
Figure A.17 – Correlation plots of volume conductivity ( $\sigma_V$ ) as a function of the volume density ( $d_V$ ) of graphene oxide pellet (G-a, G-b, G-c, and G-d).....	30
Figure A.18 – Comparison plots of (A) volume resistivity ( $\rho_V$ ) and (B) volume conductivity ( $\sigma_V$ ) as a function of the volume density ( $d_V$ ) of graphene oxide pellet (G-a, G-b, G-c, and G-d).....	30
Table 1 – Minimum thickness of the pellet vs amount of the used sample at the maximum applied pressure .....	12
Table A.1 – An example of the measurement parameters for rGO-A (0,2 g) .....	17
Table A.2 – Volume resistivity and volume conductivity of rGO pellets .....	21
Table A.3 – Volume resistivity and volume conductivity of GNP pellets .....	23
Table A.4 – Summary of XPS data of three graphene samples in a powder form.....	24
Table A.5 – Volume resistivity ( $\rho_V$ ) and volume conductivity ( $\sigma_V$ ) of graphene pellets .....	25
Table A.6 – Volume resistivity ( $\rho_V$ ) and volume conductivity ( $\sigma_V$ ) of four graphene oxide pellets.....	31

This is a preview of "PD IEC TS 62607-6-1:...". [Click here to purchase the full version from the ANSI store.](#)

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

### **NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –**

### **Part 6-1: Graphene-based material – Volume resistivity: four probe method**

#### 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.

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 TS 62607-6-1, which is a Technical Specification, has been prepared by IEC technical committee 113: Nanotechnology for electrotechnical products and systems.

This is a preview of "PD IEC TS 62607-6-1:...". [Click here to purchase the full version from the ANSI store.](#)

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

Draft TS	Report on voting
113/454/DTS	113/511/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

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

**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.**

This is a preview of "PD IEC TS 62607-6-1:...". [Click here to purchase the full version from the ANSI store.](#)

## INTRODUCTION

Graphene has attracted great interest as a next generation electronic material due to its extremely high mobility and ballistic transport of electrons [1]<sup>1</sup>. The unique properties of graphene enable it to be an effective candidate used in electronic products such as transparent conducting films, sensors, field emitters, supercapacitors, etc.

Characterization of the electrical properties of graphene itself is essential to both manufacturers and users in order to develop innovative electronic devices or to improve existing electronic devices using it.

Commercialized graphene products can be categorized by their manufacturing methods as follows: (i) graphene flakes and/or nanoplatelets in powder form (hereinafter called GNP), (ii) graphene sheets suspended in liquids or (iii) graphene films grown by chemical vapour deposition (CVD).

Many electrical properties of a powder-type graphene product are significantly affected by its geometric and electronic parameters [2]. First, it is required to select the parameter that best represents the quality of the graphene products. Second, a suitable sample preparation for the purpose of electrical measurements is also elucidated and described. Finally, measurement conditions are also crucial factors to determine the representative value of the powder product in terms of its electrical properties.

Among the measurands in determining electronic properties of powder-type graphene – sheet resistance (or conductance), resistivity (or conductivity), volume resistivity (or volume conductivity), and so on – this document selects volume resistivity (or volume conductivity) for the representative measurand which reveals the electrical properties of powder-type graphene through a series of experiments.

This document describes a simple method to evaluate the volume resistivity (or volume conductivity) of powder-type graphene, which includes preparation of its pellet and a measurement method.

Case studies illustrating the application of the standard are provided in Annex A.

---

<sup>1</sup> Numbers in square brackets refer to the Bibliography.



This is a preview of "PD IEC TS 62607-6-1:...". Click here to purchase the full version from the ANSI store.

## **NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –**

### **Part 6-1: Graphene-based material – Volume resistivity: four probe method**

#### **1 Scope**

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

- volume resistivity  
for powder consisting of graphene-based material like flakes of graphene, few layer graphene and/or reduced graphene oxide after preparation of a sample in pellet form by
- four probe method  
using powder resistivity measurement system.

The volume resistivity is a measure of the quality of powder-type graphene products in terms of electrical property and reflects the density-dependency shown in a pellet of powder-type graphene.

The volume conductivity can directly be derived from the volume resistivity.

Typical application areas are industries that use powder-type graphene products for graphene manufacture, potential developers, and users who produce graphene-based products. As the volume resistivity measured according to this document requires the preparation of a sample in the form of a pellet, this document describes in detail

- an apparatus to prepare consistently a test sample, the pellet,
- the preparation of the pellet starting from powder-type graphene,
- the measurement procedure to measure the volume resistivity (or volume conductivity) of the pellet, and
- the data analysis, the interpretation and reporting of the results.

#### **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>

NOTE A comprehensive nanotechnology vocabulary is under ongoing development in IEC TC 113 and ISO/TC 229, in cooperation with ISO/TC 229. The vocabulary is being published as different parts of IEC TS 80004 and ISO/TS 80004. The terms and definitions in this document are harmonized with the terms and definitions of IEC 80004 (all parts) and ISO 80004 (all parts). They will remain harmonized during the maintenance of the document. Definitions not yet specified are taken from scientific literature.