Nanomaterials in science and technology

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Recent work on nanomaterials and their applications in science, technology, biology and medicine has been reviewed. Nanomaterials of different shapes and geometries and their characterization techniques are described. Methods for synthesis of different types of nanomaterials have been explained.

Keywords: Applications in science & technology, Characterization techniques, Nanomaterials

Introduction

Nanoparticles (NPs), nanointermediates and nanocomposites (NCs) belong to nanomaterials (NM) that are materials with sizes smaller than a micron (1-100 nm). When materials are made into NPs, their reactivity increases; gold is chemically inert at normal scales, but can serve as a potent chemical catalyst at nanoscales. Properties of NPs depend strongly on their dimension¹. NPs or nanocrystals have variety of unique spectroscopic, electronic and chemical properties arising from their small sizes and high surface/volume ratios. NPs are usually derivatized or stabilized with organic molecules to modify their solubility, stability and luminescence². Colloidal semiconductor nanocrystals or quantum dots (QDs), are used as light emitting devices and lasers³. Magnetic nanoparticles (MNPs) find variety of uses including bioapplications. MNPs (size, < 20 nm) exhibit super magnetism. Supermagnetic molecules are attracted to a magnetic field but do not retain residual magnetism after field is removed⁴.

Among MNPs, NPs of λ-Fe₂O₃ and its derivatives have gained importance in biomedical application. Spinel ferrite (AB₂O₄, where A sites have tetrahedral coordination by oxygen while B sites are octahedrally coordinated) is a very informative crystal system for understanding and designing magnetic properties of NPs (Fig. 1). Spinel ferrites, MFe₂O₄ (M = Mn, Fe, Co, Zn, Mg etc) are a ferromagnetic system. Magnetic properties of substituted iron oxides γ-MnₓFe₂₋ₓO₃ or MₓFe₃₋ₓO₄, where M= Al, Zn, Mn or Co can be further improved compared to those of parent oxide⁴. Cr³⁺ ions usually occupy octahedral B sites in spinels. α-Fe₂O₃ NPs work as a rechargeable electrode material⁵. Hexagonal like Fe₃O₄ NPs⁶ and size controlled synthesis⁷ of MNPs (diam, 3-20 nm) are also reported. CoCrₓFe₂₋ₓO₄ spinel ferrite nano particulate system offers an opportunity to study the role of Fe³⁺ in spinel ferrites through variation of Cr³⁺ ion concentration. Chemistry of NMs has been reviewed⁸.

Synthesis of Nanomaterials (NMs)

NMs of different types are: i) metal NPs; ii) Metal oxide NPs; iii) carbon NMs; iv) other NMs; v) polymer

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Metal Nanoparticles

Synthesis of NM gives nanostructures of a specific size, size distribution and that synthesis is reproducible. Copper NPs with antioxidation property is described\(^1\). Seeding and autocatalytic reduction of platinum salts in aqueous surfactant solution using ascorbic acid (AA) as reductant leads to dendritic NMs\(^2\).

\[
Pt^{2+} + AA \rightarrow Pt^{0} + AA_{ox}
\]

Photocatalytic reduction of platinum salts by SnP is accomplished in presence of visible light and an electron donor AA. In photoreaction, Pt\(^{2+}\) is reduced as

\[
SnP + hv \rightarrow SnP^-
\]

**Table 1—Nanomaterials of different geometries**

<table>
<thead>
<tr>
<th>No.</th>
<th>Nanostructures*</th>
<th>Shapes</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Zero dimensional nanostructures(^1)</td>
<td>Highly symmetric, isotropic, spheres, cubes, tetradecahedron and tetrahedrons</td>
<td>Spherical shapes of semiconductors metal oxide and metal nanocrystals</td>
</tr>
<tr>
<td>2</td>
<td>One dimensional nanostructures(^2)</td>
<td>Rods, wires, papers</td>
<td>Group II-IV semiconductors (CdS, CdSe, CdTe, ZnSe); Group III-V semiconductors (GaP, InP); Group IV semiconductor (Ge, PbS, PbSe, MnS); transition metal oxides (ZnO, TiO(_2), W(<em>6)O(</em>{19}), Mn(_2)O(_3), V(_2)O(_5), BaTiO(_4) and Fe(_2)O(_3)); carbon nanotube and semiconductor nanowires</td>
</tr>
<tr>
<td>3</td>
<td>Two dimensional nanostructures</td>
<td>Disks (D(<em>{\alpha h})), plates with polygon shape (D(</em>{\alpha h}))</td>
<td>Transition metal sulphides Cu(_2)S, NiS, co metal nanodisks, Gd(_2)O(_3) nanodisks, Fe(_2)O(<em>3) trigonal prisms(D(</em>{\alpha h})) CdS, CdSe, CdTe, MnS, ZnSe</td>
</tr>
<tr>
<td>4</td>
<td>Three dimensional nanostructures</td>
<td>Consisting of uniform nanorods (diam 100-400 nm)</td>
<td>ZnO nanostructures, α-Fe(_2)O(_3) urchinlike • nanostructure</td>
</tr>
<tr>
<td>5</td>
<td>Multipod Structures of semiconductors</td>
<td>Bipods (C(<em>{2v})), tripods (C(</em>{3v})) and tetrapods (T(_{\alpha})) star shaped dendritic</td>
<td>PbS (0h), CdSe, CdTe.</td>
</tr>
</tbody>
</table>

\*0-dimensional nanocrystals are recognized as nanoparticles; One-dimensional crystals (nanowires, nanorods and nanobuds) with nanometer scale diameters and high aspect ratios are currently focus of interest for their potential applications to key components of electronics, photonics, conductors and sensing in nano devices.

NM; and vi) NCs. Some advanced NPs include dots, rods, spindle, tetrapod wires, tubes, ribbons nanobelts, nanoscales, nanosheet and nanobuds (Fig. 2, Table 1). Methods\(^10\) for NMs synthesis include sol process, micelles, sol-gel process, chemical precipitation, hydrothermal synthesis, pyrolysis and vapour deposition.

Metal NPs can be prepared by receiving metal salts in reversed micelles (Fig. 3). Strong reduction agents such as NaBH\(_4\), N\(_2\)H\(_4\) and sometimes H\(_2\) gas were used. Pt, Rh, Pd, Ir, Ag, Au, Cu, Co, Ni and bimetallics FeNi, Cu\(_3\)Au, CoNi etc have been synthesized by this method. Normal micelles are oil droplets in water and act as a polymer that controls NP size. Using micelles produces Cu NPs. Smaller pore Ni and Au wires were prepared from 300 nm channel alumina templates and 140 nm silica spheres. Porous wires can be grown from anodized alumina or polycarbonate membranes containing silica or polystyrene spheres. Metal nanocrystals have been prepared by photochemical, electrochemical, biochemical and thermochemical methods\(^13\).

Gold NPs of different shapes (monopod, bipod, tripod and tetrapod) have been prepared\(^15\). An electrochemical method for preparing branched gold NPs has been reported\(^14\). Shin et al\(^16\) also reported preparation of gold
Palladium (Pd) NPs were electrodeposited from aqueous solution of PdCl$_2$ in 0.1M HCl. Kinetics of electrodeposition of Pd follows parabolic law indicating involvement of instantaneous nucleation and subsequent three-dimensional growth. Light plays an important role in shaping NPs. Au nanorods can be transformed into spherical NPs by using femtosecond laser pulses. Spherical silver – silver NPs were converted into silver nanorods. In this process, proposed mechanism included initial melting of small silver NPs and subsequent disintegration into smaller silver NPs.
NPs (20-60 nm) sized metallic face-centered cubic cobalt were synthesized by a modified flame synthesis method. Nanosized metal cores (Pt, Pd, or Pt/Au alloy) coated with ultrathin aerogel porous overlayers of controlled size and composition were also developed. Colloidal solutions of silver NPs (diam, 10 nm) were prepared by using sodium citrate as reductant. Formation of Ag NPs in multilamellar vesicles has been reported by using AgNO₃ as metallic source. Gas phase synthesis of fcc-cobalt NPs (diam, 20-60 nm) is reported.

**Metal oxide Nanoparticles**

Zinc oxide (ZnO) is a versatile semiconductor material with a wide direct-band gap of 3.37 eV and with promising applications in sensors, optoelectronic devices, solar cells and field emitters. Li et al. have synthesized flower like ZnO microstructures with different sizes and shapes via a simple aqueous solution route using ZnCl₂ and NaOH as reactants and triethanolamine as modifying agent. Self-organized <0001> oriented ZnO nanowires grown on supplier substrate have been synthesized with a simple vapour transport and condensation process. Hierarchical ZnO NsMs were obtained by electrodeposition. Porous plates of ZnO and porous single crystalline ZnO nanodisks have also been synthesized.

Thermal evaporation and solution-based chemistry (hydrothermal, solvothermal, sol-gel and electrochemical deposition) have been used to synthesize 1D and 2D ZnO NMs. In thermal evaporation method, use of high temperature (>900°C) and an Au catalyst is required to synthesize 3D ZnO NMs. An activated carbon assisted route was developed to synthesize a ZnO nanoparticle network. Surface area measurements showed that activated carbon assisted ZnO NPs had a higher surface area than those synthesized without activated carbon as confirmed by images from Field emission scanning electron microscope (FESEM) and high-resolution transmission electron microscope (HRTEM).

Flower like ZnO 3D NMs have been synthesized by a hydrothermal method using KNO₃ as inorganic mineralizer. ZnO 1D NMs have been synthesized using chemical vapour transport, physical vapour deposition approaches, ligand assisted synthesis and anodic alumina membrane template methods. Out of various methods (reduction of hemocite by CO/CO₂ or H₂, coprecipitation of solution of iron/ferric mixed salt, microwave plasma synthesis, microemulsion methods, ultrasound irradiation) reported for preparation of ultrafine particles of Fe₃O₄, hydrothermal process has been widely used to prepare single crystal and ceramic powder. Size controlled Fe₃O₄ (magnetite) NPs (diam, 4 nm) were prepared by reaction of iron (III) acetylacetonate [Fe(acac)₃] in phenyl ether in presence of alcohol, oleic acid and oleylamine as

\[
\text{Fe(acac)₃} + \text{ROH} + \text{RCOOH} + \text{RNH}_2 + \text{Ph}_2\text{O} \rightarrow 265°C \text{ agnetite}
\]

Novel 3D urchinlike hematite (α-Fe₂O₃) superstructures having weak ferromagnetic behaviour were prepared by a template free hydrothermal synthetic route using FeSO₄·7H₂O and NaClO₃ as reagents. α-Fe₂O₃ NPs with an extremely narrow distribution were also prepared by microwave heating. Single crystal nanobelts of α-Fe₂O₃ have been prepared in NaCl flux using a simple solid-state reactions and morphology was characterized by TEM, XRD and XPS. Uniform sized MnO nanospheres and nanorods have been synthesised. Mn³⁺ ions have been introduced in γ-Fe₂O₃ through sonochemical methods; phase becomes more stable compared to γ-Fe₂O₃. Substitution of Mn³⁺ suppresses transition to antiferromagnetic γ-Fe₂O₃ structure. Kadoma et al. synthesized MnO₂ nanosheet with acetylene black composite materials from layered K₀.₄₅MnO₂ powder. Highly uniform γ-MnO₂ 3D NMs were prepared by hydrothermal method as

\[
5\text{MnSO₄} + 2\text{KBrO}_₃ + 4\text{H₂O} \rightarrow 5\gamma-\text{MnO}_2 + \text{Br}_2 + \text{K}_2\text{SO}_₄ + 4\text{H}_2\text{SO}_₄
\]

Bacterial catalytic oxidation of water soluble Mn(II) to water insoluble manganese oxide MnO₂ is believed to be dominant process of MnO₂ mineral formation in aqueous environment because bacteria can catalyse oxidation of Mn(II) faster (up to 10⁵ times) than oleic acid catalysts. Nanocrystalline MnO₂ was produced by bacterial catalysis as

**Leptothrix discophora SP-6 bacterium**

Mn(II) → MnO₂

MgO NMs (orthogonally branched NMs, nanocubes and straight nanowires) were obtained through heating Mg powder with different oxygen partial pressure. Various other MgO NMs (nanorods, fishbone fractal NMs and nanowires) have also been synthesized. Transformation of nanocrystalline Mg(OH)₂ to MgO (570-770 K) is reported as
Metal NPs can also be prepared inside reverse micelles by hydrolysis where metal alkoxide dissolved in oil reacts with water inside the droplets. Nanowires (BaCO$_3$ and BaSO$_4$) have been synthesized using reverse micelles. NsM porous SnO$_2$ was synthesized$^{36}$ with high surface areas. A new structure-directing agent, haxadecyl-2-pyridinyl-methylamine, have been prepared through Schiff base condensation between pyridine-2-carboaldehyde and haxadecylamine followed by reduction of imine with NaBH$_4$.

**Carbon Nanomaterials**

Carbon NMs (nanowires and nanotubes), made of organic or inorganic materials, exhibit interesting, electronic, mechanical and structural properties. Carbon NPs, available in several geometries including cylindrical nanotubes$^{37}$ and fullerenes$^{38}$ (Fig. 4), are promising for applications in medicinal chemistry and material science. Archetype of fullerene family is carbon 60 (C$_{60}$; diam, 1 nm), which are closed cage carbon molecules with three coordinate carbon atoms. Fullerenes have been proposed as lubricants, catalysts and in drug delivery.

Carbon nanotubes (CNTs) are hollow cylinders (diam, 100 nm) of carbon atoms consisting of graphite sheets (Fig. 5a) in cylindrical shapes (Fig. 5b). Depending on the arrangement of hexagon rings along tubular surface, CNTs can be metallic or semiconducting. Most promising applications of CNTs are as a field effect transistors, nanotube interconnects and nanosensors. Depending on growth process, single wall nano tubes (SWNTs) or multiple wall nano tubes (MWNTs) can be obtained. SWNTs usually arrange in bundles of several tens of tubes in a hexagonal lattice, whereas MWNTs are concentric arrangements of up to several tens of tubes (inner tube distances, ~ 3.41 A°). Diameter (20 nm) was achieved as minimum grain size without deformation of hexagonal mesostructure. Unique properties of SWNTs have led to investigate their use in CMs for applications in electrostatic discharge, structural reinforcement and thermal dissipation. A SWNT is a one atom thick sheet of graphite, resembling chicken wire, rolled seamlessly into a tube. Semiconducting nanotube can be electrically switched on and off as field effect transistors$^{39}$. Fabrication strategies are based on arc-discharge, laser ablation, chemical vapour deposition, templated synthesis and high pressure experiments$^{40}$.

CNTs and metal filled anion like structure have been prepared by pyrolysis of ferrocine, cobaltocene and nickelocene under reductive condition wherein precursor acts as a source of metal as well as carbon$^{40}$. SWNTs were first prepared by metal-catalyzed dc arcing of graphite rods in a helium (He) atmosphere. Graphite anode was filled with metal powder (Fe, Co or Ni) and cathode was pure graphite. SWNTs occur in web like material deposition behind cathode. CNTs are readily prepared by striking an arc between graphite electrodes in 2/3 atm (~ 500 torr) of He, considerably higher than pressure of He used in production of fullerene soot. A current (60-100 A) across a potential drop of about 25V gives high yield of CNTs. SWNTs with well ordered graphite structure have been synthesized under hydrothermal condition using a polyethylene and water mixture in the presence of Ni catalyst at around 800°C. Besides conventional arc evaporation technique, CNTs are produced by decomposition of hydrocarbons (C$_2$H$_2$) under inert conditions at around 700°C over Fe/graphite, Co/graphite or Fe/silica catalyst.

A stable carbon nanobuds structure (Fig. 6) is a newly discovered material combining allotropes of carbon: CNTs and fullerenes. In this new material, fullerene-like buds are covalently bonded to outer sidewalls of underlying CNT. This material has useful properties of both fullerenes and CNTs, and found to be exceptionally good field emitter.

**Other Nanomaterials**

Inorganic NPs that exhibit unique shape-dependent nanoscale properties can be classified according to
dimensionality and crystal symmetry (Table 1). TiO$_2$ NPs of different shapes (bullets, diamonds, short rods, long rods and branched rods) have been prepared. Nanosized material (av thickness of particle aggregates, 50-115 nm) from glucose-cupric sulphate has been developed$^{41}$. Calcium phosphate NPs were functionalized$^{42}$ using suitable polymeric additives electrophoretically deposited on Ti and Si substrates.

Bimetallic Nanocrystals

Bimetallic NPs (FePt and CoPt) have been prepared. Fe$_{58}$Pt$_{42}$ NPs were made by reduction of platinum acetylacetonate [Pt(acac)$_2$] and decomposition of Fe(CO)$_5$ in octyl ether solvent under air free conditions, Pt(acac)$_2$, 1,2 hexadecanediol and dioctyl ether are mixed and heated to 100°C. Oleic acid, oleylamine and Fe(CO)$_5$ were added and heated to reflux at 297°C for 30 min. High quality Zn$_{1-x}$Cd$_x$Se NPs were prepared$^5$ at high temperature by incorporating stoichiometric amounts of Zn and Se into prepared CdSe NPs. CdTe NPs have cubic zinc blend structure and found to reorganize into crystalline nanowires$^{43}$.

Silphide Nanoparticles

Among sulphide NPs, Samokhvolov et al$^{44}$ synthesized CdS quantum particles assembled at predetermined distance from a gold substrate. Two kinds of CdS particulate film have been generated in situ by Pan et al$^{45}$ by exposing stearic acid Langmuir monolayer at air aqueous CdCl$_2$ interface to hydrogen sulphide gas: particulate films composed of oriented rod like NPs and those of dot like NPs, which formed a stripelike domain with straight edges aligned with 6-fold symmetry. Routkevitch et al$^{46}$ also performed electrochemical fabrication of CdS nanowire arrays in porous anodic aluminium oxide templates. Hu et al$^{47}$ synthesized ZnS nanobelts by using a H$_2$ assisted thermal evaporation approach. ZnS nanobelts were grown on a Si substrate and self assembled into a network structure. Zhu et al$^{48}$ have synthesized nanocable aligned ZnS tetrapod NPs. ZnS and carbon powders were mixed as precursors and placed in a graphite tube enclosed within a quartz tube. Precursors were heated at 900°C for 1 h in a N$_2$ flow to prepare ZnS-C nanocables and then heated at 1100°C for 1 h to fabricate nanocable aligned tetrapods.

Shchukin et al$^{49}$ synthesized nanosized magnetic ferrite particles inside hollow polyelectrolyte capsules. Different ferrites (CoFe$_2$O$_4$, ZnFe$_2$O$_4$, MnFe$_2$O$_4$) and magnetite were synthesized from corresponding salts exclusively inside poly(styrenesulphonate)/poly(allylamine hydrochloride) polyelectrolyte capsules (diam, 10 μm). Polyelectrolyte capsules with synthesized ferrite (magnetite) particles possess enough magnetic activity to be manipulated in water solution by an external magnetic field. Magnetic NPs of γ-Mn$_{2-x}$Fe$_x$O$_{3.5}$ (0≤x≤1.3) have also been synthesized$^4$. High quality Zn$_{1-x}$Cd$_x$Se NPs have been prepared$^{50}$ at high temperature by incorporating stoichiometric amounts of Zn and Se into prepared CdSe nanocrystals. Han et al$^{51}$ synthesized spinel ferrite CoCr$_{1-x}$Fe$_{x}$O$_4$ NPs over a compositional range 0≤x≤1 using a reverse micelle microemulsion method, which provided excellent control over composition and gave a reasonable size distribution. Upon increased Cr substitution, blocking temperature, saturation, magnetization, remnant magnetization and coercivity were all found to decrease.

Silica Nanoparticles

Suzuki et al$^{52}$ prepared silica NPs having mesopores using a cationic surfactant as a templating agent and a nonionic surfactant as a suppressant of grain growth. Hydrolysis of tetraethoxysilane with HCl and subsequent assembly of cationic surfactant micelles and anionic silicate at a basic condition produced hexagonal arrangement of mesopores (20 nm) in NPs.

Polymer Nanomaterials

Nanoscale π-conjugated organic molecules and polymers can be used for biosensors, electrochemical devices, single electron transistors, nanotops in field emission displays. Kim et al$^{53}$ studied doped and dedoped nanotubes and nanowires of polypyrrole, polyaniline and poly(3,4-ethylene dioxythiophene) by electrochemical polymerization. Zhang et al$^{54}$ studied wire, ribbons and sphere like nanostructures of polypyrrole obtained by solution chemistry methods in presence of surfactants with oxidizing agents. Silver/polypyrrole NCs were developed$^{55}$ via an interfacial polymerization. Preparation of polypyrrole-Fe$_3$O$_4$ NCs is also reported$^{56}$. 
Nanocrystals of Coordination Polymers

Coordination polymers are metal-ligand compounds prepared as

\[
\text{Metal cation} + \text{bridging ligands} \rightarrow \text{Nanocrystals (inorganic part)} \rightarrow \text{bulk crystal (2-100 nm)}
\]

Properties of coordination polymers (2-100 nm) are different from those of bulk coordination polymers because of surface effects and quantum size effects; examples are cobalt hexacyanoferrate and cobalt pentacyanonitrosyl ferrate NPs synthesized in water in oil microemulsions. Coordination polymer NPs may be dispersed in solvents and play a key role for understanding their chemistry in solution state.

Dendrimers

Dendrimers are hyper-branched materials (Fig. 7) gaining wide use in nanomedicine (nanoscale catalysts and reaction vessels and chemical sensors agents for delivering drugs or jeans into cells) because of multiple molecular hooks on their surface that can be used to attach cell-identification tags, fluorescent dyes, enzymes and other molecules. Dendrimers are two basic structural types: i) Globular with a central core from which branches radiate; and ii) This type has no central core and consist simply a series of highly branched polymers. Commonly available dendrimers are poly (amidoamines) (PAMAM).

Nanocomposites (NCs)

NCs are multiphase materials containing two or more distinctly dissimilar components mixed at nanometer scale. Phase may be inorganic - inorganic, inorganic - organic or organic - organic and resulting material may be amorphous, crystalline or semi crystalline. NCs synthesis is an innovative route to complex advanced materials. NCs are also used for sporting products such as frames of rackets, racing cars and bicycles. Advanced NCs are used in cutting tools, laser mirrors and aerospace components. Nanotube-polymer NCs have potential application in aerospace science. NCs have been derived from polyethylene oxide (PEO) and polyethyleneimine (PEI). NCs derived from nylon family, polyester, polypropylene, polystyrene etc are finding commercial applications as light and tough automobile parts and coatings for packaging and fire retarding materials. NCs containing carbon NPs, electrically compiled to biomolecules, could yield an array of high performance technologies. CNT epoxy composites include hydrocarbon polymer composites, conjugated polymer composites, polyanilontetnitrile composites, composites of CNTs with polycarbonates, fluoropolymers, polyvinyl alcohol, polyethylene glycol, silicon polymers, polyelectrolytes, polyesters polyamides, polyvinylcarbazole, poly (p-phenylene benzobisoxazole), phenoxy resin, natural rubber etc.

Bionanoparticles (Bio NPs)

Bio NPs are naturally produced entities of nanometer size. Recent demand for nanoparticulate products (viruses, plasmids, protein NP and drug delivery systems) has resulted in the requirement for predictable and controllable processes. Successful application of these materials depends on availability of selective methodologies and purification. Living organisms are built of cells (10 µm across). Proteins (5 nm) are comparable with smallest man made NPs. This simple size comparison gives an idea of using NPs as very small probes that would allow as to spy at cellular machinery without introducing too much interference. Understanding of biological processes on nanoscale level is a strong driving force behind development of nanotechnology. Liposomes are lipid-based NPs used extensively in pharmaceutical and cosmetic industries because of their capacity for breaking down inside cells, once their delivery function has been met. Liposomes were the first engineered NPs used for drug delivery.

Characterization of Nanomaterials (NMs)

NM characterization is done by using a variety of techniques including HRTEM, scanning electron microscopy (SEM), atomic force microscopy (AFM), dynamic light scattering (DLS), X-ray photoelectron spectroscopy (XPS), powder X-ray diffractometry.
(XRD), fourier transform infrared spectroscopy (FTIR), matrix assisted laser desorption time of hight mass spectroscopy (MALDI-TOF), UV visible spectroscopy, $^1$H and $^1$C NMR, high resolution mass spectrometry, and superconducting quantum interface device (SQUID) for reading out signal from detector. Technology for NP tracking analysis (NTA) allows direct tracking of Brownian motion and this method therefore allows sizing of individual NP in solution. Among various NPs lithography methods, scanning probe techniques are simple inexpensive and capable of direct patterning on a surface. AFM has been a powerful tool in imaging and lithography of nanoparticles. Grobelny et al. performed scanning tunneling microscopy (STM) imaging on gold surface.

Femto second transient absorption dynamics of gold-polypyrrole NPs have been studied by photo excitation at various wavelengths. Size distribution of $\alpha$-Fe$_2$O$_3$ NPs has been studied by dynamic light scattering method. XRD patterns, SEM and transmission electron microscopy (TEM) images characterized flower like ZnO microstructures. XRD patterns indicated that obtained ZnO crystals were of wurtzite structures. SEM and TEM images illustrated that flower like ZnO bundles consisted of prism like or petal like branches. Scanning transmission electron microscopy (STEM), HRTEM and selection area electron diffraction (SAED) confirmed that nanodiscs of ZnO are single crystalline and porous. MnO$_2$ nanosheet materials were characterized by X-ray absorption spectroscopic techniques. Magnetic behaviour of $\gamma$-Fe$_3$O$_4$ NPs dispersed in colloidal silica particles has been studied. 3-Dimensional urchin like X-ray diffraction, SEM, TEM, BET and vibrating sample magnetometry (VSM) characterized $\alpha$-Fe$_3$O$_4$ superstructures. Ultrafine $\alpha$-Fe$_2$O$_3$ NPs were extremely stable colloidal state. $\alpha$-Fe$_2$O$_3$ NPs worked as a rechargeable electrode material. Zhang et al. characterized hexagonal like Fe$_2$O$_4$. Single crystal $\alpha$-Fe$_2$O$_3$ was characterized by XPS and complementry methods as prepared nanobelts are single crystalline CdS quantum particles assembled at predetermined distance from gold substrate. MNPs of $\alpha$-Mn$_{x}$Fe$_{2x-3}$O$_{3}$ (0 ≤ x ≤ 1.3) have been characterized by XRD, TEM and specific absorption rate (SAR) measurements. SAR determines heating ability of magnetic materials in the presence of AC magnetic field.

Nanosized silica particle diameter was determined by using photon correlation spectroscopy (PCS), AFM and TEM. Size particle measurement showed that small particles were more swollen than larger ones and swelled more in ethanol than water, whereas larger ones swelled more in water than in ethanol. Formation of fractal clusters and network during deposition of metal particle under the influence of diffusion-limited aggregation (DLA) has been the subject of intense theoretical and experimental investigation. Fractal dimensions (12, 17) (av 1.73 ± 0.08) of nanosheets were obtained by TEM analysis.

Photoinduced aggregation of polymer NPs in dilute noneaqueous dispersion has been studied. There exist two limiting regimes for aggregation: diffusion limited cluster-cluster aggregation (DLCA) and reaction limited cluster-cluster aggregation (RLCA). DLCA process leads to aggregates with fractal dimension D approximately 1.7-1.8. RLCA process leads to more uniform aggregates with a higher fractal dimension (2.0-2.5). Recently, various MgO nanostructures have been synthesized including fish bone fractal nanostructures induced by Co.

Applications of Nanomaterials in Science And Biology

NMs can be used in catalysis, photochemistry, sensors, tagging, optical, electronic and magnetic devices. Nanosized copper particles are used in polymer and plastic, lubricants, inks and metallic coatings. Nanotechnology has led to fabricate semiconductor materials of nanometer size. A series of multipod gold nanostructures, synthesized including fish bone fractal nanostructures, are expected to have wide applications in nanoelectronics and other related fields. NMs are of considerable interest due to their vastly increased surface area over macro-scale materials. NMs are of high activity catalysts, and also used as desirable starting materials for a variety by reactions in photochemistry, sensors, optical, electronic and magnetic devices. Nanostructural platinum finds applications in catalysis, sensors and other devices.

Nanoscale engineering using nanoparticle assembly, manipulation and lithography offers tremendous opportunities for developing new devices in a variety of applications. Among various methods, scanning probe techniques are simple, inexpensive and capable of direct patterning on a surface. ZnO 3D nanostructured products may be a good choice for anode materials in Li ion batteries. Magnese oxides have found wide applications as catalysis and electrode materials. MnO NPs exhibit ferromagnetic characteristics even though this material
is antiferromagnetic in bulk form\textsuperscript{1}. Iron oxides and hydroxides find applications in pigments, magnetic devices, anticorrosive agents, and catalysis etc\textsuperscript{28}. Among MNPs, NPs of $\gamma$-Fe$_2$O$_3$ and its derivatives have gained more importance in biochemical applications due to their higher biocompatibility along with their suitable magnetic properties. Unique electronic and mechanical properties of CNTs offer enormous potential for various applications\textsuperscript{45}. Most promising applications of nanotubes as a field effect transistor, nanotube interconnects and nanosensors. Most electronic applications require aligned SWNT that are reasonably homogeneous in diameter, length and electronic properties\textsuperscript{39}. CNTs possess both metallic and semiconducting structures.

NMs based on organic polymer particles and their colloidal crystals are extensively studied. NCs containing photomagnetic K$_3$Co$_2$[Fe(CN)$_6$]$_2$ NPs in a porous silica matrix has been reported. Organic-inorganic NPs with a variety of combinations may be utilized in development of advanced NMs. Some applications of NMs in biology and medicine have been reviewed\textsuperscript{46-70} as: i) fluorescent biological labels; ii) drug and gene delivery; iii) biodetection of pathogens; iv) detection of proteins; v) probing of DNA structure; vi) tissue engineering; vii) tumour destruction via heating (hyperthermia); viii) separation and purification of biological molecules and cells; ix) MRI contrast enhancement; and x) phagokinetic studies.

A real bone is a NC material, composed of hydroxyapatite crystallites in organic matrix, which is mainly composed of collagen. An artificial hybrid material was prepared from 15-18 nm ceramic NPs and poly(methylmethacrylate)copolymers using tribology approach. A viscoelastic behaviour (healing) of human teeth was demonstrated. An investigated hybrid material, deposited as a coating on tooth surface, improved scratch resistance as well as possessed a healing behavior similar to that of tooth. Hybrid bio NPs can also be applied to build novel electronic, optoelectronics and memory devices\textsuperscript{80-81}. Gold NPs are widely used in immunohistochemistry to identify protein-protein interaction. In biosciences, NPs are replacing dyes in applications that require high photo-stability as well as high multiplexing capabilities.

Conclusions

Salient features of nanomaterials of different types such as metal nanomaterials, oxide nanomaterials, carbon nanomaterials, polymer nanomaterials, nanocomposites and several others, their shapes and geometries, synthesis and applications have been reviewed. These materials are of considerable interest from electronic industry, optics, biomolecules, catalysis, lubricants, pharmaceuticals and cosmetic industries etc.

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