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Nanotechnologies — Vocabulary —

Part 8:
Nanomanufacturing processes

Nanotechnologies — Vocabulaire —

Partie 8: Processus de nanofabrication

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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 of 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 www.iso.org/iso/foreword.html.

This document was prepared jointly by Technical Committee ISO/TC 229, *Nanotechnologies*, and Technical Committee IEC/TC 113, *Nanotechnology for electrotechnical products and systems*, 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 80004-8:2013), 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

Nanomanufacturing is the essential bridge between the discoveries of the nanosciences and real-world nanotechnology products.

Advancing nanotechnology from the laboratory into volume production ultimately requires careful study of manufacturing process issues including product design, reliability and quality, process design and control, shop floor operations, supply chain management, workplace safety and health practices during the production, use and handling of nanomaterials. Nanomanufacturing encompasses directed self-assembly and assembly techniques, synthetic methodologies, and fabrication processes such as lithography and biological processes. Nanomanufacturing also includes bottom-up directed assembly, top-down high-resolution processing, molecular systems engineering and hierarchical integration with larger scale systems. As dimensional scales of materials and molecular systems approach the nanoscale, the conventional rules governing their behaviour may change significantly. As such, the behaviour of a final product is enabled by the collective performance of its nanoscale building blocks.

Biological process terms are not included in this second edition of the nanomanufacturing vocabulary, but considering the rapid development of the field, it is expected that terms in this important area will be added in a future update to this document or in companion documents in the ISO/TS 80004 series. This could include both the processing of biological nanomaterials and the use of biological processes to manufacture materials at the nanoscale.

Similarly, additional terms from other developing areas of nanomanufacturing, including composite manufacturing, roll-to-roll manufacturing and others, will be included in future documents.

There is a distinction between the terms "nanomanufacturing" and "nanofabrication". Nanomanufacturing encompasses a broader range of processes than does nanofabrication. Nanomanufacturing encompasses all nanofabrication techniques and also techniques associated with materials processing and chemical synthesis.

This document provides an introduction to processes used in the early stages of the nanomanufacturing value chain, namely the intentional synthesis, generation or control of nanomaterials, including fabrication steps in the nanoscale. The nanomaterials that result from these manufacturing processes are distributed in commerce where, for example, they may be further purified, be compatabilized to be dispersed in mixtures or composite matrices, or serve as integrated components of systems and devices. The nanomanufacturing value chain is, in actuality, a large and diverse group of commercial value chains that stretch across these sectors:

— the semiconductor industry (where the push to create smaller, faster, and more efficient microprocessors heralded the creation of circuitry less than 100 nm in size);

— electronics and telecommunications;

— aerospace, defence and national security;

— energy and automotive;

— plastics and ceramics;

— forest and paper products;

— food and food packaging;

— pharmaceuticals, biomedicine and biotechnology;

— environmental remediation;

— clothing and personal care.

There are thousands of tonnes of nanomaterials on the market with end-use applications in several of these sectors, such as carbon black and fumed silica. Nanomaterials that are rationally designed with specific purpose are expected to radically change the landscape in areas such as biotechnology, water purification and energy development.

The majority of clauses in this document are organized by process type. In Clause 6, the logic of placement is as follows: in the step before the particle is made, the material itself is in a gas/liquid/solid phase. The phase of the substrate or carrier in the process does not drive the categorization of the process. As an example, consider iron particles that are catalysts in a process by which you seed oil with iron particles, the oil vaporizes and condenses forming carbon particles on the iron particles. What vaporizes is the oil, and therefore it is a gas phase process. Nanotubes grow from the gas phase, starting with catalyst particles that react with the gas phase to grow the nanotubes, thus this is characterized as a gas process. Indication of whether synthesis processes are used to manufacture nano-objects, nanoparticles or both is provided in Annex A.

In addition, Annex A identifies the processes that are also applicable to macroscopic materials and are therefore not exclusively relevant to nanomanufacturing. A common understanding of the terminology used in practical applications will enable communities of practice in nanomanufacturing and will advance nanomanufacturing strength worldwide. Extending the understanding of terms across the existing manufacturing infrastructure will serve to bridge the transition between the innovations of the research laboratory and the economic viability of nanotechnologies.

For informative terms supportive of nanomanufacturing terminology, see BSI PAS 135[11].

This document belongs to a multi-part vocabulary covering the different aspects of nanotechnologies.

Nanotechnologies — Vocabulary —

Part 8:
Nanomanufacturing processes

1 Scope

This document defines terms related to nanomanufacturing processes in the field of nanotechnologies.

All the process terms in this document are relevant to nanomanufacturing, however, many of the listed processes are not exclusively relevant to the nanoscale. Terms that are not exclusive are noted within the definitions. Depending on controllable conditions, such processes can result in material features at the nanoscale or, alternatively, at larger scales.

There are many other terms that name tools, components, materials, systems control methods or metrology methods associated with nanomanufacturing that are beyond the scope of this document.

Terms and definitions from other parts of the ISO/TS 80004 series are reproduced in Clause 3 for context and better understanding.

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
carbon nanotube
CNT
nanotube (3.9) composed of carbon

Note 1 to entry: Carbon nanotubes usually consist of curved graphene layers, including single-walled carbon nanotubes and multi-walled carbon nanotubes.

[SOURCE: ISO/TS 80004-3:2010, 4.3]

3.2
nanocomposite
solid comprising a mixture of two or more phase-separated materials, one or more being nanophase

Note 1 to entry: Gaseous nanophases are excluded (they are covered by nanoporous material).

Note 2 to entry: Materials with *nanoscale* (3.7) phases formed by precipitation alone are not considered to be nanocomposite materials.

[SOURCE: ISO/TS 80004-4:2011, 3.2]

3.3
nanofibre
nano-object (3.5) with two external dimensions in the *nanoscale* (3.7) 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: The largest external dimension is not necessarily in the nanoscale.

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

3.4
nanomaterial
material with any external dimension in the *nanoscale* (3.7) or having internal structure or surface structure in the nanoscale

Note 1 to entry: This generic term is inclusive of *nano-object* (3.5) and *nanostructured material* (3.8).

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

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

3.5
nano-object
discrete piece of material with one, two or three external dimensions in the *nanoscale* (3.7)

Note 1 to entry: Generic term for all discrete nano-objects.

[SOURCE: ISO/TS 80004-1:2015, 2.5, modified — Note 1 to entry has been replaced.]

3.6
nanoparticle
nano-object (3.5) with all external dimensions in the *nanoscale* (3.7) 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" or "nanoplate" may be preferred to the term "nanoparticle".

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

3.7
nanoscale
length range from approximately from 1 nm to 100 nm

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

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

3.8
nanostructured material
material having internal or surface structure in the *nanoscale* (3.7)

Note 1 to entry: If external dimensions are in the nanoscale, the term *nano-object* (3.5) is recommended.

Note 2 to entry: Adapted from ISO/TS 80004-1:2015, 2.7.

[SOURCE: ISO/TS 80004-4:2011, 2.11]

3.9
nanotube
hollow *nanofibre* (3.3)

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

4 Terms related to general aspects

4.1
bottom-up nanomanufacturing
processes that use small fundamental units in the *nanoscale* (3.7) to create larger, functionally rich structures or assemblies

4.2
co-deposition
simultaneous deposition of two or more source materials

Note 1 to entry: Common methods include vacuum, *thermal spray* (8.2.16), *electrodeposition* (8.2.7) and liquid suspension deposition techniques.

4.3
comminution
crushing or *grinding* (7.5.6) for particle size reduction

Note 1 to entry: The term is not exclusive to nanomanufacturing.

4.4
directed assembly
guided formation of a structure guided by external intervention using components at the *nanoscale* (3.7) that can, in principle, have any defined pattern

4.5
directed self-assembly
self-assembly (4.11) influenced by external intervention to produce a preferred structure, orientation or pattern

Note 1 to entry: Examples of external intervention include an applied field, a chemical or structural template, chemical gradient and fluidic flow.

4.6
lithography
reproducible creation of a pattern

Note 1 to entry: The pattern can be formed in a radiation sensitive material or by transfer of material onto a substrate by one of the following: transfer, printing or direct writing.

4.7
multilayer deposition
alternating deposition of two or more source materials to produce a composite layer structure

4.8
nanofabrication
ensemble of activities to intentionally create *nano-objects* (3.5) or *nanostructured materials* (3.8)

4.9
nanomanufacturing
intentional synthesis, generation or control of *nanomaterials* (3.4), or fabrication steps in the *nanoscale* (3.7), for commercial purposes

[SOURCE: ISO/TS 80004-1:2015, 2.11]

4.10
nanomanufacturing process
ensemble of activities to intentionally synthesize, generate or control *nanomaterials* (3.4), or fabrication steps in the *nanoscale* (3.7), for commercial purposes

[SOURCE: ISO/TS 80004-1:2015, 2.12]

4.11
self-assembly
autonomous action by which components organize themselves into patterns or structures

4.12
surface functionalization
chemical process that acts upon a surface to impart a selected chemical or physical functionality

4.13
top-down nanomanufacturing
processes that create structures at the *nanoscale* (3.7) from macroscopic objects

5 Terms related to directed assembly

5.1
electrostatic driven assembly
use of electrostatic force to orient or place *nanoscale* (3.7) elements in a device or material

5.2
fluidic alignment
use of fluid flow to orient *nanoscale* (3.7) elements in a device or material

5.3
hierarchical assembly
use of more than one type of *nanomanufacturing* (4.9) process to control a structure at multiple length scales

5.4
magnetic driven assembly
use of magnetic force to assemble elements/particles at the *nanoscale* (3.7) in a desired pattern or configuration

5.5
shape-based assembly
use of geometric shapes of *nanoparticles* (3.6) to achieve a desired pattern or configuration

5.6
supramolecular assembly
use of non-covalent chemical bonding to assemble molecules or *nanoparticles* (3.6) with surface ligands

5.7
surface-to-surface transfer
transfer of *nanoparticles* (3.6) or structures from the surface of one substrate, on which they have been deposited, grown or assembled, onto another substrate

6 Terms related to self-assembly processes

6.1
colloidal crystallization
sedimentation of *nanoparticles* (3.6) from a solution containing *nano-objects* (3.5) and their aggregates and agglomerates (NOAAs) to form a solid, which consists of an organization of particles to form an array of repeating units

Note 1 to entry: The term is not exclusive to nanomanufacturing but has been adapted to apply to nanomanufacturing processes.

6.2
graphioepitaxy
directed self-assembly (4.5) using *nanoscale* (3.7) topographical features

Note 1 to entry: Includes the growth of a thin layer on the surface and growth of an additional layer on top of a substrate, which has the same or different structure as the underlying crystal.

Note 2 to entry: The term is not exclusive to nanomanufacturing but has been adapted to apply to nanomanufacturing processes.

6.3
ion beam surface reconstruction
use of an accelerated ion beam to cause surface modification, which can be at the *nanoscale* (3.7)

Note 1 to entry: The term is not exclusive to nanomanufacturing but has been adapted to apply to nanomanufacturing processes.

6.4
Langmuir-Blodgett film formation
creation of a film at an air-liquid interface

6.5
Langmuir-Blodgett film transfer
transfer of a Langmuir-Blodgett film formed at an air-liquid interface onto a solid surface by dipping a solid substrate into the supporting liquid

6.6
layer-by-layer deposition
LbL deposition
electrostatic process of depositing polyelectrolytes with opposite charges laid over or under another

6.7
modulated elemental reactant method
use of vapour deposited precursors with regions of controlled composition as a template for the formation of interleaved layers of two or more structures

Note 1 to entry: The term is not exclusive to nanomanufacturing.

6.8
self-assembled monolayer formation
SAM formation
spontaneous formation of an organized molecular layer on a solid surface from solution or the vapour phase, driven by molecule-to-surface bonding and weak intermolecular interaction

6.9
Stranski-Krastanow growth
mode of thin film growth which starts as a two-dimensional *Frank-van der Merve growth* (6.10), and then continues as a three-dimensional *Volmer-Weber growth* (6.11)

6.10
Frank-van der Merve growth
layer-by-layer film growth

Note 1 to entry: Frank-van der Merve growth corresponds to the situation when atoms of a film have a stronger connection with a substrate than with each other. As a result, the next layer growth could not begin until the previous is completed.

Note 2 to entry: Frank-van der Merve growth is strictly a two-dimensional growth mode.

6.11
Volmer-Weber growth
island film growth

Note 1 to entry: Volmer-Weber growth mode corresponds to the situation when atoms of a film have a stronger connection with each other than with a substrate.

Note 2 to entry: *Frank-van der Merve growth* (6.10) is a three-dimensional growth mode.

7 Terms related to synthesis

7.1 Gas process phase — Physical methods

7.1.1
cold gas dynamic spraying
process in which either *nanoscale* (3.7) crystalline powders or conventional powders are fluidized and then consolidated onto a surface coating in a high velocity inert gas

Note 1 to entry: The term is not exclusive to nanomanufacturing but has been adapted to apply to nanomanufacturing processes.

7.1.2
electro-spark deposition
pulsed-arc micro-welding process using short-duration, high-current electrical pulses to deposit an electrode material onto a substrate

7.1.3
electron-beam evaporation
process in which a material is vaporized by incidence of high energy electrons in high or ultra-high vacuum conditions for subsequent deposition onto a substrate

7.1.4
wire electric explosion
formation of *nanoparticles* (3.6) by applying an electrical pulse of high current density through a wire causing it to volatilize with subsequent recondensation

7.1.5
freeze drying
dehydration or solvent removal by rapid cooling immediately followed by vacuum sublimation

Note 1 to entry: The term is not exclusive to nanomanufacturing.

7.1.6
spray drying
method in which a dry powder is produced from a liquid or slurry by rapid *evaporation* (8.2.10) of the liquid from droplets formed by nebulization, via contact with a hot gas or equivalent

Note 1 to entry: The term is not exclusive to nanomanufacturing.

