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# TECHNICAL SPECIFICATION

## Nanomanufacturing - Key control characteristics -
## Part 6-36: Graphene-related products - Reduction status of graphene oxide and reduced graphene oxide: UV-Vis absorption spectroscopy



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# Nanomanufacturing - Key control characteristics - Part 6-36: Graphene-related products - Reduction status of graphene oxide and reduced graphene oxide: UV-Vis absorption spectroscopy

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IEC TS 62607-6-36 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 |
|---|---|
| 113/961/DTS | 113/971/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 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

– reconfirmed,
– withdrawn, or
– revised.

# INTRODUCTION

Metallic van der Waals materials composed of a monolayer have recently drawn interest as a potential and adaptable application platform in a variety of industrial applications (electronics, optoelectronics, and energy storage devices). Because of its lower energy level, strong electrical and thermal conductivity, and high transparency due to its atomic thickness, graphene is among the most attractive possibilities for metallic van der Waals materials.[1] [1]

Chemical vapour deposition is a typical bottom-up approach, which is widely accepted as an effective synthetic method for producing monolayer graphene. The approach is very well suited for nano-structuring and obtaining superior monolayer graphene. However, to advance toward genuinely practical methods for commercialization, several issues are still to be addressed, such as the long synthesis time, high-temperature heat treatment, and the requirement for additional post-transfer-process, which limit the scalability and production of graphene. For the mass manufacturing of graphene, a solution-based direct reduction technique (top-down) has been taken into consideration.

Graphene oxide (GO) can be converted into graphene using a variety of reducing substances and solutions. To perfectly replicate the remarkable properties of graphene, it is important that the level of oxygen functionalization in GO be lowered or eliminated. A subsequent transformation of GO into reduced graphene oxide (rGO) can be performed to induce the π-π conjugated structure. Determining the completeness of the reduction is important because it indicates that the rGO possesses properties closer to those of graphene, specifically a lower oxygen concentration. This restoration of graphene-like properties makes the material more suitable for industrial applications that rely on its excellent electrical and thermal conductivity. The reduction status, which can be evaluated using spectral information from UV-Vis, is a critical factor for characterizing GO, rGO, and related products.



This document provides a method for evaluating the reduction status of GO and rGO by spectral information from UV-Vis. The reduction status is not a quantitative standard but can be determined through six parameters obtained from UV-Vis absorption spectroscopy. These parameters from GO and rGO references indirectly indicate the reduction status through spectral changes that reflect the restoration of $sp^2$ conjugation and removal of oxygen functional groups.



Furthermore, this standardized UV-Vis method enables quality control throughout the rGO production lifecycle and in final products. Since reduction status can degrade during storage or processing due to environmental factors, UV-Vis provides a non-destructive way to track the reduction status footprint over time. The technique is particularly valuable for industrial applications where maintaining consistent material properties is critical, allowing manufacturers to verify reduction completeness and monitor any re-oxidation that can occur in practical use. [2], [3]

[1] Numbers in square brackets refer to the Bibliography.

## 1 Scope

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

– reduction status

for graphene oxide (GO) and reduced graphene oxide (rGO) by

– ultraviolet-visible spectroscopy (UV-Vis).

The reduction status is not a quantitative value, but rather a compilation (table) of six parameters extracted from UV-Vis absorption spectra. These six parameters can be obtained from GO and rGO as follows:

(1) the peak location of GO, (2) the shoulder peak of GO, (3) the full width at half maximum (FWHM) of the main absorption peak of GO, (4) the peak location of rGO, (5) FWHM of the main absorption peak of rGO and (6) the spectral peak shifts between GO and rGO.

– The method is applicable to the characterization of GO and rGO materials (where rGO is obtained from the corresponding GO) produced by different reduction techniques, as well as to commercial products in solution or film form.
– Individual GO or rGO materials can also be characterized, but only partial parameters can be obtained. Specifically, peak location, FWHM, and shoulder peak can be measured from each GO or rGO material, while peak shift requires both GO and its corresponding rGO for comparison.
– The method is suitable for quality assurance and for monitoring the reduction process during the production of rGO.
– The method does not provide full chemical analysis. Complementary techniques can be required beyond the UV-Vis spectral features.



## 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.

ISO 18115-1, *Surface chemical analysis - Vocabulary - Part 1: General terms and terms used in spectroscopy*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18115-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

– IEC Electropedia: available at https://www.electropedia.org/
– ISO Online browsing platform: available at https://www.iso.org/obp

## 3.1 General terms

**3.1.1**
**key control characteristic**
**KCC**
key performance indicator
material property or intermediate 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, modified – "key performance indicator" has been changed from a preferred term to an admitted term. "material property or intermediate" has been added at the start of the definition.]

## 3.2 Terms related to general material description

**3.2.1**
**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-layered graphene (FLG).



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

[SOURCE: ISO/TS 80004-13:2024, 3.1.2.1, modified – Note 4 to entry has been deleted.]

**3.2.2**
**graphene-related material**
carbon-based two-dimensional materials consisting of one to 10 layers, including graphene, graphene oxide, reduced graphene oxide, and functionalized variations thereof

Note 1 to entry: This includes bilayer graphene, trilayer graphene and few-layered graphene.

**3.2.3**
**graphene oxide**
chemically modified graphene prepared by oxidation and exfoliation of graphite, causing extensive oxidative modification of the basal plane

Note 1 to entry: Graphene oxide is a single-layer material with a high oxygen content, typically characterized by C/O atomic ratios of approximately 2,0 depending on the method of synthesis.