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Nanomanufacturing — Key control characteristics

Part 6-10: Graphene-based material — Sheet resistance: Terahertz time-domain spectroscopy

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Nanomanufacturing – Key control characteristics –
Part 6-10: Graphene-based material – Sheet resistance: Terahertz time-domain spectroscopy

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CONTENTS

FOREWORD....4
INTRODUCTION....6
1 Scope....7
2 Normative references....7
3 Terms and definitions....7
3.1 General terms....7
3.2 Key control characteristics measured according to this document....9
3.3 Terms related to the measurement method described in this document....10
4 General....11
4.1 Measurement principle....11
4.2 Sample preparation method....13
4.3 Description of measurement equipment....13
4.3.1 Principal components of a THz-TDS system....13
4.3.2 Measurement configurations....14
4.4 Supporting materials....16
4.5 Calibration standards....17
4.6 Measurement conditions....17
5 Measurement procedure....17
5.1 Calibration of the measurement equipment....17
5.2 Detailed protocol of the measurement procedure....17
5.3 Measurement accuracy....19
6 Data analysis / interpretation of results....20
7 Results to be reported....24
7.1 Cover sheet....24
7.2 Measurement conditions....24
7.3 Measurement specific information....24
7.4 Measurement results....25
Annex A (informative) Worked example....26
A.1 Background....26
A.2 Measurement protocol....26
A.3 Test report....29
Annex B (informative) Application examples....33
B.1 General....33
B.2 Conductance map of CVD graphene on quartz....33
Annex C (informative) Theoretical background....35
C.1 Reflection and transmission of plane electromagnetic waves....35
C.2 Transmission coefficient through a thin, conductive film....37
C.3 Sheet conductivity of a thin, conductive film....39
C.3.1 Reflection-mode geometry....40
C.3.2 Transmission-mode geometry....41
Annex D (informative) Considerations for custom-built systems....43
D.1 Linearity of the THz-TDS detection system....43
D.2 Calibration of custom-built equipment....43
Bibliography....44

Figure 1 – Time trace of a typical THz waveform....12
Figure 2 – Sample scheme comprised of a thin film of graphene on a dielectric substrate. 12
Figure 3 – Principal components of a classical THz-TDS system....14
Figure 4 – Comparison of different transmission geometries. 15
Figure 5 – Comparison of different reflection geometries 16
Figure 6 – Photograph of a CVD monolayer of graphene on PET substrate....21
Figure 7 – THz-TDS conductance and resistance maps of the sample 21
Figure 8 – Analysis of high conductive areas in the conductivity map....22
Figure 9 – Analysis of low conductive areas in the conductivity map 22
Figure 10 – Analysis of low resistance areas in the resistance map 23
Figure 11 – Analysis of high resistance areas in the resistance map....23
Figure 12 – Conductance maps at two different frequencies: 0,5 THz and 0,75 THz 24
Figure A.1 – Colour map of sheet resistance results at the selected frequency. Sheet resistance map of the wafer at 0.5 THz, with step size 1 mm.. 32
Figure B.1 – Photograph of a graphene film on a 100 mm quartz wafer and related conductivity map....33
Figure B.2 – Detailed view of subsections....34
Figure C.1 – Reflection and transmission for a thin film on a substrate 35
Figure C.2 – Reflection and transmission for a thin film on a substrate. 40

Table A.1 – Illustration of measurement protocol 26
Table A.2 – Product identification 30
Table A.3 – General material description 30
Table A.4 – Sampling plan....31
Table A.5 – Measurement related information....31
Table A.6 – Measurement results: Sheet resistance at the selected frequency....32

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-10: Graphene-based material – Sheet resistance: Terahertz time-domain spectroscopy

FOREWORD

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IEC TS 62607-6-10 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
113/568/DTS	113/604/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.

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INTRODUCTION

Graphene is an important nanomaterial in R&D and industry due to its outstanding electrical properties. It is already present in multiple commercial products, and furthermore, it is a strong candidate as an electrical material in numerous new application areas. However, no established method to characterize its local electrical performance and quality across large areas exists yet. The four-point probe method, either as single point or mapping (scanning) technique, is an industry standard for silicon wafers and conventional thin films, but unavoidably leads to damage, due to the physical contact between the tip and the one atom thin graphene film. The microwave resonant cavity method has been demonstrated as a mapping technique for graphene, but with spatial and sample resolution limited by the cavity size: no attempt has been made to scale this technique to industrially relevant sample sizes. Other methods for providing spatial information relating in some way to electrical quality include optical, Raman and scanning electron microscopies. These ones give local information that only indirectly relates to the electrical properties of interest.

The focus of this document is to provide a method to characterize the electrical performance, quality and uniformity of large-area graphene films with terahertz time-domain spectroscopy (THz-TDS). THz-TDS allows for large-area mapping of graphene films in a non-destructive, fast and robust mode, without contact and with no sample preparation at all. This method has no upper limitations in the size of the graphene film to be analysed. It is applicable for statistical process control, comparison of graphene films produced by different vendors, obtaining information about imperfections on the microscale such as grain boundaries and defects, and uniquely allows process modifications and development to be analysed step by step due to its non-destructive property and ability to access buried conductive layers. THz-TDS has been tested against other methods such as van der Pauw (vdP), electrical resistance tomography and calibrated Kelvin probe force microscopy with good matching of results [1] [2][1].

THz-TDS method provides direct measurements of the sheet resistance, both in transmission and reflection modes [3]. The spatial resolution is related with the diffraction limited THz beam spot size, reaching about 300 µm at 1 THz, and the maximum surface density of measurements is determined by the minimum step-size of the actuator moving the sensor or the sample.

The default sample in this document is monolayer graphene grown by chemical vapour deposition (CVD) on or transferred to a quartz substrate. Nevertheless, the methodology can be extended to graphene on silicon carbide (epitaxial graphene), multilayer graphene, and thin conductors generally, including other 2D materials, on several other dielectric and high resistive substrates including sapphire, silicon coated with silicon dioxide, silicon carbide, polymers and III-V semiconductors, among others. It is noted that for the reflection-mode THz-TDS, the technique tolerates less THz-transparent substrates (e.g. medium to highly doped silicon) than the transmission-mode THz-TDS.

1 Numbers in square brackets refer to the Bibliography.

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-10: Graphene-based material – Sheet resistance: Terahertz time-domain spectroscopy

1 Scope

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

– sheet resistance (R_s)

for films of graphene-based materials by

– terahertz time-domain spectroscopy (THz-TDS).

In this technique, a THz pulse is sent to the graphene-based material. The transmitted or reflected THz waveform is measured in the time domain and transformed to the frequency domain by the fast Fourier transform (FFT). Finally, the spectrum is fitted to the Drude model (or another comparable model) to obtain the sheet resistance.

- This non-contact inspection method is non-destructive, fast and robust for the mapping of large areas of graphene films, with no upper sample size limit.
- The method is applicable for statistical process control, comparison of graphene films produced by different vendors, or to obtain information about imperfections on the microscale such as grain boundaries and defects, etc.
- The method is applicable for graphene grown by chemical vapour deposition (CVD) or other methods on or transferred to dielectric substrates, including but not limited to quartz, silica (SiO_2), silicon (Si), sapphire, silicon carbide (SiC) and polymers.
- The minimum spatial resolution is in the order of 300 µm (at 1 THz) given by the diffraction limited spot size of the THz pulse.

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
1LG
single layer of carbon atoms with each atom bound to three neighbours in a honeycomb structure