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REVIEW PAPER

Role of NPL-India in Nanotechnology and Nanometrology

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Abstract: This article is solely intended to elucidate in brief about some of the significant activities being persuaded in the laboratory with the intention of establishing nanotechnology and nanometrology program and objectives in conjunction with various regulatory bodies, academic institutions and industries. Details of standardization activities on synthesis, measurement, characterization and properties for nanotechnology have been highlighted and the perspective of further steps in execution of nano-related programs has been reviewed and discussed.

Keywords: Standards; Nanoscience; Nanometrology; Electron microscopy

1. Introduction about NPL-India

The National Physical Laboratory (NPL-I) is the premier research laboratory in India, under the umbrella of Council of Scientific and Industrial Research (CSIR), in the field of Physical Sciences. It has developed core competencies in Standards, Apex Level Calibration, Engineering Materials, Electronic Materials, Materials Characterization, Radio & Space Physics, Global Change and Environmental Studies, Low Temperature Physics and Instrumentation. The main competence towards materials—based research at nano-scale is devoted in the four core groups consisted of: (i) Materials Physics and Engineering, (ii) Physics of Energy Harvesting, (iii) Quantum Phenomena and Applications, and (iv) Sophisticated and Analytical Instruments. Respectively, some of the important activities of materials-based divisions are illustrated as: (i) development of aerospace metallic devices, new carbon products which hold industrial and strategic importance, and a variety of conducting polymers and biosensors, (ii) organic photovoltaics and light emitting devices, inorganic light emitting diodes, amorphous and crystalline silicon solar cells, materials for thermoelectric devices and optical thin films, (iii) oxide interfaces in $LaTiO_3/SrTiO_3$, $LaAlO_3/SrTiO_3$ heterostructures, possibility of tuning the carrier density and electronic phases by changing temperature or by applying magnetic or electric fields, fabrication and characterization of magnetic tunnel junctions (MTJs), magnetic ring arrays and their influence on superconducting films and quantum phase slip processes in nanostructured superconductors, and (iv) high quality facilities for characterization of materials for morphology, chemical composition, purity, structure (including defects), crystallographic perfection and the study of solid surface thin films and interfaces. Detailed information may be obtained from NPL-website: www.nplindia.org. The responsibilities of Apex Level Standards and Industrial Metrology is nevertheless by carrying out the realization, establishment, custody, maintenance, dissemination and upgradation of the national standards for physico-mechanical, electrical, optical and thermal precision parameters. At this moment NPL-I has 246 CMCs and 149 International key/supplementary intercomparisons at the BIPM website. Another important division of Time & Frequency Standards is involved majorly on R & D activity of the development of primary frequency standard, namely cesium atomic fountain.

2. Emphasis on Nanoscience and Nanotechnology

The NPL-I has been working on several aspects of nanoscience and nanotechnology. The laboratory mainly focuses research activities on nanomaterials pertaining to polymers and soft matter, carbon-based, luminescent, multiferrites and manganites, biomolecular, optical thin films, ceramics, metals and alloys, amorphous and microcrystalline solar cells and thermoelectric materials and devices. In this regard, few publications are appended below as references [1–12]. However detailed information may be obtained on NPL-website, www.nplindia.org. It is

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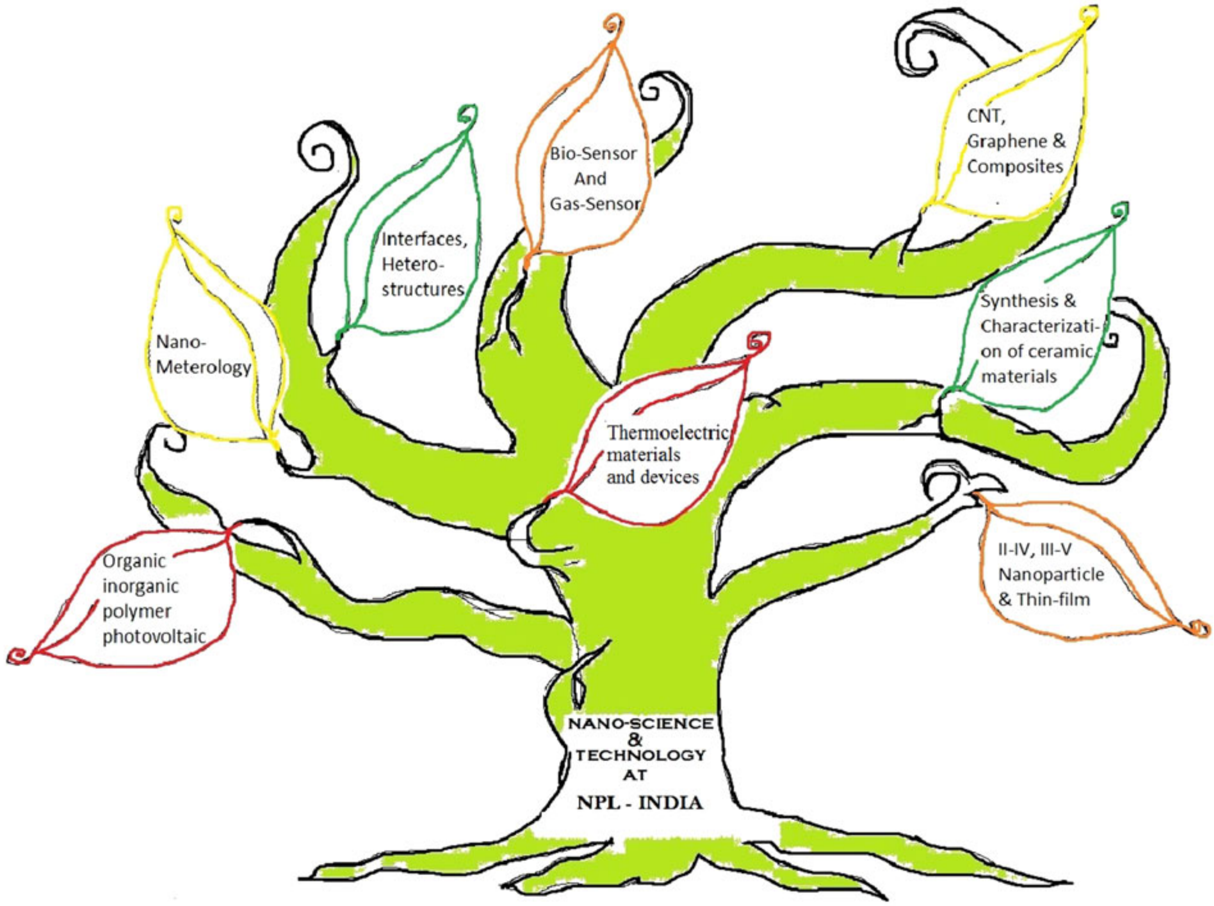

Fig. 1 Nano-tree of ongoing R & D activities in the area of nanoscience and nanotechnology at NPL-India

important to note that the nature of these materials is very diverse ranging from very highly pure and perfect single crystals to totally impure disordered materials. Therefore the characterization of these materials is concerned with all the three phases mainly solid, liquid and gases. At present high precision facilities are available for characterization of materials regarding all aspects, namely chemical composition, purity, structure, defects and crystallographic perfection. The objective of the laboratory is to develop materials, processes and technologies for components, devices, sensors and systems in the field of nanotechnology. In fact the surge in the interest level in this emerging field can be well understood by the following schematic (Fig. 1) about the materials, measurements and applications being carried out in the laboratory.

3. Programs and Perspectives on Nanometrology

The laboratory has initiated leading role in standardizing the various aspects of nanoscience and nanotechnology in union with Bureau of Indian Standards (BIS) and International Organization for Standardization (ISO). The BIS comprises a nanotechnology sectional committee headed by the Director, NPL and many scientists of NPL as experts in four compartments namely, (i) Terminology and Nomenclature, (ii) Measurement and Characterization, (iii) Health Safety and Environment and (iv) Material Specifications. The nanotechnology sectional committee of BIS is a mirror image of ISO nanotechnology technical committee dedicated for developing standard documents in this very important area of research and development. The laboratory being only National Metrology Institute (NMI) in the country is committed for strengthening ISO nanotechnology program in India.

The Department of Science and Technology, Government of India has supported the idea of standardization of nanotechnology by funding a major program in the laboratory on Standardization for nanoscience and technology: Spreading its Awareness in India and Participation in International Organization for Standards (ISO) Activities on Nano metrology. Traceability of such measurements is essential for ensuring comparability of nano measurement. To fulfill emerging needs of Nano metrology, NPL is carrying out a project “Generic Development of Nanometrology for Nanotechnology at NPL-I” funded by

Table 1 List of activities under ISO/BIS nanotechnology program and respective involvement of partnering institutes

Activities	R & D Laboratories and Academic Institutes
National standard on use of atomic force microscope for characterization	National Physical Laboratory, New Delhi
	Regional Centre of Biotechnology, Gurgaon
	Central Institute for Research on Cotton Technology, Mumbai
	Indian Institute of Technology, Roorkee
	Jawaharlal Nehru University, New Delhi
	Indian Institute of Technology, Mumbai
Electron microscopic characterization of multi-walled carbon nanotubes and Y-junctions in CNTs	National Physical Laboratory, New Delhi
	Indian Institute of Science, Bangalore
	Defence Metallurgical Research Laboratory, Hyderabad
	Bhabha Atomic Research Center, Mumbai
	International Advanced Research Centre for Powder Metallurgy and New Materials, Hyderabad
Standardization of toxicity evaluation of metal oxide nanomaterials	Indian Institute of Toxicology Research, Lucknow
	National Physical Laboratory, New Delhi
Absolute quantum efficiency determination of photoluminescent [GaN] quantum dots	National Physical Laboratory, New Delhi
	Indian Institute of Technology, New Delhi
Standardization of magnetic response of nanoparticles—using chemical process	National Physical Laboratory, New Delhi
	National Chemical Laboratory, Pune
	Indian Institute of Technology, Mumbai

Department of Electronics and Information Technology, Ministry of Communications & Information Technology. The Optical profiler established under this project has been applied to measurement of roughness of mass standards, silicon wafers, MEMS, Roughness standards and step heights etc. An activity has been initiated to understand the difference between nano particle sizes determined by various characterization techniques. ZnS and ZnS–Si nanoparticles have been developed and characterized using XRD, UV–Vis spectra, Photo Luminescence, SEM and TEM methods. A method for measurement of aperture area using image processing techniques has been developed.

The NPL-I has a strong approach of fulfilling the criteria of Nano metrology by employing different methodologies. The first and foremost approach is to effective utilization of NPL's infrastructure and experience in precision measurement of dimensions, optical emission, magnetic moment and other materials properties for standardization of nanomaterials and also characterization of the standardized photoluminescent nanoparticles and carbon nanotubes for their application as single photon source and also absolute determination of quantum yield. In this regard the formation, coordination and a very cohesive interaction of India's leading institutions academia, regulatories, industries and other government bodies is being applied very successfully. Our major programs in the field of standardization of nanomaterials, their science and technology are illustrated below in Table 1. Our partnering institutes along with NPL-I are also mentioned in Table 1.

In-house research for standardization of nanomaterials properties is mainly focused on three classes of important materials which display fascinating physical and chemical properties and thus hold enormous potential for a variety of technological applications. These materials are; (a) photoluminescent nanoparticles of II–VI compound semiconductors, (b) carbon nanotubes (multiwall and single wall), and (c) magnetic nanoparticles for recording, hyperthermia and drug delivery applications.

Characterization of standardized photoluminescent nanoparticles and CNTs for their application as single photon source and also absolute determination of quantum yield of photoluminescent nanoparticles is very important for modern developments. Another relevant field of toxic measurements on metal oxide nanoparticles [13], in particular ZnO and TiO_2 is being explored to understand the side-effects of these fascinating and important nano-scaled objects [14, 15]. We are planning to develop standard documents on, measurements on Y-junctions of carbon nanotubes. We have taken responsibility of carrying out this work and to explore the reasons of the evolutions of such fascinating nano-scale patterns of Y-junctions which are very useful in various nano-devices.

4. Contributions to ISO and BIS Nanotechnology Program

The committee ISO/TC 229 and its Working Groups on Nanotechnologies were set up by the International

Organization for Standardization (ISO), in June 2005, with the scopes of (a) understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nm in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications and (b) utilizing the properties of nanoscale materials that differ from the properties of individual atoms, molecules and bulk matter to create improved materials, devices and systems that exploit these new properties. India is a P-member, which is mainly operated by BIS and NPL-I, of this committee and its four working groups, titled as: (i) JWG 1—Terminology & Nomenclature, (ii) JWG 2—Measurements and Characterization, (iii) JWG 3—Health, Safety and Environment, and (iv) JWG 4—Material Specification.

ISO's four standards on nanotechnologies: (i) ISO/TS 10867:2010 Nanotechnologies—Characterization of single-wall carbon nanotubes using near infrared photoluminescence spectroscopy, (ii) ISO/TS 10798:2011 Nanotechnologies—Characterization of single-wall carbon nanotubes using scanning electron microscopy and energy dispersive X-ray spectrometry analysis, (iii) ISO/TS 11308:2011 Nanotechnologies—Characterization of single-wall carbon nanotubes using thermogravimetric analysis, and (iv) ISO/TS 11888:2011 Nanotechnologies—Characterization of multiwall carbon nanotubes—Mesoscopic shape factors, are being further considered by us to help BIS to adopt these ISO-standards as dual number National Standards. In addition to above standard documents, it was also committed to adopt following ISO standards as Indian Standards: (a) ISO/TS 80004-4:2011 Nanotechnologies—Vocabulary—Part 4: Nanostructured materials, (b) ISO/TS 80004-5:2011 Nanotechnologies—Vocabulary—Part 5: Nano/bio interface, (c) ISO/TS 80004-7:2011 Nanotechnologies—Vocabulary—Part 7: Diagnostics and therapeutics for healthcare, (d) ISO/TS 12805:2011 Nanotechnologies—Materials specifications—Guidance on specifying nano-objects, (e) ISO/TS 13278:2011 Nanotechnologies—Determination of elemental impurities in samples of carbon nanotubes using inductively coupled plasma mass spectrometry, and (f) ISO 29701:2010 Nanotechnologies—Endotoxin test on nanomaterial samples for in vitro systems—Limulus amebocyte lysate (LAL) test.

We, along with ISO, are in evaluation and coordination of various assessments on different projects submitted to ISO on nanotechnology. Our views brought together with other experts in India and abroad in nanotechnology and nanometrology are well taken in up-gradation of the quality of the documents persuading for acceptance as standard documents globally. Some of these projects in the areas of Measurements & Characterization and Health, Safety & Environment, where our views were considered while evaluations of the documents are referred below:

4.1. Measurements and Characterization

i. ISO 10808:2010 Nanotechnologies—Characterization of nanoparticles in inhalation exposure chambers for inhalation toxicity testing
ii. ISO/TS 10867:2010 Nanotechnologies—Characterization of single-wall carbon nanotubes using near infrared photoluminescence spectroscopy.
iii. ISO/TS 11251:2010 Nanotechnologies—Characterization of volatile components in single-wall carbon nanotube samples using evolved gas analysis/gas chromatograph-mass spectrometry
iv. ISO/TS 10798:2011 Nanotechnologies—Characterization of single-wall carbon nanotubes using scanning electron microscopy and energy dispersive X-ray spectrometry analysis
v. ISO/TS 10868:2011 Nanotechnologies—Characterization of single-wall carbon nanotubes using ultraviolet–visible-near infrared (UV–Vis-NIR) absorption spectroscopy
vi. ISO/TR 10929:2012 Nanotechnologies—Characterization of multiwall carbon nanotube (MWCNT) samples
vii. ISO/TS 11308:2011 Nanotechnologies—Characterization of single-wall carbon nanotubes using thermogravimetric analysis
viii. ISO/TS 11888:2011 Nanotechnologies—Characterization of multiwall carbon nanotubes—Mesoscopic shape factors
ix. ISO/TR 13329:2012 Nanotechnologies—Preparation of mateiral safety data sheet (MSDS)
x. ISO/TR 13014:2012 Nanotechnologies—Guidance on physico-chemical characterization of engineered nanoscale materials for toxicology
xi. ISO/TS 14101:2012 Surface characterization of gold nanoparticles for nanomaterial specific toxicity screening: FT-IR method
xii. ISO/TS 10797:2012 Nanotechnologies—Characterization of single-wall carbon nanotubes using transmission electron microscopy
xiii. ISO/TR 11811:2012 Nanotechnologies—Guidance on methods for nano-and microtribology measurements
xiv. ISO/TS 11931:2012 Nanotechnologies—Nanoscale calcium carbonate in powder form—Characteristics and measurement
xv. ISO/TS 11937:2012 Nanotechnologies—Nanoscale titanium dioxide in powder form—Characteristics and measurement
xvi. ISO/TS 12025:2012 Nanotechnologies—Quantification of nano-object release from powders by generation of aerosols

4.2. Health, Safety and Environment

xvii. ISO 10801:2010 Nanotechnologies—Generation of metal nanoparticles for inhalation toxicity testing using the evaporation/condensation method
xviii. ISO/TS 12901-1:2012 Nanotechnologies—Occupational risk management applied to engineered nanomateirals-Part 1 Principles and…
xix. ISO/TR 13329:2012 Nanotechnologies—Preparation of material safety data sheet (MSDS)

It is the first time in India that the NPL-I together with BIS has proposed to host 17th meeting of ISO/TC 229 and its four working groups in India in the year 2014. This meeting would further enrich the knowledge of ISO nanotechnology program among various scientific and technical sectors in the country. Our intentions extend towards spreading awareness about nanotechnology and its standardization by conducting national seminars and meetings.

5. Synthesis and Precise Measurements: Case Studies on Titanium Oxide and Carbon Nanotubes

5.1. Titanium Oxide

Titanium oxide (TiO_2) is an important class of materials covering the diverse and fascinating properties [16–18]. The important application of TiO_2 is its use as photocatalysts, photoluminescent, opto-electronics, hard coatings, gas sensors, etc. Nanostructuring of TiO_2 enhances several possible efficient applications due to large surface to volume fraction and quantum confinement effect. For example, its photocatalytic uniqueness is greatly enhanced due to the creation of several nano-structures leading to nanotechnology. At nano-scale, not only the surface area of TiO_2 particle increases dramatically but also it results other extraordinary effects on optical properties and size quantization. An increased rate in photocatalytic reaction is observed as the redox potential increases and the size decreases.

TiO_2 is a typical n-type semiconductor, which exists mainly in three polymorphic forms, rutile, anatase and brookite with the energy band gaps of 3.02, 3.2 and 2.96 eV, respectively. Brookite is rare in nature. Rutile is a high temperature stable phase. Anatase is not as thermodynamically stable as rutile but has proven to be the most promising photocatalyst with a wide band gap of 3.2 eV. The different-phase details and crystal structures of all three forms of TiO_2 are illustrated as in Table 2 and Fig. 2.

A set of atomic-structural coordinates are incorporated in the crystal structure formulation of all three forms of TiO_2. It is obvious that symmetrically the stability of anatase is lesser that that of rutile due to longer c-axis of anatase than rutile, although both the structures are tetragonal. A visual feel of the three different forms of TiO_2 is possible to gain by employing VESTA-software (Fig. 2).

Table 2 Different polymorphic forms and crystal structures of TiO_2

Properties	Polymorphic forms		
Crystal structures	Anatase Tetragonal	Rutile Tetragonal	Brookite Orthorhombic
Lattice constants (Å)	a = 3.78 c = 9.49	a = 4.52 c = 2.94	a = 5.46 b = 9.18 c = 5.14
Space group	$I4_1/amd$	$P4_2/mnm$	*Pcab*
Reference: JCPDS card no.	73-1764	88-1175	29-1360

Several batches of TiO_2 nano-structures in the form of powder are prepared with their repeatability in terms of phase formation (anatase), morphology and dimensions, employing a chemical route. The thermal stability of anatase-phase has been checked at different temperatures. Figure 3 exhibits X-ray diffraction (XRD) measurements and reveals the presence of anatase even up to post annealing at 400 and 500 °C of as synthesized nano-particles of TiO_2. The peak positions are denoted by corresponding hkl-indices on Fig. 3. An aggregate of nanoparticles with an average size between 10 and 15 nm are shown in Fig. 4 (insets A and B in Fig. 4). However few particles with size finer and coarser than average size are also revealed. As an illustrative example, atomic scale image of one of these nano-particles of size about 8 nm clearly elucidates that the individual particles are nanocrystallites and in this particular case, the crystallite is stacked with planes (hkl: 101) with spacing of 0.35 nm of anatase crystal structure (inset A in Fig. 4). A preliminary observations of photoluminescence (PL) experiments revealed that there is red shift in the band gap of TiO_2 nanoparticles (inset C in Fig. 4). Figure 4 shows that in general on using excitation wavelength of 250 nm, maximum emission occurs at around 430 nm which is attributed to violet in color. PL experiments are useful in understanding the band gap engineering of these nanostructures.

A pictorial view of five batches of nano-particles of TiO_2 having similar dimensional morphology and preserved in vials is depicted in Fig. 5. We are in the process of distributing these vials containing TiO_2-nanoparticles for different toxicological measurements on mammalian and plant cells in coordination with Indian Institute of Toxicology Research, Lucknow, our partnering CSIR-laboratory in nanotechnology and nanometrology program.

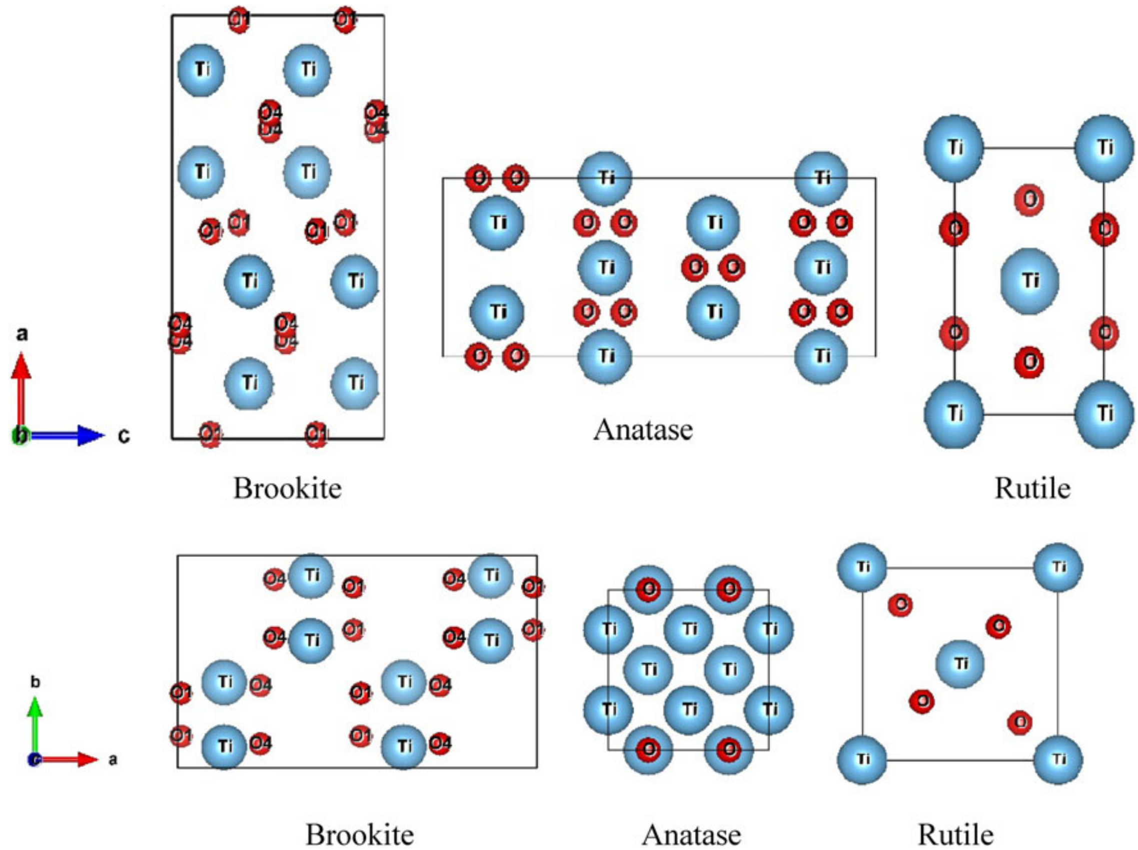

Fig. 2 Atomic sites of Ti and O atoms in different phases of TiO_2 along b and c axes of unit cells

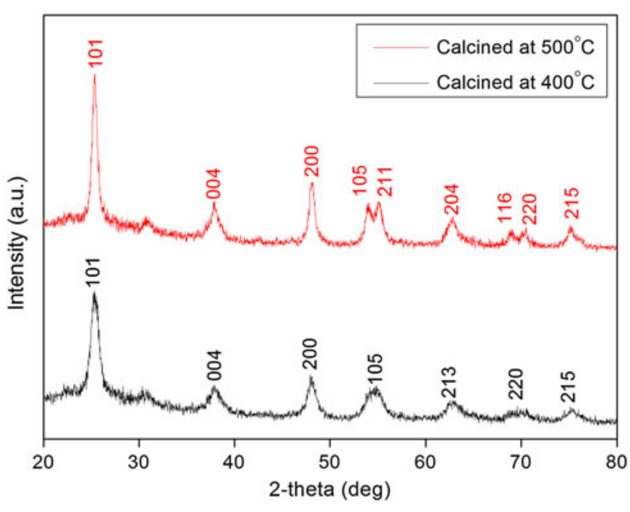

Fig. 3 XRD measurements showing the presence of anatase-phase after annealing of as synthesized TiO_2 at 400 and 500 °C

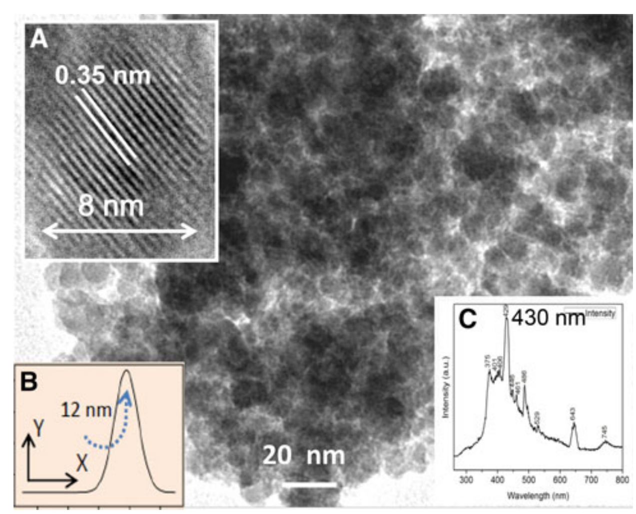

Fig. 4 HRTEM image exhibiting the presence of nano-particles of TiO_2. *Insets* show (*A*) a single crystalline nature of individual particle, (*B*) size distribution of nanoparticles, and (*C*) PL spectra of nanoparticles. X-axis: 300–800 nm (wavelength) and Y-axis: Intensity (arb. unit)

5.2. Carbon Nanotubes

Carbon nanotubes (CNTs) are allotropes of carbon with a hollow one-dimensional nanostructure, composed of parallel layers of graphene sheets in the form of tubes placed along the longitudinal axis. High resolution transmission electron microscopy (HRTEM) was the technique to resolve the distinctive features of these unique materials and played key task of their development subsequently. However HRTEM is a precise technique and needs several

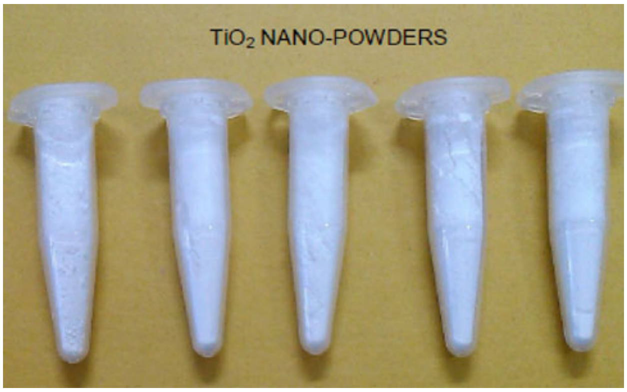

Fig. 5 Large scale synthesis of nano-particles of TiO_2

steps of sampling, imaging and interpretation of results and therefore, it is important to expand and follow a methodical protocol for employing HRTEM to attain reliable and comprehensive report of a given CNT sample. It is vital to distinguish the CNTs with the following essential points, like, (a) estimate of purity of single- and multi- wall carbon nanotubes, (b) evaluation of impurities such as metals, amorphous carbon, and other carbonaceous by-products, (c) examination of bundling, de-bundling, orientation, packing morphology, (d) study of diameter distribution, and (e) measurement, counting statistics, etc.

We are in the process of evaluating CNTs procured through international suppliers like M/S Nanocyl and in-house synthesized at different laboratories like NPL New Delhi and IARCPMNM, Hyderabad. These CNTs are normally prepared by Catalytic Carbon Vapor Deposition. This is a proven process for the synthesis of CNTs and is well known for its reliability and scalability. It involves growing nanotubes on substrates, thus enabling uniform, large-scale production of the high-quality nanotubes.

In addition to the above described research problems associated to CNTs we emphasize working to explore the reasons for the evolutions of Y-junctions in CNTs [19–22]. These microstructural patterns of CNTs are very useful for various applications. CNTs having unique dimensions and electrical properties are the most potential material in the fast developing semiconductor circuit technology as a device miniaturization with an improved efficiency. It is known that the formation of Y-junctions can be understood by introducing a non-hexagonal ring in the hexagonal—ring networking appear in the carbon nanotube at the atomic-coordinates wherever junctions can be nucleated. A set of preliminary observations made after clubbing the joint efforts of three partnering institutes (NPL New Delhi, DMRL Hyderabad, IISc Bangalore) are depicted in the following micrographs (Fig. 6). It is important to mention that the varying angles (approximately: 71°, 75° and 38°) obtained in three geometries of Y-junctions may be attributed to the coordinates of catalytic-nanoparticle while nucleation and growth and subsequent bifurcation of original CNT in branches leading to Y-junctions (Fig. 6a, b and lower inset of Fig. 6b). In the same nanotube, it interesting to note that two branches (marked as A and B in upper inset of Fig. 6b) are delineating the presence of Y-junctions. A catalytic nano-particle trapped in an individual carbon nanotube at the point of bifurcation is also denoted with a white dotted line in lower inset of Fig. 6b. From the electron microscopy observations, it is possible to differentiate between a Y-junction carbon nanotube (Fig. 6a, b) and two overlapped nanotubes (region encircled with white dotted line in Fig. 6c) present in the same carbon nanocluster. We have also revealed a nanotube with only a three walled co-axial structure (Fig. 6d) with an outer diameter of about 8 nm. To complete the visibility of a normal structure of a carbon nanotube, we have demonstrated an atomic scale schematic (Fig. 6e) of such fascinating carbon allotrope.

6. Facilities of High Resolution Transmission Electron Microscopy and Spectroscopy

The implication of atomic scale high resolution transmission electron microscopy (HRTEM) is that it provides high resolution images containing information up to 0.1–0.2 nm and also operates with small electron probes in various microanalytical modes with a spatial resolution of 0.2–100 nm. The acceleration voltage normally employed to operate HRTEM to study materials of metals & alloys, ceramics, composites, etc. is between 200 and 300 kV. HRTEM is extremely useful to study and interpret the crystal structures, phase identifications, phase transformations, epitaxial growth, lattice imaging, crystallization, particle shape, particle size, surface finish, interface structures, defects, dislocations, voids, twins, stacking faults, inclusions, precipitates and more recently several parameters pertaining to nanostructured materials. Electron microscopy equipped with spectroscopic measurements like energy dispersive spectroscopy (EDS) and electron energy loss spectroscopy (EELS) are beneficial in analyzing inclusions, dopants and their chemical mapping. The coupled mode of image-spectrum has been realized as a powerful tool for determining structure—property correlation at interfaces and grain boundaries, local stoichiometry, impurity segregation and electronic structure pertaining to atomic states and refined electronic energy shells. Our state-of-the-art facility of analytical high resolution transmission electron microscopy (equipment model, HRTEM, FEI Tecnai G^2 F30 STWIN with field emission gun and electron accelerating voltage up to 300 kV) attached with STEM and EDAX is dedicated for materials characterization at nano- and atomic- scale in real and

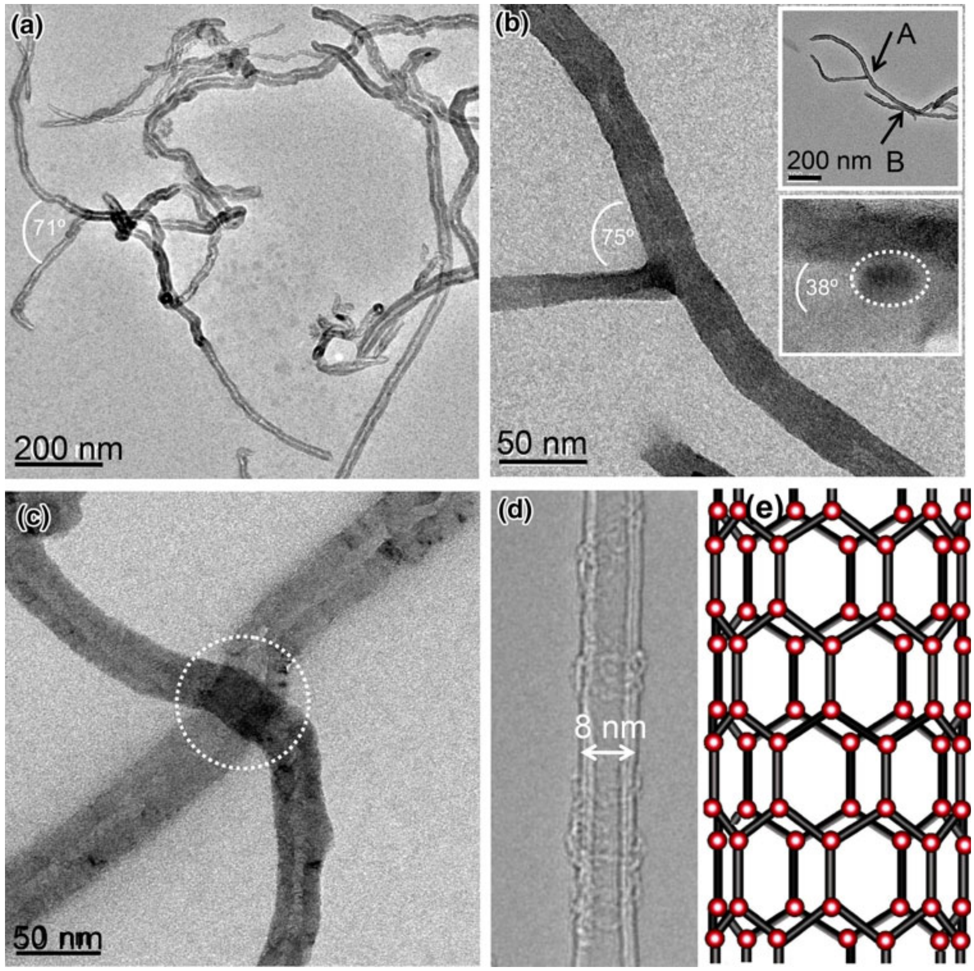

Fig. 6 TEM micrographs of carbon nanotubes showing **a** cluster of nanotubes, **b** Y-junction in an individual tube, **c** two overlapped tubes, **d** a tube constituted of three walls, and **e** a general schematic of a carbon nanotube. *Insets* in **b** two branches of Y-junctions at point *A* and *B* (*upper*) and Y-junction along with a catalytic particle (*lower*)

reciprocal space (inset A in Fig. 7). The resolution of the system is 0.205 nm (point to point in TEM mode) and 0.17 nm (STEM mode) for imaging and with energy resolution of 136 eV for chemical composition. The current research on different R & D projects is devoted for in-depth analysis of materials being developed for thermoelectric, solar cell, automobile, bio-medical, magnetic and nano-structured morphologies of various kinds. The equipment is calibrated at repeated interval of time to maintain the consistency of the observations on different precious samples. Figure 7 elucidates an atomic scale high resolution micrograph recorded on a gold test-sample received from M/S Ted Pella, USA for different real and reciprocal space apex level calibration purposes of the microscope. It is important to mention that the reliability in terms of traceability and calibration are important parameters for the instrument. The instrument (HRTEM) is routinely calibrated using the standard specimens of gold [23, 24]. The other aspect is to elaborate basic concepts of electron energy, wavelength, resolution, lenses and other influencing parameters which control the performance of a transmission electron microscope. Moreover the accuracy of operating parameters on image formation, measurements and subsequent interpretations are very important. Several such parameters are being concise and the efforts are being put to prepare an article in near future. In the present experiment, several fine-scaled crystallites of gold are visible on the micrograph. A few interplanar spacings of gold (face centered cubic crystal structure, lattice constant; a = 0.408 nm) as 0.24 and 0.21 nm corresponding to hkl values: 111 and 200, are marked on the micrograph (Fig. 7). Although the specified resolution of the machine is 0.205 nm, however in practice we are able to resolve the objects even finer distance apart. As an example, the insets B and C shows the interplanar spacings of 0.14 and 0.12 nm corresponding to hkl: 220 and 311, crystal structure of Gold. A selected area electron diffraction pattern (SAEDP) of Gold is displayed as inset D in Fig. 7, along [001] zone axis. At this juncture, it is worth mentioning that a new HRTEM assisted with field emission gun as electron source is under procurement from M/S JEOL, Japan (model: JEM 2100 F) equipped with EDS from M/S Oxford, UK and EELS from M/S Gatan, USA. The point to point resolution of basic TEM is 0.23 nm. The energy

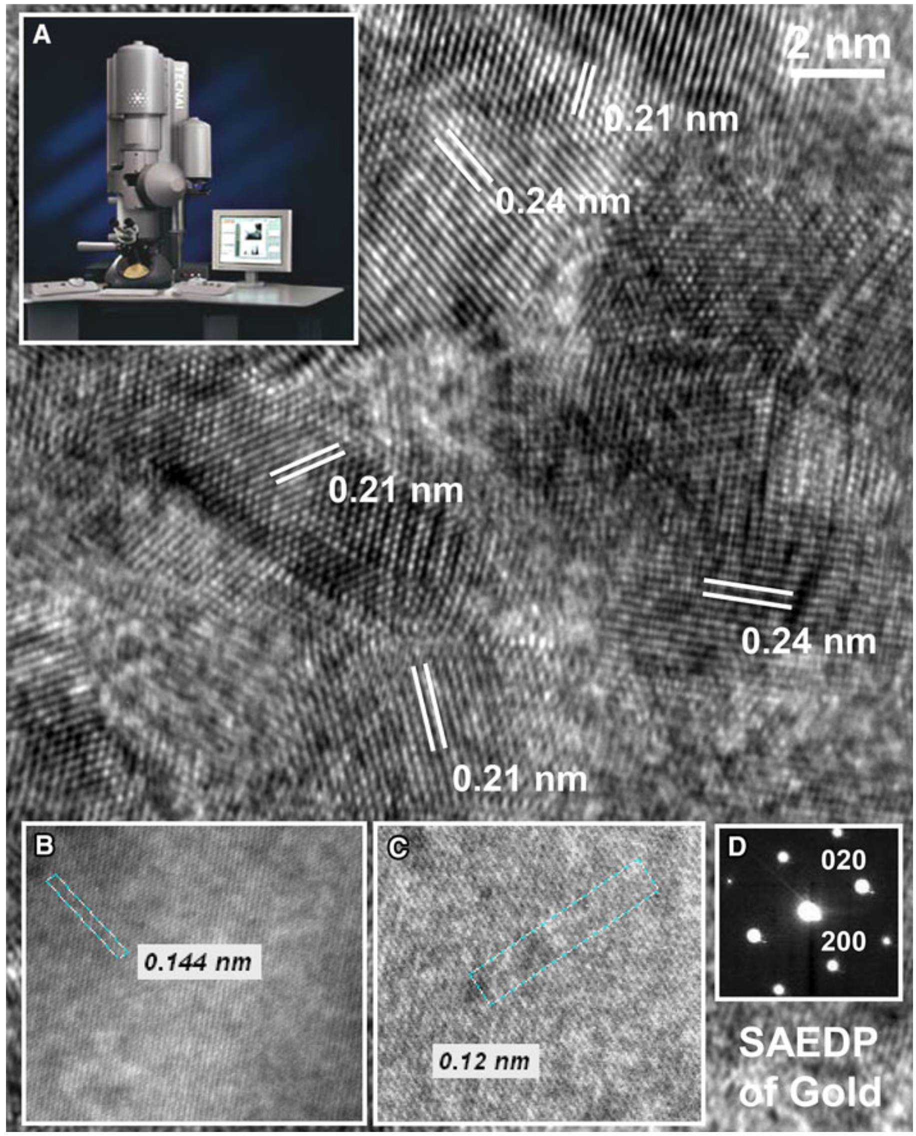

Fig. 7 Atomic scale electron micrograph revealing various interplanar spacings of a standard gold specimen. *Insets A* photograph of FEI Tecnai 300 kV HRTEM, *B*, *C* lattice scale images of different atomic planes, and *D* a SAEDP recorded along [001] zone axis of cubic crystal structure

resolution of EELS is 0.6 eV, which is sufficient to resolve various electronic structures of elements and compounds present in the material. The laboratory is looking forward to its process of installation and smooth functioning, so that, a detail and precise image—spectrum analysis is possible even at sub-nano scale.

7. Summary

The activities of NPL-India in the area of nanoscience and nanotechnology being persuaded for nanometrology has been well planned and synchronized with BIS and ISO. Our efforts are strengthened by the two government sponsored programs of Ministries of science and technology and information technology. The idea behind both these funding sources is to understand and establish the awareness and precise facilities of measurements in this emerging and highly valuable field of research. Moreover our parent organization, the Council of Scientific and Industrial Research (CSIR), has launched a mega-project on Nanomaterials: Applications and Impact on Safety, Health and Environment. The NPL-India has committed towards nanomaterials standardization activity and creates consciousness in India about the importance of evenness in nanotechnology and nanometrology.

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