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Review

Nanotechnology: Interdisciplinary science of applications

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Nanotechnology is the study of particle sizes between 1 and 100 nanometers at least at one dimension. Particle size reduced to nanometer length scale exhibit more surface area to volume size ratio and showing unusual properties makes them enable for systematic applications in engineering, biomedical, agricultural and allied sectors. Nanomaterial can create from bottom up or top down approaches using physical, chemical and biological mode of synthesis.

Key words: Nanotechnology, nanomaterial, nanobiotechnology, nanotech-applications.

INTRODUCTION

A nanometer is one billionth of a meter (10^{-9} m or 10^{-7} cm), about one hundred thousand times smaller than the diameter of a human hair, a thousand times smaller than a red blood cell, or about half the size of the diameter of DNA (Scott and Chan, 2002). Nanotechnology is defined as research and technology development at the atomic, molecular, or macromolecular levels using a length scale of approximately one to one hundred nanometers at least at one dimension. The creation and use of structures, devices and systems that have novel properties and functions because of their small size and the ability to control or manipulate matter are done on an atomic scale (Lengke et al., 2007). Nanotechnology infuse scientific branches from biology, chemistry, physics and engineering, hence called interdisciplinary subject opens new doors of applications (Kulzer and Orrit, 2004).

The fundamental of nanotechnology lies in the fact that properties of material change dramatically when size reduced to the nanometer scale (Raliya and Tarafdar, 2012). In the long-term, nanotechnology will likely be increasingly discussed within the context of the convergence, integration, and synergy of nanotechnology, biotechnology, information technology, and cognitive technology. Convergence involves the development of novel products with enhanced capabilities that incorporate bottom-up assembly of miniature components with accompanying biological, computational and cognitive capabilities. The convergence of nanotechnology and biotechnology, already rapidly progressing, will result in the production of novel nanoscale materials. The convergence of nanotechnology and biotechnology with information technology and cognitive science is expected to rapidly accelerate in the coming decades. The increased understanding of biological systems will provide valuable information towards the development of efficient and versatile biomimetic tools, systems, and architecture. The unique properties of these various types of intentionally produced nanomaterials give them novel electrical, catalytic, magnetic, mechanical, thermal, or imaging features that are highly desirable for applications in commercial, agricultural, medical, military, and environmental sectors (Boisselier and Astruc, 2009).

There are two process for nanomaterial creation including "bottom-up" processes (such as self-assembly) that create nanoscale materials from atoms and molecules, and "top-down" processes (such as milling) that create nanoscale materials from their macro-scale counterparts. Nanoscale materials that have macro-scale counterparts frequently display different or enhanced properties compared to the macro-scale form (Petit et al., 1993). Such engineered or manufactured nanomaterials will be referred to as “intentionally produced nanomaterials,” or simply “nanomaterials.” The definition

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Table 1. Successive development of complexity in the nanotechnology.

Generation	Period	Theme	Foremost infuse area of applications in which advancement happens
First	Up to 2001	Passive nanotechnology	Top down approach, nano-structured metal, polymer, ceramics, catalyst, MEMS
Second	2001-2005	Active nanotechnology	Bottom up approach, adaptive nanostructure, solar cell, transistors, sensor, diagnostic assay, NEMS
Third	2005-2010	Nanosystem technology	Biomemetic nanostructure, novel therapeutics, targeted drug delivery, nanochips, agriculture
Fourth	2010-2015	Molecular nanosystem	Atomic manipulations and design nanoscale architecture

of nanotechnology does not include unintentionally produced nanomaterials, such as diesel exhaust particles or other friction or airborne combustion byproducts, or nanosized materials that occur naturally in the environment, such as viruses or volcanic ash (Roco, 2003). Information from incidentally formed or natural nanosized materials (such as ultrafine particulate matter) may aid in the understanding of intentionally produced nonmaterial.

ORIGIN AND HISTORY OF NANOTECHNOLOGY

The first use of the concepts found in 'nano-technology' (but pre-dating use of that name) was in "There's Plenty of Room at the Bottom", a talk given by physicist Richard Feynman at an American Physical Society meeting at California Institute of Technology on December 29, 1959. Feynman described a process by which the ability to manipulate individual atoms and molecules might be developed, using one set of precise tools to build and operate another proportionally smaller set, and so on down to the needed scale. In the course of this, he noted, scaling issues would arise from the changing magnitude of various physical phenomena: gravity would become less important, surface tension and Vander Waal attraction would become increasingly more significant, etc. This basic idea appeared plausible, and exponential assembly enhances it with parallelism to produce a useful quantity of end products. The term "nanotechnology" was defined by Professor Norio Taniguchi, Tokyo University of Science in a 1974 paper as follows: Nano-technology' mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule. In the 1980s the basic idea of this definition was explored in much more depth by Dr. K. Eric Drexler, who promoted the technological significance of nanoscale phenomena and devices through speeches and the books Engines of Creation: The Coming Era of Nanotechnology (1986) and Nanosystems: Molecular Machinery, Manufacturing, and Computation, and so the term acquired its current sense. An engine of Creation is considered the first book on the topic of nanotechnology (Drexler, 1992).

GLOBAL SCENARIO

The global nanotechnology market had been touched, approximately US$ 29 billion by 2010 (Subramanian and Tarafdar, 2011). The exponential growth of global investments in nanotechnology research can be directly corresponding with the number of patents filing related to technology and products developed from nanotechnology and nanoscience. Global market forecasts indicating US$ 1880 billion investments in nanotechnology industries by 2015.

EVOLUTION OF NANOTECHNOLOGY

Successive development of complexity in the nanotechnology leads advancement and application in widespread area that can be explained by different generations in which major changed scenario was observed or expected. It can be simplified in Table 1.

MATERIALS PERSPECTIVE

A number of physical phenomena become pronounced as the size of the system decreases. These include statistical mechanical effects, as well as quantum mechanical effects, for example the “quantum size effect” where the electronic properties of solids are altered with great reductions in particle size. This effect does not come into play by going from macro to micro dimensions. However, quantum effects become dominant when the nanometer size range is reached, typically at distances of 100 nanometers or less, the so called quantum realm. Additionally, a number of physical (mechanical, electrical, optical, etc.) properties change when compared to macroscopic systems.

One example is the increase in surface area to volume ratio altering mechanical, thermal and catalytic properties of materials. Diffusion and reactions at nanoscale, nanostructures materials and nanodevices with fast ion transport are generally referred to nanoionics. Mechanical properties of nanosystems are of interest in the nanomechanics research. The catalytic activity of nanomaterials also opens potential risks in their interaction with biomaterials. Materials reduced to the nanoscale can show different properties compared to what they exhibit on a macroscale, enabling unique applications (Ahmad et al., 2003). For instance, opaque substances are become transparent (copper); stable materials turn combustible (aluminum); insoluble materials become soluble (gold). A material such as gold, which is chemically inert at normal scales, can serve as a potent chemical catalyst at nanoscales. Much of the fascination with nanotechnology stems from these quantum and surface phenomena that matter exhibits at the nanoscale.

MOLECULAR PERSPECTIVE

Modern synthetic chemistry has reached the point where it is possible to prepare small molecules to almost any structure. These methods are used today to manufacture a wide variety of useful chemicals such as pharmaceuticals or commercial polymers. This ability raises the question of extending this kind of control to the next-larger level, seeking methods to assemble these single molecules into supra-molecular assemblies consisting of many molecules arranged in a well defined manner. These approaches utilize the concepts of molecular self-assembly and/or supra-molecular chemistry to automatically arrange themselves into some useful conformation through a bottom-up approach. The concept of molecular recognition is especially important: molecules can be designed so that a specific configuration or arrangement is favored due to non-covalent intermolecular forces (Schmid, 2004). The Watson–Crick base pairing rules are a direct result of this, as is the specificity of an enzyme being targeted to a single substrate, or the specific folding of the protein itself. Thus, two or more components can be designed to be complementary and mutually attractive so that they can be more complex and useful. Such bottom-up approaches should be capable of producing devices in parallel and be much cheaper than top-down methods, but could potentially be overwhelmed as the size and complexity of the desired assembly increases. Most useful structures require complex and thermodynamically unlikely arrangements of atoms. Nevertheless, there are many examples of self-assembly based on molecular recognition in biology, most notably Watson–Crick base pairing and enzyme-substrate interactions. The challenge for nanotechnology is whether these principles can be used to engineer new constructs in addition to natural ones. Other challenges apply specially to the use of nanostructures within biological systems. Nanostructures can be so small that the body may clear them too rapidly for them to be effective in detection or imaging. Larger nanoparticles may accumulate in vital organs, creating a toxicity problem. Scientists will need to consider these factors as they attempt to create nanodevices the body will accept.

TYPE OF NANOMATERIALS

Carbon-based nanomaterials

These nanomaterials are composed mostly of carbon, most commonly taking the form of a hollow spheres, ellipsoids, or tubes. Spherical and ellipsoidal carbon nanomaterials are referred to as fullerenes, while cylindrical ones are called nanotubes. These particles have many potential applications, including improved films and coatings, stronger and lighter materials, and applications in electronics (Oberdorster et al., 2006).

Metal-based nanomaterials

These nanomaterials include quantum dots, nanogold, nanosilver and metal oxides, such as titanium dioxide, zinc oxide, magnesium oxide, iron oxide etc. A quantum dot is a closely packed semiconductor crystal comprised of hundreds or thousands of atoms, and whose size is on the order of a few nanometers to a few hundred nanometers. Changing the size of quantum dots changes their optical properties (Dreizin, 2009).

Dendrimers

These nanomaterials are nanosized polymers built from branched units. The surface of a dendrimer has numerous chain ends, which can be tailored to perform specific chemical functions. This property could also be useful for catalysis. Also, because three-dimensional dendrimers contain interior cavities into which other molecules could be placed, they may be useful for drug delivery (Astruc et al., 2010).

Nanocomposites

Combine nanoparticles with other nanoparticles or with larger, bulk-type materials. Nanoparticles, such as nanosized clays, are already being added to products ranging from auto parts to packaging materials, to enhance mechanical, thermal, barrier, and flame-retardant properties (Ajayan et al., 2003).

MOLECULAR NANOTECHNOLOGY

Molecular nanotechnology, sometimes called molecular manufacturing, described as engineered nanosystems (nanoscale machines) operating on the molecular scale. Molecular nanotechnology is especially associated with the molecular assembler, a machine that can produce a desired structure or device atom-by-atom using the principles of mechanosynthesis. Manufacturing in the context of productive nanosystems is not related to, and should be clearly distinguished from the conventional technologies used to manufacture nanomaterials such as carbon nanotubes and nanoparticles (Lapshin, 2011).

NANOBIOTECHNOLOGY

A potential technology used for enhancing the exploitation of nanoscale properties to increase agriculture food grain production and subsequently value added products. Nanobiotechnology opens up new reasonable area of research and applications such as neutraceutical and pharmaceutical applications. It provides technology for higher resolution materials and devices for the purification of biomolecules (Gazit, 2007).

NANOTECHNOLOGY APPLIANCES IN ALLIED SCIENCE SECTOR

Agriculture

Agriculture is the backbone of most developing countries, with more than 60% of the population reliant on it for their livelihood (Brock et al., 2011). As well as developing improved systems for monitoring environmental conditions and delivering nutrients or pesticides as appropriate, nanotechnology can improve our understanding of the biology of different crops and thus potentially enhance yields or nutritional values. In addition, it can offer routes to added value crops or environmental remediation. Nanotechnology, as a new enabling technology, has the potential to revolutionize agriculture and food systems. Agricultural and food systems security, disease treatment delivery systems, new tools for molecular and cellular biology, new materials for pathogen detection and protection of the environment are examples of the important links of nanotechnology to the science and engineering of agriculture and food systems (Welch and Graham, 1999).

Nanotechnology operates at the same scale as a virus or disease infecting particle, and thus holds the potential for very early detection and eradication. Nanotechnology holds out the possibility that "Smart" treatment delivery systems could be activated long before macro symptoms appear. For example, a smart treatment delivery system could be a miniature device implanted in an animal that samples saliva on a regular basis. Long before a fever develops, the integrated sensing, monitoring and controlling system could detect the presence of disease and notify the farmer and activate bioactive systems such as drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactors.

Nanofertilizer

Fertilizer play pivotal role in the agriculture production up to 35 to 40% of the productivity. To enhance nutrient use efficiency and overcome the chronic problem of eutrophication, nanofertilizer might be a best alternative. Attempts have been made to synthesize nanofertilizer in order to regulate the release of nutrients depending on the requirements of the crops, and it is also reported that nanofertilizer are more efficient than ordinary fertilizer (Liu et al., 2006).

Nanofood

The definition of nanofood is that nanotechnology techniques or tools are used during cultivation, production, processing or packaging of the food. It does not mean atomically modified food or food produced by nanomachines. Although there are ambitious thoughts of creating molecular food using nanomachines, this is unrealistic in the foreseeable future. Instead nanotechnologists are more optimistic about the potential to change the existing system of food processing and to ensure the safety of food products, creating a healthy food culture. They are also hopeful of enhancing the nutritional quality of food through selected additives and improvements to the way the body digests and absorbs food. Although some of these goals are further away, the food packaging industry already incorporates nanotechnology in products.

Food and bioprocess engineering

Set of engineering and scientific challenges in the food and bioprocess industry for manufacturing high quality and safe food through efficient and sustainable means can be solved through nanotechnology. Bacteria identification and food quality monitoring using biosensors; intelligent, active, and smart food packaging systems; nano-encapsulation of bioactive food compounds are few examples of emerging applications of nanotechnology for the food industry. Nanotechnology can be applied in the production, processing, safety and packaging of food. A nanocomposite coating process could improve food packaging by placing anti-microbial agents directly on the surface of the coated film. Nanocomposites could increase or decrease gas permeability of different fillers as is needed for different products. They can also improve the mechanical and heat-resistance properties and lower the oxygen transmission rate. Research is being performed to apply nanotechnology to the detection of chemical and biological substances in foods.

Medicine

The biological and medical research communities have exploited the unique properties of nanomaterials for various applications (for example, contrast agents for cell imaging and therapeutics for treating cancer). Terms such as biomedical nanotechnology, nanobiotechnology, and nanomedicine are used to describe this hybrid field. Functionalities can be added to nanomaterials by interfacing them with biological molecules or structures. The size of nanomaterials is similar to that of most biological molecules and structures. Therefore, nanomaterials can be useful for both *in vivo* and *in vitro* biomedical research and applications. Thus, the integration of nanomaterials with biology has led to the development of diagnostic devices, contrast agents, analytical tools, physical therapy applications, and drug delivery vehicles. Nanotechnology-on-a-chip is one more dimension of lab-on-a-chip technology. Magnetic nanoparticles bound to a suitable antibody, are used to label specific molecules, structures or microorganisms. Gold nanoparticles tagged with short segments of DNA can be used for detection of genetic sequence in a sample. Multicolor optical coding for biological assays has been achieved by embedding different-sized quantum dots into polymeric micro beads. Nanopore technology for analysis of nucleic acids converts strings of nucleotides directly into electronic signatures (Langer and Tirrell, 2004).

Disease detection and diagnosis

There are a number of highly promising areas of nanoscience based on nanomaterials prepared by chemical and biochemical methods. Perhaps the most well known is the use of bio-labeled nanoparticles to diagnose and treat cancer. This is an extremely active area of research with some early successes that look quite promising. However, more work will need to be done before nanoparticles are broadly used by doctors for cancer treatment. Detection of cancer at early stages is a critical step in improving cancer treatment. Currently, detection and diagnosis of cancer usually depend on changes in cells and tissues that are detected by physical touch or imaging expertise. Instead, scientists would like to make it possible to detect the earliest molecular changes, long before a physical exam or imaging technology is effective (Ferrari, 2005). In order to successfully detect cancer at its earliest stages, scientists must be able to detect molecular changes even when they occur only in a small percentage of cells. This means the necessary tools must be extremely sensitive. The potential for nanostructures to enter and analyze single cells suggests they could meet this need. Many nanotechnology tools will make it possible for clinicians to run tests without physically altering the cells or tissue they take from a patient. This is important because the samples clinicians use to screen for cancer are often in limited supply. It is also important because it can capture and preserve cells in their active state. Scientists would like to perform tests without altering cells, so the cells can be used again if further tests are needed. Nanotechnologies that will aid in cancer care are in various stages of discovery and development. Experts believe that quantum dots, nanopores, and other devices for detection and diagnosis may be available for clinical use in 5 to 15 years. Therapeutic agents are expected to be available within a similar time frame. Devices that integrate detection and therapy could be used clinically in about 15 or 20 years.

Drug delivery

Nanotechnology has been a boom in medical field by delivering drugs to specific cells using nanoparticles. The overall drug consumption and side-effects can be lowered significantly by depositing the active agent in the morbid region only and in no higher dose than needed. This highly selective approach reduces costs and human suffering. An example can be found in dendrimers and nanoporous materials. Another example is to use block co-polymers which form micelles for drug encapsulation. They could hold small drug molecules transporting them to the desired location. Another vision is based on small electromechanical systems; NEMS are being investigated for the active release of drugs. Some potentially important applications include cancer treatment with iron nanoparticles or gold shells. A targeted or personalized medicine reduces the drug consumption and treatment expenses resulting in an overall societal benefit by reducing the costs to the public health system. Most animal cells are 10 000 to 20 000 nanometers in diameter. This means that nanoscale devices (less than 100 nanometers) can enter cells and the organelles inside them to interact with DNA and proteins. Tools developed through nanotechnology may be able to detect disease in a very small amount of cells or tissue (Sahoo and Labhasetwar, 2003). They may also be able to enter and monitor cells within a living body. Nanotechnology is also opening up new opportunities in implantable delivery systems, which are often preferable to the use of injectable drugs because the latter frequently display first-order kinetics (the blood concentration goes up rapidly, but drops exponentially over time). This rapid rise may cause difficulties with toxicity, and drug efficacy can diminish as the drug concentration falls below the targeted range.

Tissue engineering

Nanotechnology can help to reproduce or to repair damaged tissue. “Tissue engineering” makes use of artificially stimulated cell proliferation by using suitable nanomaterial-based scaffolds and growth factors. Tissue engineering might replace today’s conventional treatments like organ transplants or artificial implants. Advanced forms of tissue engineering may lead to life extension. For patients with end-state organ failure, there may not be enough healthy cells for expansion and transplantation into the ECM (extracellular matrix). In this case, pluripotent stem cells are needed. One potential source for these cells is induced pluripontent stem cells (IPS), these are ordinary cells from the patient’s own body that is reprogrammed into a pluripotent state, and has the advantage of avoiding rejection and potentially life-threatening complications associated with immunosuppressive treatments (Cunha et al., 2011).

CHEMISTRY, ENVIRONMENT AND ENERGY

Chemical catalysis and filtration techniques are two prominent examples where nanotechnology already plays a role. The synthesis provides novel materials with tailored features and chemical properties: for example, nanoparticles with a distinct chemical surrounding (ligand), or specific optical properties. In this sense, chemistry is indeed a basic nanoscience. In a short-term perspective, chemistry will provide novel “nanomaterials” and in the long run, superior processes such as “self-assembly” will enable energy and time preserving strategies. In essence, all chemical synthesis can be understood in terms of nanotechnology, because of its ability to manufacture certain molecules (Mauter and Elimelech, 2008). Thus, chemistry forms a base for nanotechnology providing tailor-made molecules, polymers, etcetera, as well as clusters and nanoparticles.

Catalyst

Benefits especially from nanoparticles are due to the extremely large surface to volume ratio. The application potential of nanoparticles in catalysis ranges from fuel cell to catalytic converters and photo-catalytic devices. Catalysis is also important for the production of chemicals. Platinum nanoparticles are now being considered in the next generation of automotive catalytic converters because the very high surface area of nanoparticles could reduce the amount of platinum required. However, some concerns have been raised due to experiments demonstrating that they will spontaneously combust if methane is mixed with the ambient air. Ongoing research at the Centre National de la Recherche Scientifique (CNRS) in France may resolve their true usefulness for catalytic applications. Nanofiltration may come to be an important application, although future research must be careful to investigate possible toxicity.

Filtration

A strong influence of photochemistry on waste-water treatment, air purification and energy storage devices is to be expected. Mechanical or chemical methods can be used for effective filtration techniques. One class of filtration techniques is based on the use of membranes with suitable whole sizes, whereby the liquid is pressed through the membrane. Nanoporous membranes are suitable for a mechanical filtration with extremely small pores smaller than 10 nm (nanofiltration) and may be composed of nanotubes. Nanofiltration is mainly used for the removal of ions or the separation of different fluids. On a larger scale, the membrane filtration technique is named ultra filtration, which works down between 10 and 100 nm. One important field of application for ultra filtration is medical purposes as can be found in renal dialysis. Magnetic nanoparticles offer an effective and reliable method to remove heavy metal contaminants from waste water by making use of magnetic separation techniques. Using nanoscale particles increases the efficiency to absorb the contaminants and is comparatively inexpensive compared to traditional precipitation and filtration methods. Some water-treatment devices incorporating nanotechnology are already on the market, with more in development. Low-cost nano structured separation membranes methods have been shown to be effective in producing potable water in a recent study (Thembela and Mbhuti, 2007).

Energy

A reduction of energy consumption can be reached by better insulation systems, by the use of more efficient lighting or combustion systems, and by use of lighter and stronger materials in the transportation sector. Currently used light bulbs only convert approximately 5% of the electrical energy into light. Nanotechnological approaches like light-emitting diodes (LEDs) or quantum caged atoms (QCAs) could lead to a strong reduction of energy consumption for illumination. Increasing the efficiency of energy production in solar cells have layers of several different semiconductors stacked together to absorb light at different energies but they still only manage to use 40 percent of the Sun's energy. Commercially available solar cells have much lower efficiencies (15 to 20%). Nanotechnology could help increase the efficiency of light conversion by using nanostructures with a continuum of band gaps. The degree of efficiency of the internal combustion engine is about 30-40% at the moment. Nanotechnology could improve combustion by designing specific catalysts with maximized surface area. In 2005, scientists at the University of Toronto developed a spray-on nanoparticle substance that, when applied to a surface, instantly transforms it into a solar collector (TERI Report, 2009).

INDUSTRIES AND ENGINEERING

Cosmetics

One field of application is in sunscreens. The traditional chemical UV protection approach suffers from its poor long-term stability. A sunscreen based on mineral nanoparticles such as titanium dioxide offer several advantages. Titanium oxide nanoparticles have a comparable UV protection property as the bulk material, but lose the cosmetically undesirable whitening as the particle size is decreased. Finally, it may be possible one day to manufacture food and other essentials from component atoms and molecules, so-called “Molecular Manufacturing”. Already some research groups are exploring this, but still from a top-down approach, using cells rather than molecules. Although the practical application of such technology is far into the future, it is expected that this could allow a more efficient and sustainable production process to be developed where less raw materials are consumed and product of a higher quality is obtained (Raj et al., 2012).

Textiles

The use of engineered nanofibers already makes clothes water- and stain-repellent or wrinkle-free. Textiles with a nanotechnological finish can be washed less frequently and at lower temperatures. Nanotechnology has been used to integrate tiny carbon particles membrane and guarantee full-surface protection from electrostatic charges for the wearer.

Optics

In the modern communication technology traditional analog electrical devices are increasingly replaced by optical or optoelectronic devices due to their enormous bandwidth and capacity, respectively. Two promising examples are photonic crystals and quantum dots. Photonic crystals are materials with a periodic variation in the refractive index with a lattice constant that is half the wavelength of the light used. They offer a selectable band gap for the propagation of a certain wavelength, thus they resemble a semiconductor, but for light or photons instead of electrons. Quantum dots are nanoscaled objects, which can be used, among many other things, for the construction of lasers. The advantage of a quantum dot laser over the traditional semiconductor laser is that their emitted wavelength depends on the diameter of the dot. Quantum dot lasers are cheaper and offer a higher beam quality than conventional laser diodes. Displays the production of displays with low energy consumption could be accomplished using carbon nanotubes (CNT). Carbon nanotubes are electrically conductive and due to their small diameter of several nanometers, they can be used as field emitters with extremely high efficiency for field emission displays (FED). The principle of operation resembles that of the cathode ray tube, but on a much smaller length scales (Capitanio et al., 2005).

Computers

It is a device that makes direct use of quantum mechanical phenomena, such as superposition and entanglement, to perform operations on data. Quantum computers are different from traditional computers based on transistors. The basic principle behind quantum computation is that quantum properties can be used to represent data and perform operations on these data. A theoretical model is the quantum Turing machine, also known as the universal quantum computer. Although quantum computing is still in its infancy, experiments have been carried out in which quantum computational operations were executed on a very small number of quantum bit. Both practical and theoretical research continues, and many national government and military funding agencies support quantum computing research to develop quantum computers for both civilian and national security purposes, such as cryptanalysis. If large-scale quantum computers can be built, they will be able to solve certain problems much faster than any current classical computers (Drexler, 1992).

FUTURE CHALLENGE AND POSSIBILITY OF NANOTECHNOLOGY

One of the greatest challenges to the field of nanotechnology is the societal acceptance of new types of technology. It will be important for scientists and engineers in this field to work with other citizens to ensure long-term investments and commercial acceptance of new high technologies, such as nanotechnology. In the last few years, there has been a decreasing investment in research and development on the part of industry. This is becoming a serious obstacle to introducing nanotechnology into the commercial sector. While government investments in science and technology have not decreased in dollars, they are not growing at a sufficient rate to support American competitiveness in nanotechnology. This is a serious problem that is already having a negative impact on the critical and necessary early stages of science and technology in this field

One of the most important future trends in nanotechnology research will be the integration of these technologies into cutting-edge products. In order to achieve this, it will be increasingly important for teams of industrial, academic and government scientists and engineers to address the complex issues that are raised by nanotechnology. In the specific area of chemically or colloidally prepared nanostructures, some important directions include the development of useful nanoparticles from non-toxic materials, the development of new fabrication strategies that allow for the manufacturing of ultra-pure nanoparticles, the development of scale-up technologies offering the ability to manuscript nanoparticles inexpensively on the many kilogram level, and finally the continuing exploration of new technological applications based on the unique properties of nanoparticle systems.

REFERENCES

Ahmad A, Senapati S, Khan MI, Kumar R, Ramani R, Srinivas V, Sastry M (2003). Intracellular synthesis of gold nanoparticles by a novel alkalotolerant actinomycete, *Rhodococcus* species. Nanotechnology 14:824-828.

Ajayan PM, Schadler LS, Braun PV (2003). Nanocomposite science and technology. Wiley.

Astruc D, Boisselier E, Ornelas C (2010). Dendrimers designed for functions: from physical, photophysical, and supramolecular properties to applications in sensing, catalysis, molecular electronics, and nanomedicine. Chem. Rev. 110:1857-1959.

Boisselier E, Astruc D (2009). Gold nanoparticles in nanomedicine: preparation, imaging, diagnostics, therapies and toxicity. Chem. Society Rev. 38:1759-1782.

Brock DA, Douglas TE, Queller DC, Strassmann JE (2011). Primitive agriculture in a social amoeba. Nature 469:393-396.

Capitanio M, Cicchi R, Pavone FS (2005). Position control and optical manipulation for nanotechnology applications. The European Physical J. B - Condensed Matter and Complex Systems 46:1-8.

Cunha C, Panseri S, Antonini S (2011). Emerging nanotechnology approaches in tissue engineering for peripheral nerve regeneration. Nanomedicine: NBM 7:50-59.

Dreizin EL (2009). Metal-based reactive nanomaterials. Prog. Energy Combust. Sci. 35:141-167.

Drexler KE (1992) Nanosystems. New York: Wiley-Interscience.

Ferrari M (2005). Cancer Nanotechnology: Opportunities and Challenges. Nat. Rev. Cancer 5:161-171.

Gazit E (2007). Plenty of room for biology at the bottom: An introduction to bionanotechnology. Imperial College Press.

Kulzer F, Orrit M (2004). Single-molecule optics. Annu. Rev. Phys. Chem. 55:585-611.

Langer R, Tirrell DA (2004). Designing materials for biology and medicine. Nature 428:487-492.

Lapshin RV (2011). Feature-oriented scanning probe microscopy. In: Nalwa H. S. (PDF). Encyclopedia of Nanoscience and Nanotechnology. ACS pp. 105-115.

Lengke FM, Fleet EM, Southam G (2007). Biosynthesis of silver nanoparticles by filamentous cyanobacteria from a silver (I) nitrate complex. Langmuir 23:2694-2699.

Liu X, Feng Z, Zhang S, Zhang J, Xiao Q, Wang Y (2006). Preparation and testing of cementing nano-subnano composites of slow- or controlled release of fertilizers. Scientia Agricultura Sinica 39:1598-1604.

Mauter MS, Elimelech M (2008). Environmental applications of carbon-based nanomaterials. Environ. Sci. Technol. 42:5843–5859.

Oberdorster E, Zhu S, Blickley TM, Green PM, Haasch ML (2006). Ecotoxicology of carbon-based engineered nanoparticles: Effects of fullerene (C_{60}) on aquatic organisms. Carbon 44:1112-1120.

Petit C, Lixon P, Pileni MP (1993). *In situ* syntheses of silver nanocluster in AOT reverse micelles. J. Phys. Chem. 97:12974-12983.

Raj S, Jose S, Sumod US, Sabitha M (2012). Nanotechnology in cosmetics: Opportunities and challenges. J. Pharm. Bioallied. Sci. 4:186-193.

Raliya R, Tarafdar JC (2012). Novel Approach for Silver Nanoparticle Synthesis Using *Aspergillus terreus* CZR-1: Mechanism Perspective. J. Bionanosci. 6:12-16.

Roco MC (2003). Broader societal issues of nanotechnology. J. Nanopart. Res. 5:181-189.

Sahoo SK, Labhasetwar V (2003). Nanotech Approaches to Drug Delivery and Imaging. Drug Discov. Today 8:1112–1120.

Schmid G (2004). Nanoparticles from Theory to Applications. Wiley-VCH, Weinheim.

Scott N, Chan H (2002). Nanoscale science and engineering for agriculture and food system report. National Planning Workshop, Washington DC.

Subramanian KS, Tarafdar JC (2011). Prospects of nanotechnology in Indian farming. Indian J. Agric. Sci. 81:887-893.

TERI Report (2009). Nanotechnology development in India- a status report. TERI, India.

Thembela H, Mbhuti H (2007). Nanotechnology and the challenge of clean water. Nat. Nanotechnol. 2:663-664.

Welch RM, Graham RD (1999). A New Paradigm for World Agriculture: Meeting Human Needs, Productive, Sustainable, and Nutritious. Field Crops Res. 60:1-10.