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TECHNICAL SPECIFICATION

colour inside

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

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CONTENTS

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NANOMANUFACTURING –
KEY CONTROL CHARACTERISTICS –

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

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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- withdrawn,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.

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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.

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
graphene
graphene layer
single-layer graphene
monolayer graphene
single layer of carbon atoms with each atom bound to three neighbours in a honeycomb structure

Note 1 to entry: It is an important building block of many carbon nano-objects.

Note 2 to entry: As graphene is a single layer, it is also sometimes called monolayer graphene or single-layer graphene and abbreviated as 1LG to distinguish it from bilayer graphene (2LG) and few-layer graphene (FLG).

Note 3 to entry: Graphene has edges and can have defects and grain boundaries where the bonding is disrupted.

[SOURCE: ISO/TS 80004-13:2017, 3.1.2.1]

3.1.2
bilayer graphene
2LG
two-dimensional material consisting of two well-defined stacked graphene layers

Note 1 to entry: If the stacking registry is known, it can be specified separately, for example, as "Bernal stacked bilayer graphene".

[SOURCE: ISO/TS 80004-13:2017, 3.1.2.6]

3.1.3
few-layer graphene
FLG
two-dimensional material consisting of three to ten well-defined stacked graphene layers

[SOURCE: ISO/TS 80004-13:2017, 3.1.2.10]

3.2
key control characteristic
KCC
product characteristic which can affect safety or compliance with regulations, fit, function, performance, quality, reliability or subsequent processing of the final product

Note 1 to entry: The measurement of a key control characteristic is described in a standardized measurement procedure with known accuracy and precision.

Note 2 to entry: It is possible to define more than one measurement method for a key control characteristic if the correlation of the results is well-defined and known.

[SOURCE IEC TS 62565-1:2023, 3.1]

3.3
blank detail specification
BDS
structured generic specification providing a comprehensive set of key control characteristics which are needed to describe a specific product without assigning specific values or attributes

Note 1 to entry: Examples of nano-enabled products are: nanocomposites and nano-subassemblies.

Note 2 to entry: Blank detail specifications are intended to be used by industrial users to prepare their detail specifications used in bilateral procurement contracts. A blank detail specification facilitates the comparison and benchmarking of different materials. Furthermore, a standardized format makes procurement more efficient and more error robust.

[SOURCE IEC TS 62565-1:2023, 3.2]

3.4
detail specification
DS
specification based on a blank detail specification with assigned values and attributes

Note 1 to entry: The characteristics listed in the detail specification are usually a subset of the key control characteristics listed in the relevant blank detail specification. The industrial partners define only those characteristics which are required for the intended application.

Note 2 to entry: Detail specifications are defined by the industrial partners. Standards development organizations will be involved only if there is a general need for a detail specification in an industrial sector.

Note 3 to entry: The industrial partners may define additional key control characteristics if they are not listed in the blank detail specification.

[SOURCE IEC TS 62565-1:2023, 3.3]

3.5 Key control characteristics measured in accordance with this standard

3.5.1
sheet resistance
R_S
electrical resistance of a conductor with a square shape (width equal to length) and thickness significantly smaller than the lateral dimensions (thickness much less than width and length)

Note 1 to entry: There is no definition of the unit ohm per square (Ω/sq) in the International System of units (SI). Nevertheless, R_S is a normalized quantity, in which the symbol represents the SI ohm. So there is no ambiguity concerning the traceability of measurements of R_S to the SI, provided the measurements are performed with calibrated instrumentation.

[SOURCE: IEC TS 61836:2007, 3.4.79, modified – The entry has been adapted to this document.]

3.6 Terms related to the measurement method

3.6.1
four-point probe method
4PP
method to measure electrical sheet resistance of thin films that uses separate pairs of current-carrying and voltage-sensing electrodes

Note 1 to entry: The method is local with a characteristic length scale defined by the probe distance, and generally requires the resistivity variations to be on a much larger scale than the probe spacing. Depending on the positions of the sample-probe contact of the four probe contacts with the surface, different geometrical factors must be used to extract the sheet resistance.

[SOURCE: ISO/TS 80004-13:2017, 3.3.3.1, modified – The entry has been adapted to this document.]