IEC TS 62607-6-8

Edition 1.0 2023-06

TECHNICAL SPECIFICATION

Nanomanufacturing – Key control characteristics –
Part 6-8: Graphene – Sheet resistance: In-line four-point probe

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 07.120 ISBN 978-2-8322-7113-1

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

® Registered trademark of the International Electrotechnical Commission

CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 7
2 Normative references 7
3 Terms and definitions 7
3.1 General terms 8
3.5 Key control characteristics measured in accordance with this standard 9
3.6 Terms related to the measurement method 9
4 General 10
4.1 Measurement principle 10
4.2 Sample preparation method 11
4.3 Description of measurement apparatus 11
4.4 Ambient conditions during measurement 11
4.5 Related standards 12
5 Measurement procedure 12
5.1 Calibration of measurement equipment 12
5.2 Detailed protocol of the measurement procedure 12
5.3 Measurement accuracy 13
6 Data analysis and interpretation of results 13
7 Results to be reported 14
7.1 Cover sheet 14
7.2 Product and sample identification 14
7.3 Measurement conditions 14
7.4 Measurement results 14
Annex A (informative) Effects of ambient conditions on graphene resistance measurements 17
A.1 General 17
A.2 Temperature (T) 17
A.3 Relative humidity (RH) 17
Annex B (normative) More specific cases 18
B.1 Non-equidistant probes 18
B.2 Proximity to the edge 18
B.3 Non-equidistant probes and proximity to the edge 18
Annex C (informative) Experimental example 19
C.1 Sample 19
C.2 Ambient conditions 19
C.3 Instrumentation 19
C.4 Sampling plan 19
C.5 Measurement procedure 20
C.6 Results 20
Annex D (informative) Other standards related to the measurement of sheet resistance 21
Bibliography 22

Figure 1 – Schematic representation of the four-point probe method (left) and detail of the structure of a spring-mounted probe (right) 11

Figure 2 – Schematic representation of a possible measurement location 12
Figure 3 – Schematic view of possible sample plans for a) circular and b) square substrates 15
Figure C.1 – Sampling plan used for the present example 20

Table 1 – Example of measurable values for R_S, and the corresponding measurement settings and type-B uncertainty, when using a current source Keithley 2602B System SourceMeter® and a Nano Volt / Micro Ohm Meter (1y calibration specifications) 13
Table 2 – Sampling plan for circular substrates 15
Table 3 – Results of R_S measured in accordance with this document 16
Table C.1 – Measured values for V and $R_S(p)$ using the described procedure and equipment 20

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-8: Graphene – Sheet resistance: In-line four-point probe

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 not 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 62607-6-8 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
113/678/DTS	113/745/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 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 is a single layer of carbon atoms arranged in a honeycomb lattice. Graphene has shown many outstanding properties, among which is a high electrical conductivity. Nowadays graphene can be easily grown and transferred on large area (cm^2 to even m^2) and even roll-to-roll supports using chemical vapour deposition (CVD) techniques. This is already enabling its commercial applications in electrotechnical products.

Electrical conductivity of graphene samples can depend on many factors: structural quality, contamination, coupling with the physical support used for a given application to name a few. On practical grounds, the sheet resistance, R_S, is a quantity which can be used as global measure of the local conductivity of a sample with finite geometrical dimensions. In order to check the reproducibility of the electrical properties of graphene, the sheet resistance is clearly a key control characteristic for this material.

The in-line four-point probe method (4PP) allows the measurement of the sheet resistance of samples of arbitrary shape, with isotropic conductivity and uniform carrier density by performing four-terminal resistance measurements with electrical contact provided by a commercially available dedicated tool. The method is fast (it takes a few minutes) and easy to implement, since many commercial fixtures are available.

The four-terminal resistance measurements approach allows to minimize the effect of the contact resistance that appears between graphene and the measurement probes.

The 4PP method provides a certain degree of spatial resolution in principle, depending on the sampling plan adopted to map the sample area.

In this document it is explained how to specifically apply the 4PP method on chemical vapour deposited graphene on rigid insulating support and perform a reliable estimation of the sample KCC sheet resistance, R_S, also considering the non-ideal nature of commercial graphene.

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-8: Graphene – Sheet resistance: In-line four-point probe

1 Scope

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

- sheet resistance R_S [measured in ohm per square (Ω/sq)],

by the

- in-line four-point probe method, 4PP.

The sheet resistance R_S is derived by measurements of four-terminal electrical resistance performed on four electrodes placed on the surface of the planar sample.

- The measurement range for R_S of the graphene samples with the method described in this document goes from 10^{-2} Ω/sq to 10^4 Ω/sq.
- The method is applicable for CVD graphene provided it is transferred to quartz substrates or other insulating materials (quartz, SiO_2 on Si, as well as graphene grown from silicon carbide.
- The method is complementary to the van der Pauw method (IEC 62607-6-7) for what concerns the measurement of the sheet resistance and can be useful when it is not possible to reliably place contacts on the sample boundary.

2 Normative references

There are no normative references in this document.