
**Nanotechnologies — Vocabulary —
Part 13:
Graphene and related two-
dimensional (2D) materials**

Nanotechnologies — Vocabulaire —

Partie 13: Graphène et autres matériaux bidimensionnels

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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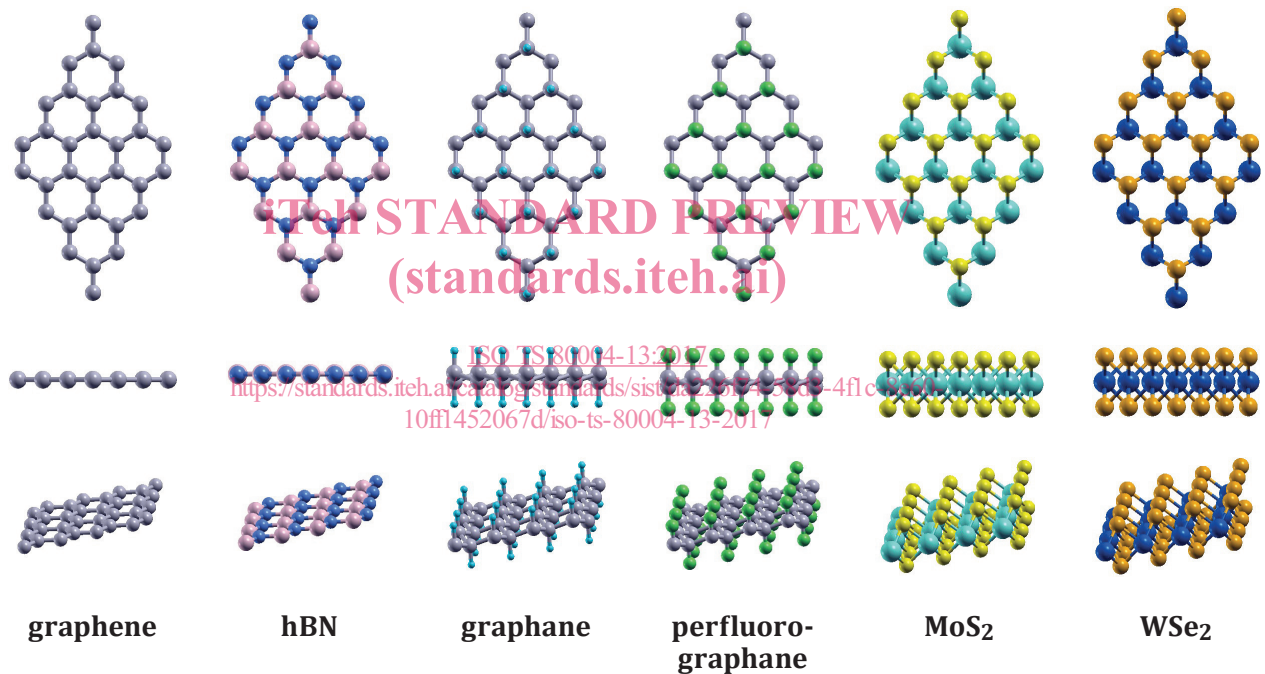
For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html. (standards.iteh.ai)

This document was prepared by Technical Committee ISO/TC 229, *Nanotechnologies*, and IEC/TC 113, *Nanotechnology for electrotechnical products and systems*.

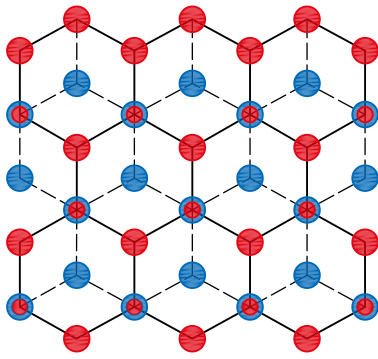
A list of all parts in the ISO 80004 series can be found on the ISO website.

Introduction

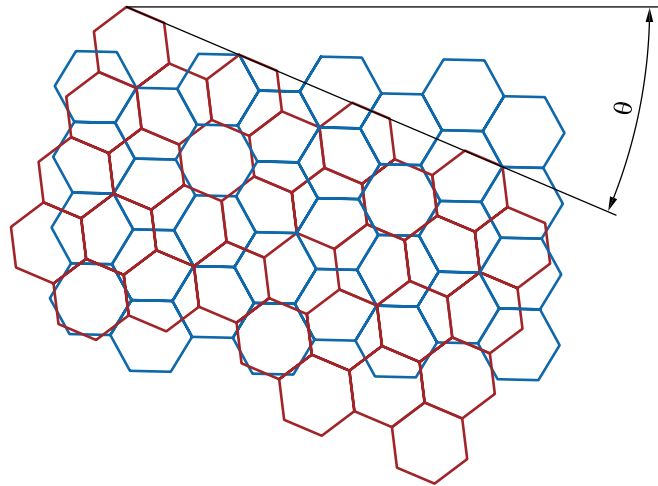
Over the last decade, huge interest has arisen in graphene both scientifically and commercially, due to the many exceptional properties associated with this material, properties such as the electrical and thermal conductivity. More recently, other materials with a structure similar to that of graphene have also shown promising properties including monolayer and few-layer versions of hexagonal boron nitride (hBN), molybdenum disulphide (MoS_2), tungsten diselenide (WSe_2), silicene and germanene and 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 two-dimensional 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](#). It should be noted that 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. Two-dimensional materials are an important subset of nanomaterials.



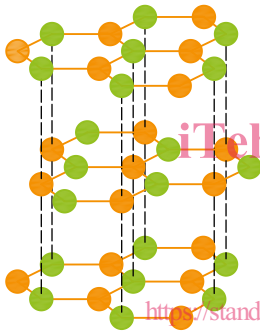
a) Examples of different two-dimensional materials consisting of different elements and structures, as shown by the different coloured orbs and top-down and side views



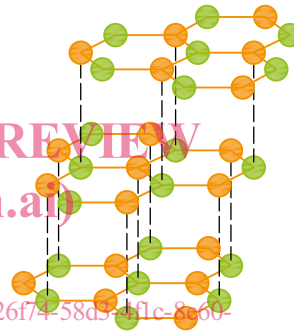
b) Bernal stacked bilayer graphene (3.1.2.6)



c) turbostratic bilayer or twisted bilayer graphene with relative stacking angle, θ , (3.1.2.7)



ABA trilayer



ABC trilayer

d) Bernal stacked (AB) (3.4.1.10) tri-layer graphene (3.1.2.9) and Rhombohedral (ABC) (3.4.1.11) stacked tri-layer graphene (3.1.2.9)

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

It is important to standardize the terminology for graphene, graphene-derived and related 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.

This document belongs to a multi-part vocabulary covering the different aspects of nanotechnologies. It builds upon ISO/TS 80004-3, ISO/TS 80004-11 and ISO/TS 80004-6 and uses existing definitions where possible.

Nanotechnologies — Vocabulary —

Part 13:

Graphene and related two-dimensional (2D) materials

1 Scope

This document lists terms and definitions for graphene and related two-dimensional (2D) materials, and includes related terms naming production methods, properties and their 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

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 Terms related to materials

3.1.1 General terms related to 2D materials

3.1.1.1

two-dimensional material

2D material

material, consisting of one or several *layers* (3.1.1.5) 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 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 may contain more than one element.

Note 4 to entry: A two-dimensional material can be a *nanoplate* (3.1.1.2).

3.1.1.2

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/TS 80004-2:2015, 4.6]

3.1.1.3

nanofoil

nanosheet

nanoplate (3.1.1.2) 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/TS 80004-11:2017, 3.2.1.1]

3.1.1.4

nanoribbon

nanotape

nanoplate (3.1.1.2) with the two larger dimensions significantly different from each other

[SOURCE: ISO/TS 80004-2:2015, 4.10]

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3.1.1.5

layer

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

[SOURCE: ISO/TS 80004-11:2017, 3.1.2]

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3.1.1.6

quantum dot

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

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

3.1.1.7

aggregate

particle comprising strongly bonded or fused particles where the resulting external surface area is significantly smaller than the sum of surface areas of the individual components

Note 1 to entry: The forces holding an aggregate together are strong forces, for example, covalent or ionic bonds or those resulting from sintering or complex physical entanglement or otherwise combined former primary particles.

Note 2 to entry: Aggregates are also termed secondary particles and the original source particles are termed primary particles.

[SOURCE: ISO/TS 80004-2:2015, 3.5, modified – Notes 1 and 2 have been added.]

3.1.2 Terms related to graphene

3.1.2.1

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 (3.1.1.5), it is also sometimes called monolayer graphene or single-layer graphene and abbreviated as 1LG to distinguish it from *bilayer graphene* (2LG) (3.1.2.6) and *few-layered graphene* (FLG) (3.1.2.10).

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

[SOURCE: ISO/TS 80004-3:2010, 2.11, modified – Notes 2 and 3 have been added.]

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.

[SOURCE: ISO/TS 80004-3:2010, 2.12, modified – Note 2 has been added.]

3.1.2.3

graphane

single layer material consisting of a two-dimensional sheet of carbon and hydrogen with the repeating unit of $(\text{CH})_n$

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

3.1.2.4

perfluorographane

single layer material consisting of a two-dimensional sheet of carbon and fluorine with each carbon atom bonded to one fluorine atom with the repeating unit of $(\text{CF})_n$

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

Note 2 to entry: Perfluorographane is sometimes referred to as fluorographane.

3.1.2.5

epitaxial graphene

<graphene> *graphene layer* (3.1.2.1) grown on a silicon carbide substrate

Note 1 to entry: Graphene can be grown by epitaxy on other substrates, for example, Ni(111), but these materials are not termed epitaxial graphene.

Note 2 to entry: This specific definition applies only in the field of graphene. In general, the term “epitaxial” refers to the epitaxial growth of a film on a single crystal substrate.

3.1.2.6

bilayer graphene

2LG

two-dimensional material (3.1.1.1) consisting of two well-defined stacked *graphene layers* (3.1.2.1)

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

3.1.2.7

twisted bilayer graphene

turbostratic bilayer graphene

tBLG

t2LG

two-dimensional material (3.1.1.1) consisting of two well-defined *graphene layers* (3.1.2.1) that are turbostratically stacked, with a relative *stacking angle* (3.4.1.12), also known as commensurate rotation, rather than *Bernal* (hexagonal) (3.4.1.10) or *rhombohedral stacking* (3.4.1.11),

3.1.2.8

twisted few-layer graphene

t(n+m)LG

two-dimensional material (3.1.1.1) consisting of a few-layers of graphene of *n* Bernal stacked layers which are situated with a relative *stacking angle* (3.4.1.2) upon *m* Bernal stacked layers

3.1.2.9

trilayer graphene

3LG

two-dimensional material (3.1.1.1) consisting of three well-defined stacked *graphene layers* (3.1.2.1)

Note 1 to entry: If the stacking registry is known, it can be specified separately, for example, as “twisted trilayer graphene”.

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3.1.2.10

few-layer graphene

FLG

two-dimensional material (3.1.1.1) consisting of three to ten well-defined stacked *graphene layers* (3.1.2.1)

3.1.2.11

graphene nanoplate

graphene nanoplatelet

GNP

nanoplate (3.1.1.2) consisting of *graphene layers* (3.1.2.1)

Note 1 to entry: GNPs typically have thickness of between 1 nm to 3 nm and lateral dimensions ranging from approximately 100 nm to 100 µm.

3.1.2.12

graphite oxide

chemically modified *graphite* (3.1.2.2) prepared by extensive oxidative modification of the basal planes

Note 1 to entry: The structure and properties of graphite oxide depend on the degree of oxidation and the particular synthesis method.

3.1.2.13

graphene oxide

GO

chemically modified *graphene* (3.1.2.1) prepared by oxidation and exfoliation of *graphite* (3.1.2.2), causing extensive oxidative modification of the basal plane

Note 1 to entry: Graphene oxide is a single-layer material with a high *oxygen content* (3.4.2.7), typically characterized by C/O atomic ratios of approximately 2,0 depending on the method of synthesis.

3.1.2.14 reduced graphene oxide rGO

reduced oxygen content (3.4.2.7) form of graphene oxide (3.1.2.13)

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.

Note 3 to entry: It can take the form of several morphological variations such as platelets and worm-like structures.

3.1.3 Terms related to other 2D materials

3.1.3.1 2D heterostructure

two-dimensional material (3.1.1.1) consisting of two or more well-defined layers (3.1.1.5) of different 2D materials

Note 1 to entry: These can be stacked together in-plane or out-of-plane.

3.1.3.2 2D vertical heterostructure

two-dimensional material (3.1.1.1) consisting of two or more well-defined layers (3.1.1.5) of different 2D materials that are stacked out-of-plane

3.1.3.3 2D in-plane heterostructure

two-dimensional material (3.1.1.1) consisting of two or more well-defined layers (3.1.1.5) of different 2D materials that are bonded to each other in the in-plane direction

3.2 Terms related to methods for producing 2D materials

3.2.1 Graphene and related 2D material production

3.2.1.1 chemical vapour deposition CVD

deposition of a solid material by chemical reaction of a gaseous precursor or mixture of precursors, commonly initiated by heat on a substrate

[SOURCE: ISO/TS 80004-8:2013, 7.2.3]

3.2.1.2 roll-to-roll production R2R production

<2D material> CVD growth of a 2D material(s) (3.1.1.1) upon a continuous substrate that is processed as a rolled sheet, including transfer of a 2D material(s) to a separate substrate

3.2.1.3 mechanical exfoliation

<2D material> detachment of separate/individual 2D material layers (3.1.1.5) from the body of a material via mechanical methods

Note 1 to entry: There are a number of different methods to achieve this. One method is via peeling, also called the scotch tape method, mechanical cleavage or micromechanical exfoliation/cleavage. Another method is via dry-media ball milling.