Science of the Century- Nanoscience

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Abstract

Nanoscience first captured the world's attention when Nobel Prize winner Richard Feynman delivered his famous 1959 speech "There's Plenty of Room at the Bottom". Since Feynman's scientific call to action, nanoscience and nanotechnology have evolved into a revolutionary area of technology-based research, opening the door to precise engineering on the atomic scale and affecting everything from healthcare to the environment. This article gives an overview of Nanoscience and technology. Concept of nanoscience, its development, preparation, characterization and properties of nanomaterials have been discussed. Applications of nanomaterials in consumer products and also expected applications have been highlighted. Attentions are drawn towards risk assessment.

Keywords: Nanoscience, Nanotechnology, Characterization, Applications

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1. Introduction

Times are changing. It is beyond doubt that technological developments influence the way science is done, and they also redefine our relation to the society we live in. Every day we find something new may be important or less important. There are certain things which change the entire way of thinking and perception. In this century nanoscience and technology is perceived as one of the most important area affecting mankind and is considered to be an important new scientific field [1]. Nanomaterials are structurally and functionally prevalent in the organic, inorganic, and biological fields. Their unique size-dependent properties make these materials superior and indispensable in many areas of human activity. It is an emerging area of science which concerns itself with the study of materials that have very small dimensions, in the range of nano scale. In this article an overview of nanoscience and technology with emphasis on applications and risk assessments is discussed.

2. Nanosize

How big or small a nano is, can be visualized from Fig.1.

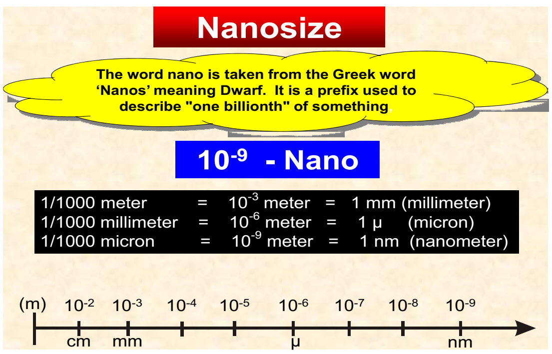

Figure1: Visualization of nanosize

One billionth of a meter (0.000000001meter) is one nanometer. One nanometer is approximately 6 carbon atoms wide. Average uman Height is 1.7 billion nm

2. Nanoscience Concept and its Domain

The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled "There is a Plenty of Room at the Bottom" by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology (CalTech) on December 29, 1959, long before the term nanotechnology was used. In his talk, Feynman described a process in which scientists would be able to manipulate and control individual atoms and molecules. The second approach was given by Jean Marie Lehn, a French chemist that there is a plenty of room at the top (Bottom up approach), where each molecule or nano structured component plugs itself into a supra-structure. The two approaches are represented in Fig. 2

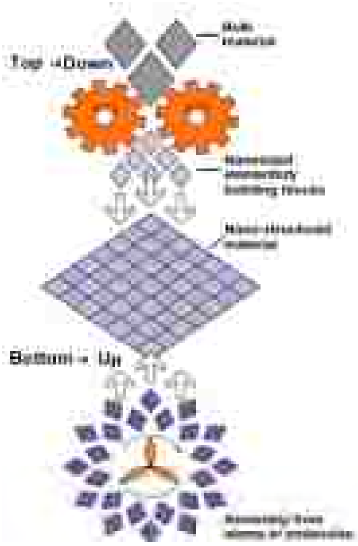

Figure 2: Illustration of the top-down and bottom-up approaches in nanotechnology.

Nanoscience and technology has emerged recently as a promising area in the knowledge bank with lots of scope for innovation to address the challenging problems faced by science, society and humanity. It is basically the study and manipulation of matter properties at sub-micron scale for technological applications in general and challenging applications in particular. It deals with fundamentals and applications of material systems/structures having at least one dimension in the size ranging from 1 nm – 100 nm (nanoscale) [2]. It is an interdisciplinary branch of knowledge representing confluence of conventional disciplines like Physics, Chemistry, Material Science, Biology, Medicine, etc. at the nanoscale. This in turn has tremendously impacted our approach towards science and technology in a fundamental way.

3. Classification of Nanomaterials

Nanomaterials can be nanoscale in one dimension (eg. surface films), two dimensions (eg. strands or fibres), or three dimensions (eg. particles). They can exist in single, fused, aggregated or agglomerated forms with spherical, tubular, and irregular shapes. Common types of nanomaterials include nanotubes, dendrimers, quantum dots and fullerenes. According to Siegel, Nanostructured materials are classified as Zero dimensional, one dimensional, two dimensional, three dimensional nanostructures (Fig.3).

Figure 3: Classification of Nanomaterials (a) 0D spheres and clusters, (b) 1D nanofibers, wires, and rods, (c) 2D films, plates, and

networks, (d) 3D nanomaterials.

4. Preparation of Nanomaterials

Some of the common methods of preparation of nanomaterials are [3, 4]: Chemical Methods, Sonochemical routes, Mechanical Attrition (Ball Milling), Lithography, Etching, etc. Most of the methods used are chemical methods which are as: i) Sol gel method ii) Chemical precipitation iii) Hydrothermal method iv) Gas phase chemical reactions v) Inert gas condensation vi) Chemical vapor deposition vii) Electro-deposition viii) Freeze drying ix) Spray drying x) Precursor techniques xi) Non-aqueous liquid Phase reactions xii) Laser pyrolysis and xiii) Ion-insertion chemistry.

5. Clean and Green Nanotechnology

Scientists with expertise in different areas need to come together. The green chemist needs to learn that a process that takes many days will never be used commercially. An engineer needs to learn which chemicals will be harmful and should be avoided.

Nanoproducts are increasing continuously but concerns about potential impacts of nano-technology on the environment, human health and safety have not yet been fully addressed. Little is known about the risks of nanomaterials, including their toxicities, their potentials for emissions and human exposures, their fate in the environment and their possible eco-friendly impacts.

One way to circumvent these unknown risks is to design and make nanoproducts as clean and green as possible from the start. Integration of green chemistry principles into nanotechnology is one of the key issues in nanoscience research today [5].

6. Characterization of Nanomaterials

The most common techniques for characterizing nanomaterials are: SPM methods which include scanning tunneling microscopy (STM) which exploits an electronic tunneling current, atomic force microscopy (AFM) which measures miniscule forces between the probe and sample, and transmission electron microscopy (TEM) whereby a beam of electrons is transmitted through an ultra thin specimen, and scanning electron microscope (SEM) which images electrons scattered from a surface. In addition to microscopic techniques, X-ray diffraction technique using Sherrer formula (Eq.1) is used to determine the crystallite size.

$$D = \frac{0.9\lambda}{\beta \cos \theta} \qquad (1)$$

where D is the diameter of the crystallite, λ is the wavelength of X-ray beam, Θ is the diffraction angle and β is the half width in radians of a particular diffraction line. SEM, TEM and AFM images of ZnO grown under different conditions are shown in Figures4-6. Under different conditions the morphology and the particle size are different [6].

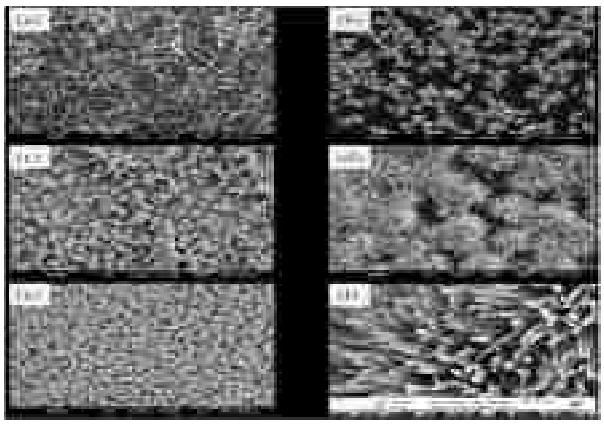

Figure 4: SEM images of ZnO nanostructures; (a) nanorods on Si substrate at neutral pH= 6.6, (b) star-like nanostructures at pH =10,

(c) flower-like nanostructures at pH =11, (d) urchin-like nanostructures at pH =12, (e) nanotubes grown on Si substrate, (f) nanorods grown on a paper substrate [6].

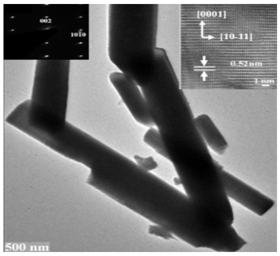

Figure5: TEM image of the ZnO nanorods, inset (right) show HRTEM image of the individul nanorods while inset (left) shows the corresponding SAED pattern [7]

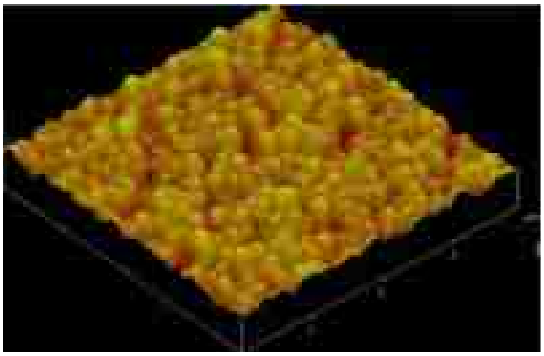

Figure 6: AFM topographic image (4 µm x 4 µm) of ZnO nanorods recorded in tapping mode by Digital Instruments Nanoscope AFM system.

7. Properties of Nanomaterials

Nanomaterials have the structural features in between of those of atoms and the bulk materials. While most microstructured materials have similar properties to the corresponding bulk materials, the properties of materials with nanometer dimensions are significantly different from those of atoms and bulk materials [8]. This is mainly due to the nanometer size of the materials which render them: (i) large fraction of surface atoms; (ii) high surface energy; (iii) spatial confinement; (iv) reduced imperfections, which do not exist in the corresponding bulk materials. Nanosize causes changes in i)Colour, ii) Conductivity, iii) Crystal Shape, iv) Magnetism, v) Melting Points, vi) Reactivity vii) Light Absorption, etc. Nanosize changes various properties of gold (Fig.7).

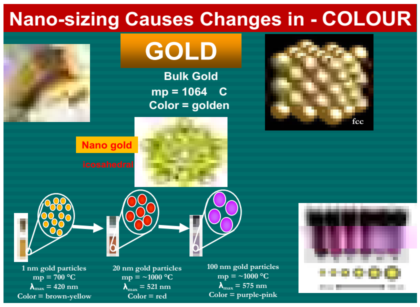

Figure7: Properties of bulk gold changes when it goes to nanoregime

Table 1. Gives a list of consumer products where nanomaterials are used [9].

Automotive	**Clothing and Textiles**	**Cosmetics**
• Air and Oil Filters • Waxes, engine oil • Anti-scratch finishes • Car wax • Air purifiers • Catalysts to improve fuel consumption • Tires	• Wrinkle and Stain resistant apparel • Anti-bacterial and anti odout clothing • Anti-bacterial fabrics • UV resistant and protective clothing • Flame retardant	• Skin creams and moisturizers • Skin cleansers • Sunscreens • Lipstick, mascara, make-up foundations • Make up removal

Electronics • Batteries • Displays-electronics • Organic Light Emitting Diodes (OLED) & LEDs • Data memory • Anti-bacterial and anti static coatings on key-boards, mouse, cell phones • DVD Coatings • Mp3 players • Computer processors and chips	**Food, Food Additives & Food Packaging** • Energy drinks • Nutritional supplements • Food storage container • Anti-bacterial utensils • Cutting boards • Plastic wrap • Food packaging • Nano-tea, chocolate shakes, canola active oil	**Household** • Anti-bacterial furniture and mattresses • Anti-bacterial coatings in appliances • Filters • Air purifiers • Self cleaning glass • Anti-bacterial UV resistant paints • Irons, vacuums • Solar cells • Cleaning products • Disinfectant sprays • Fabric softners
Personal Care/ Health • Hearing aids • Contact Lenses • Body wash • Cellulite treatment • Tooth powder • Shampoos, hair gels • Deodorants • Insect repellents • Anti-bacterial creams • Bandages • Home pregnance tests • Drug delivery patches • Man-made skin	**Sports Equipment** • Golf balls & clubs • Tennis rackets & balls • Baseball bats • Hockey sticks • Skis and snowboards • Ski wax • Bicycle parts • Wet suits • Shoe insoles • Anti fogging coatings	**Toys and Children's Goods** • Stain resistant plush toys • Anti-bacterial baby pacifiers, mugs and bottles • Anti-bacterial stuffed toys
		Medical Applications • Drugs • Medical Devices

8. The Application of Nanomaterials in Consumer Products

Nanomaterials are already in commercial use, with some having been available for several years or decades. The range of commercial products available today is very broad, including stain-resistant and wrinkle-free textiles, cosmetics, sunscreens, electronics, paints and varnishes. In fact nanotechnology, as a platform technology like the steam engine or the internet has the potential of having a significant impact on all sectors of society and being used to improve the characteristics of a wide range of consumer products.

The most common nanoscale substance reported to be used in consumer products is nano-silver. It is being applied extensively for its anti-bacterial and anti-fungal properties to coat everything from baby bottle nipples, door handles, food contact products, to the interiors of refrigerators and washing machines. Manufacturers have also identified its use in clothing, bedding, paints, cleaning products, food storage containers, bandages, medical devices, mattresses, and children's teddy bears. Carbon based nanomaterials are the second most common nanoscale materials found in consumer products. They are used due to their exceptionally high strength, light weight, and excellent electrical and thermal conductivity. To improve the strength of a product while reducing its weight, double walled carbonn-anotubes are embedded in the various resins found in baseball bats, hockey sticks, skis or vehicle parts. The unique structure of carbon nanotubes endues them with superior electronic, optoelectronic, mechanical, and chemical performance. When combining with inorganic nanomaterials, the resultant composites show additional properties and broader applications. Some properties of carbon nanotubes are given below [10].

The other areas where carbon nanotubes are used are:

8.1 Catalysis

CNTs have been used as support for the dispersion and stabilization of catalyst nanoparticles, due to their high specific surface areas, electrical conductivities, and chemical stability.

8.2 Energy conversion

The unique electrical and electronic properties, a wide electrochemical stability window, the high surface area, and the one-dimensional geometric structure enable CNTs superior electrode materials for use in energy conversion devices.

8.3 Solar cells (solar energy conversion)

CNTs can be directly used as the energy conversion materials in solar cells, serving as both photogeneration sites and charge carriers in collecting/transport layer. Introducing semi-conductornanocrystals of tunable bandgap into the system may show better promise

8.4 Fuel cells (chemical energy conversion)

A fuel cell is a kind of device that can directly convert chemical energy of fuels such as hydrogen and methanol into electricity. The conventional direct methanol fuel cells (DMFCs) and proton exchange membrane fuel cells (PEMFCs) normally use carbon black-supported Pt as the catalyst for electrode reactions. The energy crisis has pushed us to exploit fuel cellswith low pollution and high performance. One of the most important issues in the research of fuel cells is to reduce the cost of the electrodes together with the improvement of the catalytic activity. From this point, CNTs are promising to replace the commercialized carbon black as the catalyst supports for the fuel cells because they can dramatically enhance the catalysis utilization and the activity and stability of the catalytic noble metals.

8.5 Chemical sensors

Chemical sensors have important applications in environmental monitoring, chemical process controlling, as well as in agricultural and biomedical fields. CNTs have shown high sensitivity towards many gases, such as O_2, NH_3 and NO_2.

Some of the other nanomaterials used are Nano titanium dioxide and zinc oxide as UV filters in sun screens to make the sun screen transparent rather than white when the bulk form is used. It is also claimed that they are more effective when used in nano form. Nano emulsions and nanosomes are used to preserve active ingredients, such as vitamins and anti-oxidants, by encapsulating them and for their lightness and transparency. Fullerenes are used in face creams to increase their penetration into the skin and it is claimed that these tiny carbon spheres have anti-aging properties. Other materials used in nano size include nano gold in energizing' moisturiser.

8.6 Biomedical applications

Recently, nanoparticles (NPs) are introduced to a broad range of biomedical applications including drug delivery, imaging, and sensors.

8.7 Next-Generation Computer Chips

The microelectronics industry has been emphasising miniaturisation, whereby the circuits, such as transistors, resistors, and capacitors, are reduced in size. By achieving a significant reduction in their size, the microprocessors, which contain these components, can run much faster, thereby enabling computations at far greater speeds.

8.8 Phosphors for High-Definition TV

The resolution of a television, or a monitor, depends greatly on the size of the pixel. These pixels are essentially made of materials called "phosphors," which glow when struck by a stream of electrons inside the cathode ray tube (CRT). The resolution improves with a reduction in the size of the pixel, or the phosphors. Nanocrystalline zinc selenide, zinc sulfide, cadmium sulfide, and lead telluride synthesised by the sol-gel techniques are candidates for improving the resolution of monitors. The use of nanophosphors is envisioned to reduce the cost of these displays so as to render high-definition televisions (HDTVs) and personal computers affordable to be purchased by an average household

9. Risk Assessments

Nanotechnology is seen as a transformative technology, which has the potential to stimulate scientific innovation while greatly benefiting society. However, the enthusiasm with which the scientific and technical communities are embracing the technology is being tempered by concerns over possible downsides, including risks to human health [11]**.** Nanomaterials are being used in medicine (e.g., molecular targeted therapies, diagnostic imaging), consumer goods (e.g., cosmetics, electronics, baby products), and building materials (e.g., concrete, steel, windows). The physiochemical nature of these materials may vary depending on the type and size of materials. For example, nanomaterials such as carbon nanotubes and SiO_2 nanoparticles are often used to add mechanical strength and durability, TiO_2 nanoparticles are used to increase the degree of hydration of cement, and FeO_3 nanoparticles are used for abrasion resistance. The benefits of new and improved“products are often clearly stated on product packaging and advertisements. Examples include waterproof paints, stain-resistant shirts, socks that eliminate foot odor, pacifiers that fight bacteria and computers that run faster, inter alia. However, the potential human health risks following long-term exposure to some products are not certain, as there is generally a lack of exposure data to evaluate if these products are safely performing their intended purpose.

The preliminary conclusions to be drawn from the toxicology studies is that some types of nanomaterials can be toxic, if they are not bound up in a substrate and they are available to the body. Researchers must use procedures that prevent inhalation and dermal exposures because at this time toxicological information is limited.Based on particle physics and studies of fine atmospheric pollutants, the nanoparticle size range is the range of minimum settling. This means that once released into air, nanoparticles will remain airborne for considerable periods of time. Nanoparticles can be inhaled and will be collect.

Exposure to nanomaterials can be controlled using the same precautions currently used to handle toxic materials: use of exhaust ventilation (such as fume hoods and vented enclosures) to prevent inhalation exposure during procedures that may release aerosols or fibers and use of gloves and Personal protective equipment to prevent dermal exposure.

To address occupational risks of nanomaterials, WHO is developing Guidelines for "Protecting Workers from Potential Risks of Manufactured Nanomaterials" (WHO/NANOH). These Guidelines aim to facilitate improvements in occupational health and safety of workers potentially exposed to nanomaterials in a broad range of manufacturing and social environments. The guidelines will incorporate elements of risk assessment and risk management and contextual issues. They will provide recommendations to improve occupational safety and protect health of workers using nanomaterials in all countries and, especially, in low and medium-income countries.

10. Future Strategy for Nanotechnology

Educate and train a new generation of scientists and workers skilled in nanoscience and nanotechnology at all levels.

Develop specific curricula and programs designed to:

- Introduce nanoscale concepts into mathematics, science, engineering, and technological education;
- Scientists prepared to work in the nanotechnology area;
- Develop effective means for giving nanotechnology students an inter-disciplinary perspective while strengthening the disciplinary expertise they will need to make maximum professional contributions;
- Establish fruitful partnerships between industry and educational institutions to provide nanotechnology students adequate experience with nanoscale fabrication, manipulation, and characterization techniques.
- Risk assessment policies and methods.

11. Conclusions

Nanotechnology will continue to be developed and used, despite concerns over the possible health risks associated with some materials. Whether it will achieve widespread acceptance and reach its full potential will depend critically on good risk-based science.

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