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Nanotechnologies — Vocabulary —

Part 3:
Carbon nano-objects

Nanotechnologies — Vocabulaire —

Partie 3: Nano-objets carbonés

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Foreword

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This second edition cancels and replaces the first edition (ISO/TS 80004-3:2010), which has been technically revised throughout.

A list of all parts in the ISO/TS 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

In the last three decades, various new forms of nanoscale carbon materials, including fullerenes, graphene and carbon nanotubes, have been discovered, synthesized and manufactured. These are promising materials for many industrial fields associated with nanotechnologies because of their unique electronic, electromagnetic, thermal, optical and mechanical properties.

In the context of increasing scientific knowledge and a growing number of technical terms in the field of nanotechnologies (see the Bibliography), the purpose of this document is to define important terms and concepts for carbon nano-objects in a precise and consistent manner, while clarifying their interrelationship, as well as their relationship, to existing terms previously used for conventional carbon materials.

This document belongs to a multi-part vocabulary covering the different aspects of nanotechnologies. Most of the definitions in this document are deliberately determined so as to be in harmony with a rational hierarchical system of terminology under development for nanotechnologies, although in some cases the hierarchical approach needs to be compromised due to the specific usage of individual terms. ISO/TS 80004-13 further complements this document by providing terms and definitions for graphene and related two-dimensional (2D) materials. A subset of these terms is only noted herein.

Nanotechnologies — Vocabulary —

Part 3:
Carbon nano-objects

1 Scope

This document defines terms related to carbon nano-objects in the field of nanotechnologies.

It is intended to facilitate communication between organizations' and individuals' research, industry and other interested parties and those who interact with them. Additional terms and definitions for graphene and two-dimensional materials (2D) materials are provided in ISO/TS 80004-13.

Related carbon nanoscale materials are given in Annex A.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

3.1 Basic terms used in the description of carbon nano-objects

3.1.1
nanoscale
length range approximately from 1 nm to 100 nm

Note 1 to entry: Properties that are not extrapolations from a larger size are predominantly exhibited in this length range.

[SOURCE: ISO/TS 80004-1:2015, 2.1]

3.1.2
nanomaterial
material with any external dimension in the *nanoscale* (3.1.1) or having internal structure or surface structure in the nanoscale

Note 1 to entry: This generic term is inclusive of *nano-object* (3.1.3) and *nanostructured material* (3.1.4).

Note 2 to entry: See also "engineered nanomaterial", "manufactured nanomaterial" and "incidental nanomaterial".

[SOURCE: ISO/TS 80004-1:2015, 2.4]

3.1.3
nano-object
discrete piece of material with one, two or three external dimensions in the *nanoscale* (3.1.1)

Note 1 to entry: The second and third external dimensions are orthogonal to the first dimension and to each other.

[SOURCE: ISO/TS 80004-1:2015, 2.5]

3.1.4
nanostructured material
material having internal nanostructure or surface nanostructure

Note 1 to entry: This definition does not exclude the possibility for a *nano-object* (3.1.3) to have internal structure or surface structure. If external dimension(s) are in the *nanoscale* (3.1.1), the term "nano-object" is recommended.

[SOURCE: ISO/TS 80004-1:2015, 2.7]

3.1.5
nanoparticle
nano-object (3.1.3) with all external dimensions in the *nanoscale* (3.1.1) where the lengths of the longest and the shortest axes of the nano-object do not differ significantly

Note 1 to entry: If the dimensions differ significantly (typically by more than three times), terms such as *nanofibre* (3.1.7) or *nanoplate* (3.1.6) may be preferred to the term "nanoparticle".

[SOURCE: ISO/TS 80004-2:2015, 4.4]

3.1.6
nanoplate
nano-object (3.1.3) with one external dimension in the *nanoscale* (3.1.1) and the other two external dimensions significantly larger

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

Note 2 to entry: See 3.1.3, Note 1 to entry. The smallest external dimension is the thickness of the nanoplate.

[SOURCE: ISO/TS 80004-2:2015, 4.6, modified —Note 2 to entry has been replaced.]

3.1.7
nanofibre
nano-object (3.1.3) with two external dimensions in the *nanoscale* (3.1.1) and the third dimension significantly larger

Note 1 to entry: The largest external dimension is not necessarily in the nanoscale.

Note 2 to entry: The terms "nanofibril" and "nanofilament" can also be used.

Note 3 to entry: See 3.1.3, Note 1 to entry. Nano-object with two similar external dimensions in the nanoscale and the third dimension significantly larger.

[SOURCE: ISO/TS 80004-2:2015, 4.5, Note 3 to entry has been replaced.]

3.1.8
nanotube
hollow *nanofibre* (3.1.7)

[SOURCE: ISO/TS 80004-2:2015, 4.8]

3.1.9
nanorod
solid *nanofibre* (3.1.7)

[SOURCE: ISO/TS 80004-2:2015, 4.7]

3.1.10
nano-onion
spheroidal *nanoparticle* (3.1.5) with a concentric multiple shell structure

3.1.11
nanocone
cone-shaped *nanofibre* (3.1.7) or *nanoparticle* (3.1.5)

3.1.12
nanoribbon
nanotape
nanoplate (3.1.6) with the two larger dimensions significantly different from each other

Note 1 to entry: See 3.1.3, Note 1 to entry.

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

3.1.13
graphene
monolayer graphene
single-layer graphene
single *layer* (3.1.15) 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* (3.1.3).

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)* (3.1.17) and *few-layer graphene (FLG)* (3.1.18).

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

[SOURCE: ISO/TS 80004-13:2017, 3.1.2.1]

3.1.14
graphite
allotropic form of the element carbon, consisting of *graphene* (3.1.13) layers 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*[6].

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

[SOURCE: ISO/TS 80004-13:2017, 3.1.2.2]

3.1.15
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]

3.1.16
two-dimensional material
2D material
material, consisting of one or several *layers* (3.1.15) with the atoms in each layer strongly bonded to neighbouring atoms in the same layer, which has one dimension, its thickness, in the *nanoscale* (3.1.1) 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* (3.1.13), it is a two-dimensional material up to 10 layers thick for electrical measurements[7], beyond which the electrical properties of the material are not distinct from those for the bulk [also known as *graphite* (3.1.14)].

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* (3.1.6).

[SOURCE: ISO/TS 80004-13:2017, 3.1.1.1]

3.1.17
bilayer graphene
2LG
two-dimensional material (3.1.16) consisting of two well-defined stacked *graphene* (3.1.13) layers

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

[SOURCE: ISO/TS 80004-13:2017, 3.1.2.6]

3.1.18
few-layer graphene
FLG
two-dimensional material (3.1.16) consisting of three to ten well-defined stacked *graphene* (3.1.13) layers

[SOURCE: ISO/TS 80004-13:2017, 3.1.2.10]

3.1.19
aciniform
object or structure having a shape consistent with grape-like clusters

Note 1 to entry: Aciniforms are often composed of *nodules* (3.1.20) or particles.

3.1.20
nodule
rounded or irregular shaped feature distinct from its surroundings

Note 1 to entry: Nodules do not have discrete boundaries at the attachment point with the object.

3.1.21
de Broglie wavelength
wavelength of the wave associated with any particle which reflects its wave nature according to de Broglie's formula

Note 1 to entry: De Broglie's formula is:

$$\lambda = h / p$$

where

λ is the wavelength;

h is the Planck's constant;

p is the particle momentum.

[SOURCE: ISO/TS 80004-12:2016, 2.1]

3.1.22
quantum confinement
restriction of a particle's motion in one, two or three space dimensions when the size of a physical system is of the same order of magnitude as the particle's *de Broglie wavelength* (3.1.21)

Note 1 to entry: The main characteristic lengths leading to quantum confinement may be their de Broglie wavelength, their Fermi wavelength, their mean free path, their Bohr radius (for excitons) or their coherence length.

Note 2 to entry: See Reference [8].

[SOURCE: ISO/TS 80004-12:2016, 2.5]

3.1.23
quantum dot
QD
nanoparticle (3.1.5) or region which exhibits *quantum confinement* (3.1.22) in all three spatial directions.

Note 1 to entry: See References [8] to [12].

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

3.2 Terms describing specific types of carbon nanoparticles

3.2.1
fullerene
molecule composed solely of an even number of carbon atoms, which form a closed cage-like fused-ring polycyclic system with 12 five-membered rings and the rest six-membered rings

Note 1 to entry: Adapted from the definition in the IUPAC *Compendium of Chemical Terminology*[6].

Note 2 to entry: A well-known example is C_{60}, which has a spherical shape with an external dimension of about 1 nm.

3.2.2
fullerene derivative
compound that has been formed from *fullerene* (3.2.1) by substitution of carbon or covalent attachment of a moiety

3.2.3
endohedral fullerene
fullerene (3.2.1) with an additional atom or atoms enclosed within the fullerene shell

3.2.4
metallofullerene
endohedral fullerene (3.2.3) with an enclosed metal ion or ions

3.2.5
carbon nano-onion
nano-onion (3.1.10) composed of carbon

3.3 Terms describing specific types of carbon nanofibres and nanoplates

3.3.1
carbon nanofibre
CNF
nanofibre (3.1.7) composed of carbon

3.3.2
graphite nanofibre
carbon nanofibre (3.3.1) composed of *graphite* (3.1.14) multilayer structures

Note 1 to entry: Graphite layers can be any orientation with respect to the fibre axis without long-range order.

3.3.3
carbon nanotube
CNT
nanotube (3.1.8) composed of carbon

Note 1 to entry: Carbon nanotubes usually consist of curved *graphene* (3.1.13) layers, including *single-walled carbon nanotubes* (3.3.4) and *multi-walled carbon nanotubes* (3.3.6).

3.3.4
single-walled carbon nanotube
SWCNT
single-wall carbon nanotube
carbon nanotube (3.3.3) consisting of a single cylindrical *graphene* (3.1.13) layer

Note 1 to entry: The structure can be visualized as a graphene sheet rolled into a cylindrical honeycomb structure.

3.3.5
chiral vector of single-walled carbon nanotube
chiral vector of SWCNT
vector notation used to describe the helical structure of a *single-walled carbon nanotube* (3.3.4)

3.3.6
multi-walled carbon nanotube
MWCNT
multiwall carbon nanotube
carbon nanotube (3.3.3) composed of nested, concentric or near-concentric *graphene* (3.1.13) layers with interlayer distances similar to those of *graphite* (3.1.14)

Note 1 to entry: The structure is normally considered to be many *single-walled carbon nanotubes* (3.3.4) nesting each other, and would be cylindrical for small diameters but tends to have a polygonal cross-section as the diameter increases.

3.3.7
double-walled carbon nanotube
DWCNT
double-wall carbon nanotube
multi-walled carbon nanotube (3.3.6) composed of only two nested, concentric *single-walled carbon nanotubes* (3.3.4)

Note 1 to entry: Although this is a type of multi-walled carbon nanotube, its properties are rather closer to a single-walled carbon nanotube.

3.3.8
carbon nanopeapod
linear array of *fullerenes* (3.2.1) enclosed in a *carbon nanotube* (3.3.3)

Note 1 to entry: This is an example of a composite *nanofibre* (3.1.7).

3.3.9
carbon nanohorn
short and irregular-shaped *carbon nanotube* (3.3.3) with a *nanocone* (3.1.11) apex

Note 1 to entry: Usually hundreds of carbon nanohorns constitute an aggregate *nanoparticle* (3.1.5).

3.3.10
carbon nanoribbon
nanoribbon (3.1.12) composed of carbon

Note 1 to entry: Carbon nanoribbons are often in the form of multiple layers of *graphene* (3.1.13). In the case of a single graphene layer, the term “graphene ribbon” is used.

3.3.11
carbon quantum dot
carbon dot
quantum dot (3.1.23) composed of carbon

3.4 Terms describing nanostructured carbon nano-objects

3.4.1
soot
carbonaceous material produced by the incomplete and uncontrolled combustion of organic matter and, as such, having varying morphologies and limited uniformity within a given aggregate

Note 1 to entry: It is typically comprised of elemental carbon (this can vary from high 90 % to around 60 %), with remainder of organic and inorganic residue.

Note 2 to entry: Soot can be comprised of objects larger than the *nanoscale* (3.1.1).

Note 3 to entry: Soot can contain *aciniform* (3.1.19) material.

3.4.2
carbon black
industrially engineered *aciniform* (3.1.19) elemental carbonaceous material, produced from the partial combustion of hydrocarbons

Note 1 to entry: Discrete particles exist as aggregates or clustered *nodules* (3.1.20).

Note 2 to entry: Carbon black can be comprised of objects larger than the *nanoscale* (3.1.1).

Note 3 to entry: Discrete particles of carbon black are frequently larger than the nanoscale.

Note 4 to entry: Carbon black typically consists of more than 95 % elemental carbon.

Annex A
(informative)

Related carbon nanoscale materials

A.1 General

There are many kinds of conventional carbon materials that have been produced and used widely in industry for many years. Some of them may fall into the category of nanotechnologies in view of substantial recent progress in controlling their nanoscale dimensions. However, the terms associated with them are viewed as satisfactory at this time and need not be redefined in this document.

A.2 Diamond nanoparticles and related structures

Diamond nanoparticles (often called "nanodiamond") are related to a large group of carbon materials with very different production methods (e.g. explosive methods, chemical vapour deposition, physical vapour deposition), appearance, size, properties and application. Some diamond-based nanoparticles, such as diamondoids, occur naturally and can be extracted from hydrocarbon deposits. Some of the terms and definitions associated with diamond nanoparticles are listed in BS PAS 134:2007[13].

A.3 Carbon films

Carbon films have been used commercially in the coatings industry to impart certain properties to materials. Carbon films can be produced using a variety of different techniques, such as cathodic arc and magnetron sputtering. There are various terms used in the literature for carbon-based coatings, e.g. diamond-like carbon (DLC), glassy carbon and tetrahedral amorphous carbon. Basically, these films differ by the various fractions of sp^2, sp^3 hybridization and hydrogen content within them. For example, diamond-like carbon is typically used to reduce abrasive wear, while glassy carbon is used where resistance to high temperatures, chemical attack and gas or liquid impermeability is required. Some of the terms and definitions associated with carbon films are listed in BS PAS 134:2007[13].

