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Nanotechnology and its Applications - A Review

Prof. Sachin A. Mehta[1]*, Prof. Sharad R. Mahajan[2], Prof. Abhishek S. Mahajan[3]

[1]Hirasugar Institute of Technology, Nidsoshi, Karnataka, India

[2]Hirasugar Institute of Technology, Nidsoshi, Karnataka, India

[3]Assistant Manager, Mahindra Heavy Engines Ltd., Pune, Karnataka, India

Abstract – It is rare for a single technology to have the power to dramatically influence almost every sector in the day today life. Nanotechnology falls into this category and offers fundamentally new capabilities to architect a broad array of novel materials, composites and structures on a molecular scale. This technology has the potential to drastically redefine the methods used for developing lighter, stronger and high-performance structures and processes with unique and non-traditional properties. This paper focuses on some of the applications for nanotechnology and showcases a few of them that are believed to have the highest probability of success in this highly competitive world. The goal of this paper is to raise the awareness on the promise of nanotechnology and the potential impact it will have on the future.

Keywords- Nanotechnology, Awareness, Nanomaterials, Nanocomposite.

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1. INTRODUCTION

A huge amount of research and development activity has been devoted to nano-scale related technologies in recent years. The National Science Foundation projects nanotechnology related products will become 1 trillion industries by 2015. Nano-scale technology is defined as any technology that deals with structures or features in the nanometre range or that are less than 100 nanometres, about one-thousandth the diameter of a human hair, and larger than about 1 nm, the scale of the atom or of small molecules. Below about 1 nm, the properties of materials become familiar and predictable, as this is the established domain of chemistry and atomic physics. It should be noted that nanotechnology is not just one, but many wide ranging technologies in many technical disciplines including but not limited to chemistry, biology, physics, material science, electronics, MEMS and self-assembly. Nano-structures have the ability to generate new features and perform new functions that are more efficient than or cannot be performed by larger structures and machines. Due to the small dimensions of nano-materials, their physical/chemical properties (e.g. stability, hardness, conductivity, reactivity, optical sensitivity, melting point, etc.) can be manipulated to improve the overall properties of conventional materials. At nanometre scales, the surface properties start becoming more dominant than the bulk material properties, generating unique material attributes and chemical reactions. More fundamentally, the electronic structure of materials becomes size-dependent as the dimensions enter the nanoscale. Delocalized electronic states as in a metal or a semiconductor are altered by the finite dimensions. Hence, the optical properties, including light absorption and emission behaviour, will be altered. The fact that nanoscale features are smaller than the wavelength of visible photons also impacts light scattering, enabling the design of nanocrystalline ceramics that are as transparent as glass. Changes in the bonding at the surface of a nanoparticle will affect the electronic structure as well, and the implications for the reactivity of the surface can be significant. Beyond the electronic structure, nanostructuring can also affect transport properties markedly. Nanoscale features that are smaller than or comparable to the wavelengths or mean-free paths of phonons (quanta of lattice vibrations) or electrons permit the design of materials with thermal and electrical conductivity that may be outside the range accessible with ordinary materials. The most significant nano-structures investigated to date are made from single tomistic layers of carbon. These structures include hollow ball shaped "Buckyballs" (Fullerene - C60), carbon nanotubes (CNTs) and graphene sheets which have a very interesting range of mechanical, thermal and electrical properties. It should also be noted that even though the environmental and health effects of nano-scale structures are poorly understood at this time, nano-scale-based technologies are already being used in some applications. The various fields of applications for nanotechnology are discussed as belows-

2. APPLICATIONS :

With nanotechnology, a large set of materials and improved products rely on a change in the physical properties when the feature sizes are shrunk.

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Nanoparticles, for example, take advantage of their dramatically increased surface area to volume ratio. Their optical properties, e.g. fluorescence, become a function of the particle diameter. When brought into a bulk material, nanoparticles can strongly influence the mechanical properties of the material, like stiffness or elasticity. For example, traditional polymers can be reinforced by nanoparticles resulting in novel materials which can be used as lightweight replacements for metals. Therefore, an increasing societal benefit of such nano particles can be expected. Such nanotechnologically enhanced materials will enable a weight reduction accompanied by an increase in stability and improved functionality. Practical nanotechnology is essentially the increasing ability to manipulate (with precision) matter on previously impossible scales, presenting possibilities which many could never have imagined it and therefore seems unsurprising that few areas of human technology are exempt from the benefits which nanotechnology could potentially bring. The Worldwide applications of nanotechnology in different fields are discussed as follows.

2.1 Medicine :

The biological and medical research communities have exploited the unique properties of nanomaterials for various applications (e.g., 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 far, 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.

2.1.1 Diagnostics:

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. Multicolour 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.

2.1.2 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 [1].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. 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.

2.1.3 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 iPS (induced Pluripontent Stem cells); these are ordinary cells from the patients own body that are reprogrammed into a pluripotent state, and has the advantage of avoiding rejection (and the potentially life-threatening complications associated with immunosuppressive treatments). Another potential source of pluripotent cells is from embryos, but this has two disadvantages: 1) It requires that we solve the problem of cloning, which is technically very difficult (especially preventing abnormalities). 2) It requires the harvesting of embryos. Given that each one of us was once an embryo, this source is claimed by some to be ethically problematic. It is also use for anti aging medicine.

2.2 Chemistry and Environment:

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

Prof. Sachin A. Mehta1*, Prof. Sharad R. Mahajan[2], Prof. Abhishek S. Mahajan[3]

example, nanoparticles with a distinct chemical surrounding (ligands), 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 a sense, all chemical synthesis can be understood in terms of nanotechnology, because of its ability to manufacture certain molecules. Thus, chemistry forms a base for nanotechnology providing tailor-made molecules, polymers, etcetera, as well as clusters and nanoparticles.

2.2.1 Catalysis: Chemical catalysis benefits especially from nanoparticles, 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 [2]. However, some concerns have been raised due to experiments demonstrating that they will spontaneously combust if methane is mixed with the ambient air[3]. Ongoing research at the Centre National de la RechercheScientifique (CNRS) in France may resolve their true usefulness for catalytic applications [4]. Nanofiltration may come to be an important application, although future research must be careful to investigate possible toxicity [5].

2.2.2 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 hole 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 ultrafiltration, which works down to between 10 and 100 nm. One important field of application for ultrafiltration 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 nanostructured separation membranes methods have been shown to be effective in producing potable water in a recent study [6].

2.3 Energy:

The most advanced nanotechnology projects related to energy are: storage, conversion, manufacturing improvements by reducing materials and process rates, energy saving (by better thermal insulation for example), and enhanced renewable energy sources.

2.3.1 Reduction of energy consumption:

2.3.2 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.

2.3.3 Increasing the efficiency of energy production:

2.3.4 Today's best 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 (15-20%). 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.

2.3.3 The use of more environmentally friendly energy systems:

An example for an environmentally friendly form of energy is the use of fuel cells powered by hydrogen, which is ideally produced by renewable energies. Probably the most prominent nanostructured material in fuel cells is the catalyst consisting of carbon supported noble metal particles with diameters of 1-5 nm. Suitable materials for hydrogen storage contain a large number of small nanosized pores. Therefore many nanostructured materials like nanotubes, zeolites or alanates are under investigation. Nanotechnology can contribute to the further reduction of combustion engine pollutants by nanoporous filters, which can clean the exhaust mechanically, by catalytic converters based on nanoscale noble metal particles or by catalytic coatings on cylinder walls and catalytic nanoparticles as additive for fuels.

2.3.4Recycling of batteries:

Because of the relatively low energy density of batteries the operating time is limited and a replacement or recharging is needed. The huge number of spent batteries and accumulators represent a disposal problem. The use of batteries with higher energy content or the use of rechargeable batteries or super capacitors with higher rate of recharging using nanomaterials could be helpful for the battery disposal problem.

2.4 Information & Communication:

Current high-technology production processes are based on traditional top down strategies, where nanotechnology has already been introduced silently. The critical length scale of integrated circuits is already at the nanoscale (50 nm and below) regarding the gate length of transistors in CPUs or DRAM devices.

2.4.1 Memory Storage:

Electronic memory designs in the past have largely relied on the formation of transistors. However, research into cross bar switch based electronics have offered an alternative using reconfigurable interconnections between vertical and horizontal wiring arrays to create ultra high density memories. Two leaders in this area are Nantero which has developed a carbon nanotube based crossbar memory called Nano-RAM and Hewlett-Packard which has proposed the use of memristor material as a future replacement of Flash memory.

2.4.2 Novel semiconductor devices:

An example of such novel devices is based on spintronics. The dependence of the resistance of a material (due to the spin of the electrons) on an external field is called magneto resistance. This effect can be significantly amplified (GMR - Giant Magneto-Resistance) for nano sized objects, for example when two ferromagnetic layers are separated by a nonmagnetic layer, which is several nanometers thick (e.g. Co-Cu-Co). The so called tunneling magneto resistance (TMR) is very similar to GMR and based on the spin dependent tunnelling of electrons through adjacent ferromagnetic layers. Both GMR and TMR effects can be used to create a non-volatile main memory for computers, such as the so called magnetic random access memory or MRAM. In 1999, the ultimate CMOS transistor developed at the Laboratory for Electronics and Information Technology in Grenoble, France, tested the limits of the principles of the MOSFET transistor with a diameter of 18 nm (approximately 70 atoms placed side by side). This was almost one tenth the size of the smallest industrial transistor in 2003 (130 nm in 2003, 90 nm in 2004, 65 nm in 2005 and 45 nm in 2007). It enabled the theoretical integration of seven billion junctions on a €1 coin. However, the CMOS transistor, which was created in 1999, was not a simple research experiment to study how CMOS technology functions, but rather a demonstration of how this technology functions now that we ourselves are getting ever closer to working on a molecular scale. Today it would be impossible to master the coordinated assembly of a large number of these transistors on a circuit and it would also be impossible to create this on an industrial level

2.4.3 Novel optoelectronic devices:

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 nano scaled 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.

2.4.4 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 scale.

2.4.5 Quantum computers:

Entirely new approaches for computing exploit the laws of quantum mechanics for novel quantum computers, which enable the use of fast quantum algorithms. The Quantum computer has quantum bit memory space termed "Qubit" for several computations at the same time. This facility may improve the performance of the older systems.

2.5 Heavy Industry:

An inevitable use of nanotechnology will be in heavy industry.

2.5.1 Aerospace:

Lighter and stronger materials will be of immense use to aircraft manufacturers, leading to increased performance. Spacecraft will also benefit, where weight is a major factor. Nanotechnology would help to reduce the size of equipment and thereby decrease fuel-consumption required to get it airborne. Hang gliders may be able to halve their weight while increasing their strength and toughness through the use of nanotech materials. Nanotech is lowering the mass of super capacitors that will increasingly be used to give power to assistive electrical motors for launching hang gliders off flatland to thermal-chasing altitudes.

2.5.2 Construction:

Nanotechnology has the potential to make construction faster, cheaper, safer, and more varied. Automation of nanotechnology construction can allow for the creation of structures from advanced homes to massive skyscrapers much more quickly and at much lower cost.

2.5.3 Refineries:

Using nanotech applications, refineries producing materials such as steel and aluminium will be able to remove any impurities in the materials they create.

2.5.4 Vehicle manufacturers:

Much like aerospace, lighter and stronger materials will be useful for creating vehicles that are both faster and safer. Combustion engines will also benefit from parts that are more hard-wearing and more heat-resistant.

2.5.5 Glass coatings:

In the glass sector nanotechnology brings again its features through final coatings applied to the glass surface. As in the case of construction ceramics nano TiO_2 particle incorporating coatings are applied to have self-cleaning, anti-hauling effect. Another feature that nanotechnology brings to glasses is fire resistance via addition of fumed silica nanoparticles. When heated, a transparent thin layer formed of fumed silica nanoparticles turn into an opaque fire shield. For glasses which could control heat and light transmittance nanoparticles of different materials are added to the raw materials of glass at the melting ingot.

Nanotechnology would enable windows with air purifying, heat radiation and UV rays' transmittance control and also better sound and thermal insulation properties [8].

2.6 Consumer Goods:

Nanotechnology is already impacting the field of consumer goods, providing products with novel functions ranging from easy-to-clean to scratch-resistant. Modern textiles are wrinkle-resistant and stain-repellent; in the mid-term clothes will become "smart", through embedded "wearable electronics". Different nanoparticle improved products are already in use. Especially in the field of cosmetics, such novel products have a promising potential.

2.6.1 Foods:

Complex set of engineering and scientific challenges in the food and bio processing 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; nanoencapsulation of bioactive food compounds are few examples of emerging applications of nanotechnology for the food industry[9]. 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 for sensanges in foods.

2.6.2 Nano foods:

New foods are among the nanotechnology-created consumer products coming onto the market at the rate of 3 to 4 per week, according to the Project on Emerging Nanotechnologies (PEN), based on an inventory it has drawn up of 609 known or claimed nano-products. On PEN's list are three foods -- a brand of canola cooking oil called Canola Active Oil, a tea called Nanotea and a chocolate diet shake called Nanoceuticals Slim Shake Chocolate. According to company information posted on PEN's Web site, the canola oil, by Shemen Industries of Israel, contains an additive called "nanodrops" designed to carry vitamins, minerals and phytochemicals through the digestive system and urea [10].The shake, according to U.S. manufacturer RBC Life Sciences Inc., uses cocoa infused "NanoClusters" to enhance the taste and health benefits of cocoa without the need for extra sugar [11].

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2.6.3 Household:

The most prominent application of nanotechnology in the household is self-cleaning or "easy-to-clean" surfaces on ceramics or glasses. Nanoceramic particles have improved the smoothness and heat resistance of common household equipment such as the flat iron.

2.6.4 Optics:

The first sunglasses using protective and anti-reflective ultrathin polymer coatings are on the market. For optics, nanotechnology also offers scratch resistant surface coatings based on nanocomposites. Nano-optics could allow for an increase in precision of pupil repair and other types of laser eye surgery.

2.6.5 Textiles:

The use of engineered nanofibers already makes clothes water- and stain-repellent or wrinkle-free. Textiles with a nanotechnologicalfinish 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. Many other applications have been developed by research institutions such as the Textiles Nanotechnology Laboratory at Cornell University.

2.6.6 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.

2.6.7 Agriculture:

Applications of nanotechnology have the potential to change the entire agriculture sector and food industry chain from production to conservation, processing, packaging, transportation, and even waste treatment. Major Challenges related to agriculture like Low productivity in cultivable areas, Large uncultivable areas, Shrinkage of cultivable lands, Wastage of inputs like water, fertilizers, pesticides, Wastage of products and of course Food security for growing numbers can be addressed through various applications of nanotechnology [12].

3. REGULATIONS

Due to the ongoing argument on the implications of nanotechnology, there is significant debate related to the question of whether nanotechnology or nanotechnology-based products merit special government regulation. This debate is related to the circumstances in which it is necessary and appropriate to assess new substances prior to their release into the market, community and environment.

The nanotechnology label is used on an increasing number of commercially available products – from socks and trousers to tennis racquets and cleaning cloths. The emergence of such nanotechnologies, and their accompanying industries, have triggered calls for increased community participation and effective regulatory arrangements. However, these calls have presently not lead to such comprehensive regulation to oversee research and the commercial application of nanotechnologies, or any comprehensive labeling for products that contain nanoparticles or are derived from nano-processes [13].

Regulatory bodies such as the United States Environmental Protection Agency and the Food and Drug Administration in the U.S. or the Health & Consumer Protection Directorate of the European Commission have started dealing with the potential risks posed by nanoparticles. So far, neither engineered nanoparticles nor the products and materials that contain them are subject to any special regulation regarding production, handling or labelling [14].

4. CONCLUSIONS:

Various fields in the world will be influenced by the development and implementation of nanotechnology. It is our hope to raise the awareness that nanotechnology will positively influence the world over the next several years.

Due to the small size of nano-materials, their physical/chemical properties (e.g. stability, hardness, conductivity, reactivity, optical sensitivity, melting point, etc.) can be manipulated to improve the overall properties of conventional material and it can be used for different applications.

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Corresponding Author

Prof. Sachin A. Mehta*

Hirasugar Institute of Technology, Nidsoshi, Karnataka, India

E-Mail – samehta.mech@hsit.ac.in