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Nanotechnologies — Vocabulary —

Part 13: Graphene and other two-dimensional (2D) materials

Nanotechnologies — Vocabulaire —

Partie 13: Graphène et autres matériaux bidimensionnels (2D)

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Contents

Page

Foreword

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This document was prepared jointly by Technical Committee ISO/TC 229, *Nanotechnologies*, and Technical Committee IEC/TC 113, *Nanotechnology for electrotechnical products and systems,* and in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 352, *Nanotechnologies,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement). The draft was circulated for voting to the national bodies of both ISO and IEC.

This second edition cancels and replaces the first edition (ISO/TS 80004-13:2017) which has been technically revised.

The main changes are as follows:

— addition of the term "graphene-related 2D material (GR2M)";

— expansion of defined terms to include "enhanced", "modified", "enabled" and "based", and derivatives thereof;

— indication that use of some terms are deprecated.

A list of all parts in the ISO 80004 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Over the last decade, huge interest has arisen in graphene, both scientifically and commercially, due to the many exceptional properties associated with this material, such as the electrical and thermal conductivity. More recently, other materials with a structure similar to that of graphene have also shown promising properties, including:

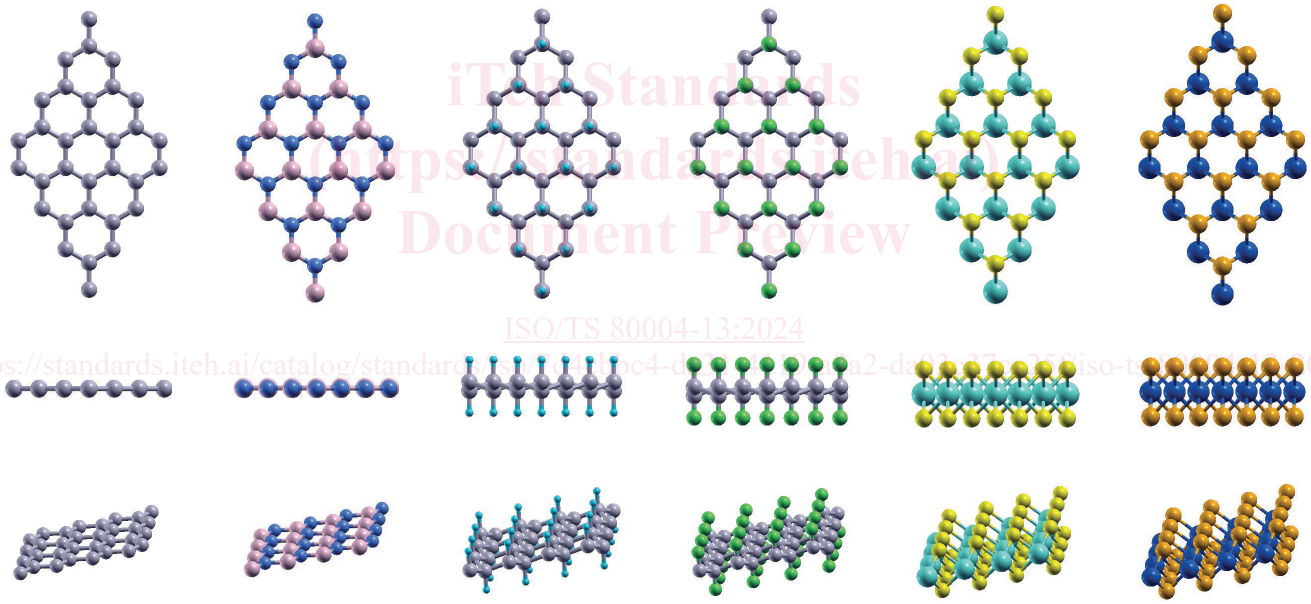
a) monolayer and few-layer versions of hexagonal boron nitride (hBN);

b) transition metal dichalcogenides such as molybdenum disulphide (MoS_2) and tungsten diselenide (WSe_2);

c) silicene and germanene;

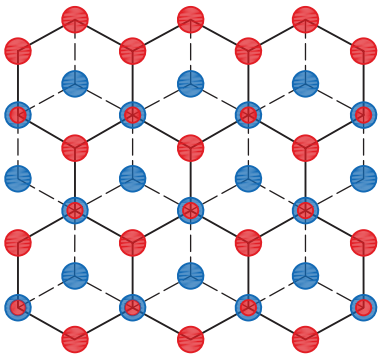
d) layered assemblies of mixtures of these materials.

These materials have their thickness constrained within the nanoscale or smaller and consist of between one and several layers. These materials are thus termed two-dimensional (2D) materials as they have one dimension at the nanoscale or smaller, with the other two dimensions generally at scales larger than the nanoscale. A layered material consists of 2D layers weakly stacked or bound to form three-dimensional structures. Examples of 2D materials and the different stacking configurations in graphene are shown in Figure 1. 2D materials are not necessarily topographically flat in reality and can have a buckled structure. They can also form aggregates and agglomerates which can have different morphologies. 2D materials are an important subset of nanomaterials.

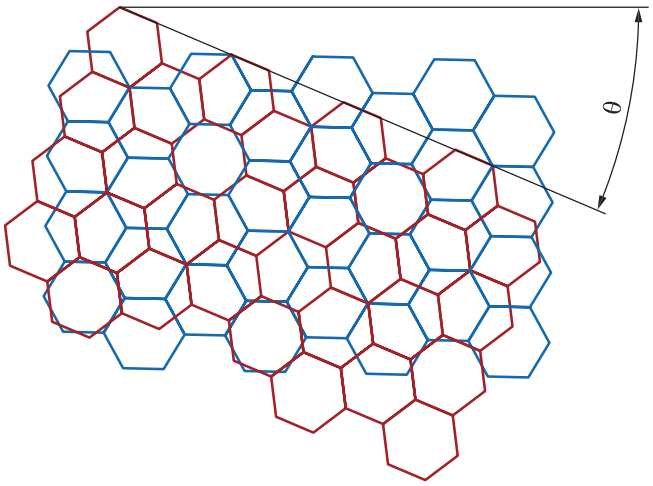


graphene | **hBN** | **graphane** | **perfluoro-graphane** | **MoS_2** | **WSe_2**

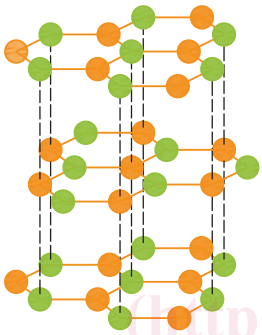
a) Examples of different 2D materials consisting of different elements and structures, as shown by the different coloured orbs and top-down and side views



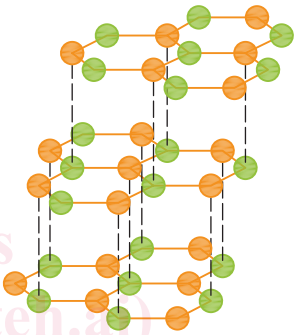
b) Bernal stacked bilayer graphene (3.1.2.7)



c) Turbostratic bilayer or twisted bilayer graphene with relative stacking angle (θ)(3.1.2.8)



ABA trilayer



ABC trilayer

d) Bernal stacked (AB) (3.4.1.12) tri-layer graphene (3.1.2.10) and rhombohedral (ABC) (3.4.1.13) stacked tri-layer graphene (3.1.2.10)

Figure 1 — Examples of 2D materials and the different stacking configurations in graphene layers

It is important to standardize the terminology for graphene, graphene-related and other 2D materials at the international level, as the number of publications, patents and organizations is increasing rapidly. Thus, these materials need an associated vocabulary as they become commercialized and sold throughout the world.

The document contains general terms related to 2D materials, those related to graphene, and those related to other 2D materials. It provides terms related to commonly used methods for producing and characterising 2D materials along, with terms related to 2D materials characteristics. It also includes performance related terms, such as “-enhanced” and “-enabled”, and those related to composition, such as “-based” and “-modified”, as shown in Figure 2.

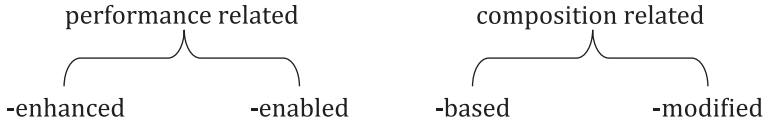


Figure 2 — General terms to describe 2D materials split into performance and composition related terms

This document belongs to a multi-part vocabulary, covering the different aspects of nanotechnologies. It builds upon ISO 80004-1, ISO/TS 80004-3 and ISO/TS 80004-6, and uses existing definitions where possible.

Nanotechnologies — Vocabulary —

Part 13:
Graphene and other two-dimensional (2D) materials

1 Scope

This document defines terms for graphene, graphene-related two-dimensional (2D) materials and other 2D materials. It includes related terms for production methods, properties and characterization.

It is intended to facilitate communication between organizations and individuals in research, industry and other interested parties and those who interact with them.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 Terms related to materials

3.1.1 General terms related to graphene and other 2D materials

3.1.1.1
two-dimensional material
2D material
material, consisting of one or several *layers* (3.1.1.8) with the atoms in each layer strongly bonded to neighbouring atoms in the same layer, which has one dimension, its thickness, in the nanoscale or smaller and the other two dimensions generally at larger scales

Note 1 to entry: The number of layers when a two-dimensional material becomes a bulk material varies depending on both the material being measured and its properties. In the case of *graphene layers* (3.1.2.1), it is a two-dimensional material of up to 10 layers thick for electrical measurements,[10] beyond which the electrical properties of the material are not distinct from those for the bulk [also known as *graphite* (3.1.2.2)].

Note 2 to entry: Interlayer bonding is distinct from and weaker than intralayer bonding.

Note 3 to entry: Each layer can contain more than one element.

Note 4 to entry: A two-dimensional material can be a *nanoplate* (3.1.1.5).

3.1.1.2
graphene-related 2D material
GR2M
DEPRECATED: graphene-based material, graphene-material
carbon-based *two-dimensional material* (3.1.1.1) consisting of one to 10 *layers* (3.1.1.8), including *graphene* (3.1.2.1), *graphene oxide* (3.1.2.15), *reduced graphene oxide* (3.1.2.16), and functionalized variations thereof

Note 1 to entry: This includes *bilayer graphene* (3.1.2.7), *trilayer graphene* (3.1.2.10) and *few-layer graphene* (3.1.2.11).

Note 2 to entry: The terms graphene-based material and graphene-material are deprecated here. They have been used to describe materials other than graphene, such as graphene oxide.

Note 3 to entry: "Graphene-related 2D material" is defined in contrast with *graphene-based* (3.1.1.20) and *GR2M-based* (3.1.1.21).

3.1.1.3
flake
<2D material> distinct particle of planar morphology, consisting of 1 or more *layers* (3.1.1.8) of material, with a nanoscale thickness that is significantly smaller than its lateral dimensions

3.1.1.4
sheet
<2D material> *2D material* (3.1.1.1) typically situated upon a substrate, with extended lateral dimensions at the micro to macroscale

3.1.1.5
nanoplate
nano-object with one external dimension in the nanoscale and the other two external dimensions significantly larger

Note 1 to entry: The larger external dimensions are not necessarily in the nanoscale.

[SOURCE: ISO 80004-1:2023, 3.3.6]

3.1.1.6
nanofoil
nanosheet
nanoplate (3.1.1.5) with extended lateral dimensions

Note 1 to entry: Nanofoil and nanosheet are used synonymously in specific industrial areas.

Note 2 to entry: Nanofoil and nanosheet extend further with respect to their length and width compared to nanoplate or nanoflake.

[SOURCE: ISO 80004-1:2023, 3.3.6.2]

3.1.1.7
nanoribbon
nanotape
nanoplate (3.1.1.5) with the two larger dimensions significantly different from each other

[SOURCE: ISO 80004-1:2023, 3.3.10]

3.1.1.8
layer
discrete material restricted in one dimension, within or at the surface of a condensed phase

[SOURCE: ISO 80004-1:2023, 3.6.2]

3.1.1.9
quantum dot
nanoparticle or region which exhibits quantum confinement in all three spatial directions

[SOURCE: ISO/TS 80004-12:2016, 4.1]

3.1.1.10
enhanced
<2D material> exhibiting function or performance intensified or improved through the use of a *2D material* (3.1.1.1)

EXAMPLE Graphene oxide-enhanced film.

Note 1 to entry: In enhanced products, the 2D material is typically used in low concentration in the product.

Note 2 to entry: Typical usage is: "X-enhanced Y", where X is the 2D material and Y is the product.

Note 3 to entry: Compare to *based* (3.1.1.19).

3.1.1.11
graphene-enhanced
exhibiting function or performance intensified or improved through the use of *graphene* (3.1.2.1)

EXAMPLE Graphene-enhanced solar cells.

Note 1 to entry: In graphene-enhanced products, the graphene is typically used in low concentration in the product.

Note 2 to entry: In common usage, this term is often incorrectly used to apply to *GR2M* (3.1.1.2) and not just to *single-layer graphene* (3.1.2.1). The correct term is *GR2M-enhanced* (3.1.1.12) or, for example, when referring to graphene nanoplatelets: GNP-enhanced.

Note 3 to entry: Compare to *graphene-based* (3.1.1.20).

3.1.1.12
GR2M-enhanced
DEPRECATED: graphene-enhanced
exhibiting function or performance intensified or improved through the use of *GR2M* (3.1.1.2)

EXAMPLE GR2M-enhanced solar cells.

Note 1 to entry: In GR2M-enhanced products, the GR2M is typically used in low concentration in the product.

Note 2 to entry: Compare to *GR2M-based* (3.1.1.21).

Note 3 to entry: Graphene-enhanced is deprecated since the use of this term only applies to the use of *(single-layer) graphene* (3.1.2.1) as defined by 3.1.1.11.

3.1.1.13
modified
<2D material> intentional addition of the indicated *2D material* (3.1.1.1)

Note 1 to entry: Typical usage is: "X-modified", where X is either a specific 2D material or a class of 2D materials.

Note 2 to entry: The use of this term does not imply property or performance enhancement through the use of the 2D material.

3.1.1.14
graphene-modified
intentional addition of *graphene* (3.1.2.1) to a material

Note 1 to entry: In common usage, this term is often incorrectly used to apply to *GR2M* (3.1.1.2) and not just to *single-layer graphene* (3.1.2.1). The correct term is *GR2M-modified* (3.1.1.15) or, for example, when referring to graphene nanoplatelets: GNP-modified.

Note 2 to entry: The use of this term does not imply property or performance enhancement through the use of graphene.

3.1.1.15
GR2M-modified
DEPRECATED: graphene-modified
intentional addition of *GR2M* (3.1.1.2) to a material

Note 1 to entry: Graphene-modified is deprecated since the use of this term only applies to the use of *single-layer graphene* (3.1.2.1) as defined by 3.1.1.14.

Note 2 to entry: The use of this term does not imply property or performance enhancement through the use of the GR2M.

3.1.1.16
enabled
<2D material> exhibiting function or performance possible through the use of a *2D material* (3.1.1.1)

Note 1 to entry: Typical usage is: "X-enabled", where X is either a specific 2D material or a class of 2D materials.

3.1.1.17
graphene-enabled
exhibiting function or performance possible through the use of *graphene* (3.1.2.1)

Note 1 to entry: This term in common usage is often incorrectly used to apply to *GR2M* (3.1.1.2) and not just to *single-layer graphene* (3.1.2.1). The correct term is *GR2M-enabled* (3.1.1.18) or, for example, when referring to graphene nanoplatelets: GNP-enabled.

3.1.1.18
GR2M-enabled
DEPRECATED: graphene-enabled
exhibiting function or performance possible through the use of *GR2M* (3.1.1.2)

Note 1 to entry: Graphene-enabled is deprecated since the use of graphene-enabled only applies to the use of *single-layer graphene* (3.1.2.1) as defined by 3.1.1.17.

3.1.1.19
based
<2D material> predominately consisting of, or as the key component

EXAMPLE GR2M-based, few-layer graphene-based.

Note 1 to entry: Typical usage is: "X-based Y", where X is either a specific *2D material* (3.1.1.1) or a class of 2D materials and Y is the product.

Note 2 to entry: When using in terms of a product, here the majority of the functional part of the product is composed of the specified 2D material.

3.1.1.20
graphene-based
predominantly consisting of *graphene* (3.1.2.1), or with graphene as a key component

EXAMPLE Graphene-based sensor, graphene-based ink.

Note 1 to entry: Typically, the majority of the functional part of the product is composed of graphene.

Note 2 to entry: While graphene-based is a commonly used expression, in many situations it is more correct to use a different term such as *graphene-enhanced* (3.1.1.11), *graphene-modified* (3.1.1.14) or *graphene-enabled* (3.1.1.17).

Note 3 to entry: In common usage, this term is often incorrectly used to apply to *GR2M* (3.1.1.2) and not just to *single-layer graphene* (3.1.2.1). The correct term is *GR2M-based* (3.1.1.21) or, for example, when referring to graphene nanoplatelets: GNP-based.

3.1.1.21
GR2M-based
DEPRECATED: graphene-based
predominantly consisting of *GR2M* (3.1.1.2), or with GR2M as a key component

Note 1 to entry: Typically, here the majority of the functional part of the product is composed of GR2M.

Note 2 to entry: In many situations, it is more correct to use a different term such as *GR2M-enhanced* (3.1.1.12), *GR2M-modified* (3.1.1.15) or *GR2M-enabled* (3.1.1.18).

Note 3 to entry: Graphene-based is deprecated since the use of graphene-based only applies to the use of *single-layer graphene* (3.1.2.1) as defined by 3.1.1.20.

3.1.2 Terms related to graphene related 2D materials

3.1.2.1
graphene
graphene layer
single-layer graphene
monolayer graphene
1LG
single *layer* (3.1.1.8) 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)* (3.1.2.7) and *few-layered graphene (FLG)* (3.1.2.11).

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

Note 4 to entry: In situations where the word graphene is used as an adjective, including in terms such as graphene-enabled, the term commonly and incorrectly refers to *GR2M* (3.1.1.2) and not just to single-layer graphene.

3.1.2.2
graphite
allotropic form of the element carbon, consisting of *graphene layers* (3.1.2.1) stacked parallel to each other in a three-dimensional, crystalline, long-range order

Note 1 to entry: Adapted from the definition in the IUPAC *Compendium of Chemical Terminology*.

Note 2 to entry: There are two primary allotropic forms with different stacking arrangements: hexagonal and rhombohedral.

3.1.2.3
nanographite
flake (3.1.1.3) that consists of *layers* (3.1.1.8) of graphene with a thickness of 11 or more *layers*, with a total thickness of up to 100 nm

3.1.2.4
graphane
single *layer* (3.1.1.8) material consisting of a two-dimensional *sheet* (3.1.1.4) of carbon and hydrogen with the repeating unit of $(CH)_n$

Note 1 to entry: Graphane is the full hydrogenated form of graphene with carbon atoms in the sp^3 bonding configuration.

3.1.2.5
perfluorographane
single *layer* (3.1.1.8) material consisting of a two-dimensional *sheet* (3.1.1.4) of carbon and fluorine with each carbon atom bonded to one fluorine atom with the repeating unit of $(CF)_n$

Note 1 to entry: Perfluorographane has carbon atoms in the sp^3 bonding configuration.