IEC TS 62607-6-4

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TECHNICAL SPECIFICATION

colour inside

Nanomanufacturing – Key control characteristics –
Part 6-4: Graphene – Surface conductance measurement using resonant cavity

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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 62607-6-4, 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
113/295/DTS	113/324/RVC

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 in the IEC 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

- transformed into an International Standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

The microwave resonant cavity test method for surface conductance is non-contact, fast, sensitive and accurate. It is well suited for standards, research and development (R&D), and for quality control in the manufacturing of two-dimensional (2D) nano-carbon materials. These sheet-like or flake-like carbon forms can be assembled into atomically-thin monolayer or multilayer graphene materials, which can be stacked, folded, crumpled or pillared into a variety of nano-carbon architectures with the lateral dimension limited to a few tenths of a nanometre. Many of these materials are new and exhibit extraordinary physical and electrical properties such as optical transparency, anisotropic heat diffusivity and charge transport that are of significant interest to science, technology and commercial applications [1, 2][1].

Depending on particular morphologies, density of states and structural perfection, the surface conductance of these materials may vary from 1 S to about 10^{-4} S. Conventional direct current (DC) surface conductance measurement techniques require a complex test vehicle and interconnections for making electrical contacts, which affect and alter the measurement, making it difficult to decouple the intrinsic properties of the material.

In comparison, the resonant cavity measurement method is fast and non-contact. Thus, it is well suited for use in R&D and manufacturing environments where the surface conductance is a critical functional parameter. Moreover, it can be employed to measure electrical characteristics of other nano-size structures.

1 Numbers in square brackets refer to the Bibliography

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-4: Graphene – Surface conductance measurement using resonant cavity

1 Scope

This part of IEC 62607 establishes a method for determining the surface conductance of two-dimensional (2D) single-layer or multi-layer atomically thin nano-carbon graphene structures. These are synthesized by chemical vapour deposition (CVD), epitaxial growth on silicon carbide (SiC), obtained from reduced graphene oxide (rGO) or mechanically exfoliated from graphite [3]. The measurements are made in an air filled standard R100 rectangular waveguide configuration, at one of the resonant frequency modes, typically at 7 GHz [4].

Surface conductance measurement by resonant cavity involves monitoring the resonant frequency shift and change in the quality factor before and after insertion of the specimen into the cavity in a quantitative correlation with the specimen surface area. This measurement does not explicitly depend on the thickness of the nano-carbon layer. The thickness of the specimen does not need to be known, but it is assumed that the lateral dimension is uniform over the specimen area.

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 60153-2, *Hollow metallic waveguides – Part 2: Relevant specifications for ordinary rectangular waveguides*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60153-2 and the following 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 Graphene layers

3.1.1
graphene
single-layer graphene
1LG
single layer of carbon atoms with sp^2-electronic hybridization bound to three neighbours in a honeycomb structure

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

[SOURCE: ISO/TS 80004-3:2010, 2.11, modified.]

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".

3.1.3
trilayer graphene
3LG
two-dimensional material consisting of three 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 trilayer graphene" or "twisted trilayer graphene".

3.1.4
few-layer graphene
FLG
two-dimensional material consisting of three to ten well-defined stacked graphene layers

3.1.5
nanoplate
nano-object with one external dimension in the nanoscale and the other two external dimensions significantly larger

[SOURCE: ISO/TS 80004-2:2015, 4.6]

3.1.6
nanosheet
nanoplate with extended lateral dimensions

3.1.7
graphene oxide
GO
chemically modified graphene prepared by oxidation and exfoliation of graphite that is accompanied by extensive oxidative modification of the basal plane

Note 1 to entry: Graphene oxide is a single material with a high oxygen content, typically characterized by C/O atomic ratios less than 3.0 and typically closer to 2.0.

3.1.8
reduced graphene oxide
rGO
graphene oxide that has been processed to reduce its oxygen content

Note 1 to entry: This can be produced by chemical, thermal, microwave, photo-chemical, photo-thermal or microbial/bacterial methods or by exfoliating reduced graphite oxide.

Note 2 to entry: If graphene oxide was fully reduced then graphene would be the product, however in practice some oxygen containing functional groups will remain and not all sp^3 bonds will return back to sp^2 configuration. Different reducing agents will lead to different carbon to oxygen ratios and different chemical compositions in reduced graphene oxide

3.1.9
graphene material
nanomaterial based on graphene

Note 1 to entry: Examples of graphene material are multilayered graphene (less than about 10 layers), chemically modified forms (GO, rGO), and materials made via another precursor material or process such as chemical vapour deposition (CVD) [3].

3.2 Measurement terminology

3.2.1
σ_s
surface conductance
characteristic physical property of two-dimensional materials describing the ability to conduct electric current

Note 1 to entry The SI unit of measure of σ_s is siemens (S). In the trade and industrial literature, however, siemens per square (S/square) is commonly used when referring to surface conductance. This is to avoid confusion between surface conductance and electric conductance (G), which share the same unit of measure:

$$G = I/U = \sigma_s\ (w/l).$$

Note 2 to entry: The surface conductance (σ_s) can be obtained by normalizing conductance G to the specimen width (w) and length (l).

3.2.2
G
electric conductance
measure of how easily electric current flows along a certain path

Note 1 to entry: The SI unit of electric conductance is siemens (S).

3.2.3
σ_v
volume conductivity
characteristic physical property of three-dimensional materials describing the ability to conduct electric current

Note 1 to entry: The volume conductivity can be obtained by dividing the surface conductance by the conductor thickness (t):

$$\sigma_v = \sigma_s/t.$$

The unit of measure of σ_v is siemens per metre (S/m).

3.2.4
ρ_s
surface resistance
sheet resistance
reciprocal of σ_s

Note 1 to entry: ρ_s is a characteristic property of two-dimensional materials. The SI unit of measure of ρ_s is ohm (Ω). In the trade and industrial literature, however, ohm per square (Ω/square) is commonly used when referring to surface resistance or sheet resistance.

3.2.5
microwave cavity
radio frequency cavity
RF cavity
resonator consisting of a closed metal structure that confines electromagnetic fields in the microwave region of the spectrum

Note 1 to entry: The structure can be filled with air or other dielectric material. A cavity acts similarly to a resonant circuit with extremely low loss at its frequency of operation. Microwave cavities are typically made from