PD IEC/TR 62834:2013

BSI Standards Publication

IEC nanoelectronics standardization roadmap

bsi.

...making excellence a habit.™

Document Sharing Hub

National foreword

This Published Document is the UK implementation of IEC/TR 62834:2013.

The UK participation in its preparation was entrusted to Technical Committee NTI/1, Nanotechnologies.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2013.
Published by BSI Standards Limited 2013

ISBN 978 0 580 81611 6
ICS 07.030

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 October 2013.

Amendments/corrigenda issued since publication

Date	Text affected

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62834:2013

IEC/TR 62834

Edition 1.0 2013-09

TECHNICAL REPORT

colour inside

IEC nanoelectronics standardization roadmap

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE V

ICS 07.030

ISBN 978-2-8322-1100-7

Warning! Make sure that you obtained this publication from an authorized distributor.

® Registered trademark of the International Electrotechnical Commission

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62834:2013

CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 7
2 Background 8
2.1 General 8
2.2 Classification of nanotechnology 9
2.2.1 General 9
2.2.2 Nanomaterials 9
2.2.3 Nanoscale devices 9
2.2.4 Nano-biotechnology 9
2.2.5 Nanofabrication process – Equipment – Measurement 9
3 Current status and prospects 9
3.1 Related markets 9
3.2 Technology development directions for nanomaterials 10
3.2.1 General 10
3.2.2 World leading group status 11
3.2.3 Nanopore materials 12
3.2.4 Nanocomposite materials 12
3.3 Overall technology status and prospects of nanoelectronic devices 12
4 Nanomaterials technology, scenario and standardization roadmap 13
4.1 Technology 13
4.1.1 Classification of nanomaterials 13
4.1.2 Standardization items of zero dimensional nanomaterials 14
4.1.3 Standardization items of one-dimensional nanomaterials 15
4.1.4 Standardization items of two-dimensional nanomaterials 16
4.1.5 Standardization items of three-dimensional nanomaterial 17
4.2 Scenarios 18
4.2.1 Scenario for nanoparticles (or nanopowders) 18
4.2.2 Scenario for quantum dots 18
4.2.3 Scenario for carbon nanotubes 19
4.2.4 Scenario for nanowires 20
4.2.5 Scenario for nanostructured thin films 20
4.2.6 Scenario for sheet resistance characterization of CNT films 21
4.2.7 Scenario for wear resistance and exposure test of CNT films 21
4.2.8 Scenario for thermal characterization of CNT films 22
4.2.9 Scenario for graphene 22
4.2.10 Scenario for nanopores 23
4.2.11 Scenario for nanocomposite materials 23
4.3 Roadmap of standardization of nanomaterials (2009-2020) 24
5 Nanoelectronic devices technology, scenario and standardization roadmap 24
5.1 Technology 24
5.1.1 Nanoscale non-volatile memory devices 24
5.1.2 New nanomaterial or new nanostructure for nanoelectronic devices 24
5.1.3 Three-dimensional nanoscale transistors 24
5.1.4 Single electron transistors 25
5.1.5 Nanoscale logic devices 25

AVA Documents
Document Sharing Hub
Full document details: PD IEC/TR 62834:2013

5.1.6 Carbon interconnects 25
5.1.7 Nanoscale magnetic devices 25
5.1.8 Molecular devices 25
5.2 Scenario 25
5.2.1 Scenario for nanoscale non-volatile memory devices 25
5.2.2 Scenario for nanostructure electronic materials 26
5.2.3 Scenario for nanoscale interconnects (CNT) 26
5.2.4 Scenario for one-dimensional nanoscale transistors 27
5.2.5 Scenario for three-dimensional nanoscale transistors 27
5.2.6 Scenario for single electron transistors 28
5.2.7 Scenario for key control characteristics of nanoscale logic devices 28
5.2.8 Scenario for molecular devices 28
5.3 Standardization roadmap of nanoelectronic devices (2009-2020) 28
Bibliography 32

Figure 1 – Roadmap format 6
Figure 2 – Technologies and related products 8
Figure 3 – Interaction of product, technology and standardization roadmaps 9
Figure 4 – ISO 229 WG3 roadmap for standardization of nanomaterials: www.nanosafe.org 11
Figure 5 – Estimated resistance of 50 nm-diameter vias dependent on the filling rate of CNTs in a via hole for 1 nm-diameter SWNT, 3 nm-diameter 3-walled MWNT, and 5 nm-diameter 6-walled MWNT 27
Figure 6 – Roadmap for standardization of nanomaterials (2009-2020) 30
Figure 7 – Roadmap for standardization of nanoelectronic devices (2009-2020) 31

Table 1 – Categories and detail potential products 7
Table 2 – Classification of nanomaterials 14
Table 3 – Characteristics to be considered in developing standards for nanoparticles 14
Table 4 – Characteristics to be considered in developing standards for quantum dot 15
Table 5 – Characteristics to be considered in developing standards for CNT 15
Table 6 – Characteristics to be considered in developing standards for nanowires 16
Table 7 – Characteristics to be considered in developing standards for nanostructured thin film 16
Table 8 – Characteristics to be considered in developing standards for nanostructured thin films 17
Table 9 – Characteristics to be considered in developing standards for nanopores 17
Table 10 – Characteristics to be considered in developing standards for nanocomposite materials 18
Table 11 – Matrix for graphene characterization 23

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62834:2013

INTERNATIONAL ELECTROTECHNICAL COMMISSION

IEC NANOELECTRONICS STANDARDIZATION ROADMAP

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 62834, which is a technical report, has been prepared by IEC technical committee 113: Nanotechnology standardization for electrical and electronic products and systems.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
113/161/DTR	113/197/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62834:2013

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62834:2013

INTRODUCTION

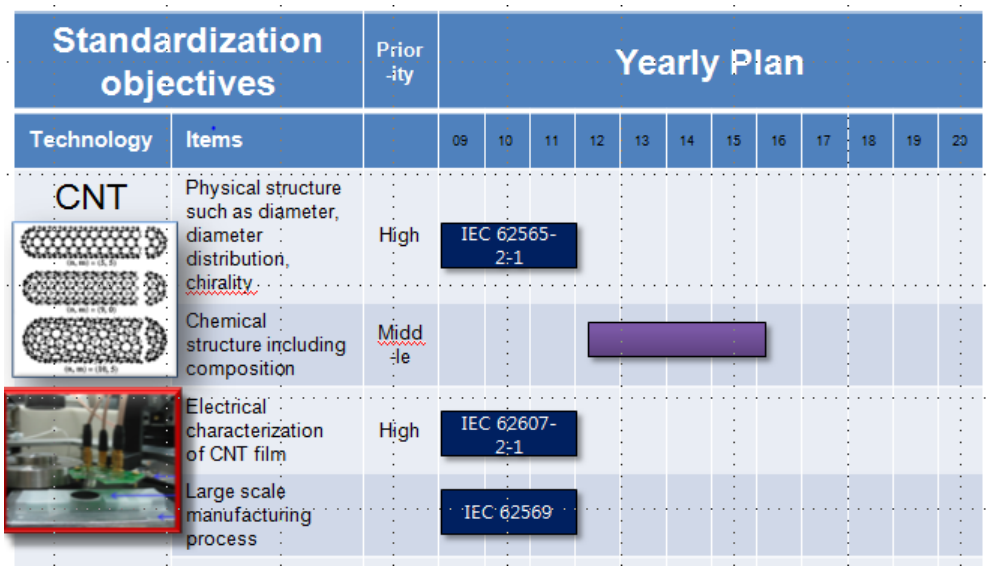
In IEC TC113 a survey on nano-electrotechnical standardization needs was initiated by the National Institute of Standards and Technology (NIST) in the USA to establish a strategy of standardization priorities regarding the nanoelectronics area. A TC 113 Project Team was then organized to build a “Nanoelectronics standards roadmap”. This document covers nanoscale devices and nanomaterials which will be in the market or are already commercialized for nanoelectronic applications. When selecting the devices and materials to be included in the roadmap, the Project Team considered their market size and the period of time needed for their technology development. Because most of the experts in TC 113 are from an electronics background, the first version (Part A) of this roadmap covers electronics and ICT (information and communication technology) rather than energy or convergence technologies.

Regarding nanomaterials, roadmaps for carbon nanotubes (CNT), graphene, nanofibres, nanoparticles and quantum dots were established. For each material there are several detailed items that need to be standardized, including physical properties and characterization methods. Some of such standards are already under development in TC 113, such as IEC 62565-2-1 and IEC 62569.

In the nanoelectronics device roadmap, nanoscale contacts, CNT interconnects, three-dimensional nanotransistors, nanoscale memory devices, and molecular devices were selected. Though the priority was on memory devices and new types of transistors, molecular devices were included in this version considering the impact of this technology.

The time span of the roadmap is important in order to cover the technology which may be realized in a certain period of time. However, with regard to nanoelectronics development, little information on the average technology development period is available at this stage. Thus TC 113 set the span of the roadmap up until the year 2020 to show the starting point of standardization tasks and the end of activity.

As the format should give insights and detailed information to the user of the roadmap, the Gantt chart format was used, including photos (see Figure 1). When a new version of the roadmap is prepared, TC 113 will develop a new format in parallel, which can give more accurate information to users.



IEC 2281/13

Figure 1 – Roadmap format

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62834:2013

IEC NANOELECTRONICS STANDARDIZATION ROADMAP

1 Scope

This Technical Report covers nanomaterials and nanoscale devices. To achieve consensus more quickly when building the roadmap, an ICT "More Moore" area has been adopted for the priority standardization items of this first version, as shown in Table 1.

Table 1 – Categories and detail potential products

Categories		Detail potential products	Version 1
Nanomaterials	Zero-dimensional nanomaterial	Nanoparticles/Nanopowders Quantum dot	√ √
	One-dimensional nanomaterial	Carbon nanotube Nanowire (Ⅲ-Ⅴ, Ⅱ-Ⅵ, ZnO)	√
	Two-dimensional nanomaterial	Nanofunctional thin film Nanostructural film Graphene	 √
	Three-dimensional nanomaterial	Nanopore materials Nanocomposites	
Nanoscale devices	Nanoelectronic devices	Nanoscale non-volatile memory devices 1- and 3-dimensional nanoscale transistors Single electron transistor Nanoscale logic devices Nanoscale interconnection Post-CMOS signal processing	√ √ √ √
	Nanoscale optical devices	Silicon optical devices Photonic crystal optical devices All-optical logic devices Quantum dot optical devices	
	Nanoscale magnetic devices	Highly integrated memory devices High-speed magnetic logic devices	√ √
	Molecular devices	Molecular logic device Molecular memory device Molecular sensors Molecular mechanics devices Molecular optical devices	√ √
	Nanomaterials-based flexible devices	Nanomaterials-based flexible devices Nanomaterials-based displays	
Nanofabrication processes, equipment measurement	Nanofabrication process	Nano lithography Self-assembly	
	Nanoscale metrology and simulation	SPM	

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62834:2013

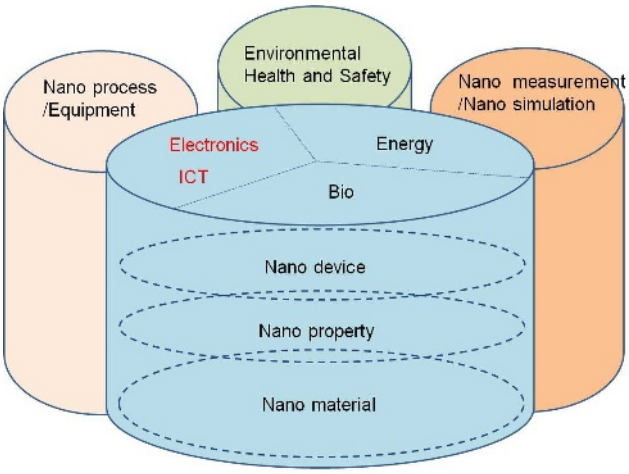
2 Background

2.1 General

The development of an "IEC nanoelectronics standardization roadmap" is necessary to establish a common standardization strategy in the area of nano-electrotechnology. The first step for determining standardization needs was carried out through a survey conducted by the National Institute of Standards and Technology (NIST) in the USA. The goal of this survey was to begin building a consensus among members of the nano-electrotechnology community on a framework leading to inputs for consideration in standards development. The results from the survey were reported in 2009. [1][1]

Nevertheless, a standardization roadmap requires more than a framework of priority needs for standards established by the foregoing survey results. It requires a vision from technical experts as to which products will be developed in the future and which technologies will be available to realize them. That means a vision of market needs and technology availability.

Figure 2 shows technologies and their related markets. It will be possible to make the roadmap for all technology areas, such as electronics, information and communications technology (ICT), bio, energy etc.. In this version, we focus on the existing information available to develop a roadmap, for example the area of "More Moore", including nanotechnologies and nanomaterials, which makes it possible to achieve technology innovation in terms of integrity and high performance. The areas not covered by this document will be provided separately after considering demands for standardization.



IEC 2282/13

Figure 2 – Technologies and related products

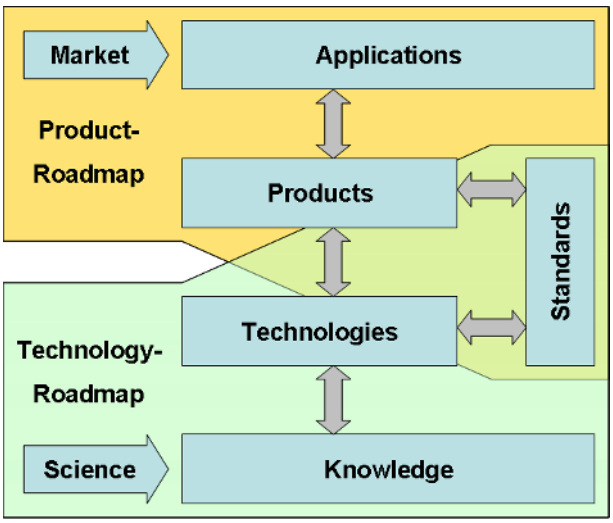
The interaction between technology, product and the standardization roadmap is illustrated in Figure 3. Most of the stakeholders in nanotechnology have their own roadmap, and from time to time, publicly available roadmaps are under development. The problem here is that company-owned roadmaps are not available to the IEC and there is no guarantee that publicly available roadmaps they will be actualized on a regular basis. Therefore, IEC TC 113 decided to develop its own integrated roadmap based on its view of technologies, products and standards.

From an IEC strategic point of view, such a project could have some very important advantages. Assuming that the roadmap would be structured in line with the IEC technical committee structure, it would provide an effective planning tool for the IEC as a whole. It would support the work of IEC TC 113 by providing the relevant market information to establish and review its programme of work. If the IEC owns the product/technology/standards roadmap and the roadmap update process, it can be used in areas of interest other than the

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

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62834:2013

production of standards. Last but not least, the roadmap would demonstrate that the IEC has a position in nanotechnology which is agreed among relevant industry stakeholders.



IEC 2283/13

Figure 3 – Interaction of product, technology and standardization roadmaps

2.2 Classification of nanotechnology

2.2.1 General

The nanotechnology industry can be largely divided into nanomaterials, nanoscale devices, nano-biotechnology, the nanofabrication process, equipment and measurement areas.

2.2.2 Nanomaterials

These are materials that control, combine, and mix materials at the nanoscale to remarkably improve physical properties and to create new physical properties and functions. They apply to mechanics, energy, environment and IT-related systems.

2.2.3 Nanoscale devices

These are devices that can perform special functions using unique characteristics of nanoscale materials.

2.2.4 Nano-biotechnology

This is an area of science and technology operating, analysing and controlling a system combining biosystems with nanomaterials and/or nanoscale devices.

2.2.5 Nanofabrication process – Equipment – Measurement

This is manufacturing technology of nanoscale processes (under 100 nm) that form nanoscale parts and devices, as well as equipment technology and performance measuring of nanomaterials, devices, subsystems and systems.

3 Current status and prospects

3.1 Related markets

Currently, zero-dimensional nanopowders, TiO_2 nanopowders for photocatalyst and anti-bacterial silver nanoparticles are widely commercially available materials. The market size of TiO_2 nanopowders for photocatalyst is 10 million US dollars (2005) worldwide.

The tool market is the largest area of application and the market of nanostructure thin film materials internationally. Although it is difficult to forecast the status of world tool markets, the world market of diamond cutting tools is estimated to be about 13 billion US dollars based on information from 1999.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62834:2013