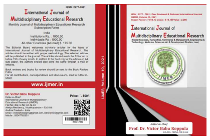
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MATERIALS SCIENCE AND NANOTECHNOLOGY: PROSPECTS AND FUTURE NEEDS

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Abstract: Materials science is an interdisciplinary scientific field comprising Physics, Chemistry, Biological Science, Medicine etc., that applies the properties of matter to various areas of science and technology. This field of science investigates the relationship between the structure of materials at atomic or molecular scales and their macroscopic properties. Nanotechnology concerns mainly with the study of manipulating matter on an atomic and molecular scale. Usually, nanotechnology deals with structures having size between 1 to 100 nanometer in at least one dimension, and involves developing materials or devices within that size. At this scale, everything, regardless of what it is, has new exotic properties governed by quantum mechanical effects.

Keywords: Interdisciplinary, Macroscopic, Nanotechnology.

Introduction: Materials Science and Nanotechnology

In the recent decades, there has been an increasing interest in the field of nanoscience and nanotechnology because of some unconventional properties exhibited by nanophase materials. The interest in this field stems from both basic research and technological applications. Preparation of nanomaterials has opened the opportunity of observing the evolution of physical properties of materials with sizes. The low-dimensional systems are the most exciting class of materials, whose properties lie between those of atomic/molecular clusters and bulk materials. The reduction in crystallite size results in the changes in the electronic structure. Also, there exists a close relationship between the electronic band structure and the optical response of materials. So, the dielectric spectra of these low dimensional systems are obviously an important source of information regarding confinement effects. Nanomaterials take advantage of their dramatically increased surface area to volume ratio. Their optical properties, e.g. fluorescence etc., 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, societal benefit of such nanoparticles can be expected to be increased. Such nanotechnologically enhanced materials will enable a weight reduction accompanied by an increase in stability and improved functionality. Practical nanotechnology is essentially meant for the ability to manipulate matter with higher precision on the nano-scales which many could never have imagined. It, therefore, seems unsurprising that few areas of human technology are exempt from the benefits which nanotechnology could potentially bring.

The field of Materials and Nanotechnology is very diverse, ranging from extensions of conventional device physics to completely new approaches based upon molecular self-assembly, from developing new materials with dimensions on the nanoscale to investigating whether we can directly control matter on the atomic scale. Nanotechnology may be able to produce many new materials and devices with a vast range of applications in the field of medicine, electronics, biomaterials, energy production etc. On the other hand, nanotechnology raises many of the same issues as any new technology, including concerns about the toxicity and environmental impact of nanomaterials, and their potential effects on global economics, as well as speculation about various doomsday scenarios. In this article, the prospects of materials science and nanotechnology with future needs and challenges have been highlighted.

Applications of Nanotechnology

The nanotechnology is today one of the main avenues of the research activities, development and innovation in all of the industrialized countries. There are some nanotechnological products in the current market, but it will obviously proliferate in near future. In this section, some of the important applications have been discussed in brief.

Applications in the field of Information and Communication

Nanotechnology finds its applications in designing storage devices. In the past, electronic memory designs largely relied on the formation of transistors. With the advent of nanotechnology carbon nanotube-based crossbar memory called Nano- RAM is now a reality. Memristor material is being thought to be a future replacement of Flash memory.

Magnetoresistance (the dependence of the resistance of a material due to the spin of the electrons, on an external field) can be significantly amplified (GMR - Giant Magneto-Resistance) for nanosized objects. The GMR effect has led to a strong increase in the

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data storage density of hard disks and made the gigabyte range possible. The so-called tunneling magnetoresistance (TMR) is very similar to GMR and based on the spin dependent tunneling of electrons through adjacent ferromagnetic layers. These effects can be used to create a non-volatile main memory for computers, such as the so called magnetic random-access memory or MRAM. Nanomaterials based CMOS enables the theoretical integration of seven billion junctions on a single coin.

In the modern communication technology traditional analog electrical devices have been fast replaced by optical or optoelectronic devices due to their enormous bandwidth and capacity, respectively. Quantum dots are nanoscaled objects can be used for the fabrication of lasers. The advantages of a quantum dot laser over the traditional semiconductor laser are that these are cheaper and the emission wavelength can easily be tailored by controlling the diameter of dot only.

Carbon nanotubes (CNT) are being used for the production of display with low energy consumption. Carbon nanotubes are electrically conductive and used as field emitters with extremely high efficiency for field emission displays (FED) due to their small diameter of several nanometers. Nanotechnology based quantum bit memory space termed Qubit are being proposed to be exploited in Quantum Computers for several computations at the same time.

Applications in the field of Medical Science

Now-a-days, nanoscience and nanotechnology opened up new pathways with regard to applications in the fields of biomedicine, diagnosis, molecular biology, biochemistry, catalysis etc. 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. That’s why; nanomaterials can be useful for both in vivo and in vitro biomedical research and applications. 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.

Magnetic nanoparticles, bound to a suitable antibody, are being 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.

Nanotechnology has been a blessing for the medical field by designing new smart drug delivery systems, which can deliver drugs to specific cells using nanoparticles, keep drugs at desirable levels in the body and avoid the need for frequent doses. This highly selective approach reduces costs and human suffering. 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. 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. Buckyballs can interrupt the allergy/immune response by preventing mast cells, which cause allergic response, from releasing histamine into the blood and tissues, by binding to free radicals.

Nanotechnology is now being exploited to reproduce or repair damaged tissue (Tissue engineering). It uses artificially stimulated cell proliferation by using suitable nanomaterial-based scaffolds and growth factors. For example, bones can be regrown on carbon nanotube scaffolds. Tissue engineering might replace today's conventional treatments like organ transplants or artificial implants. Advanced forms of tissue engineering may lead to life extension.

Another very important field of application of nanotechnology is nanorobotics. This field concerns with (i) manipulation of nanoscale objects by using micro or macro devices, and (ii) construction and programming of robots with overall dimensions at the nanoscale (or with microscopic dimensions but nanoscopic components). Nanorobots have dimensions comparable to those of biological cells, and are expected to have remarkable applications in health care and environmental monitoring. For example, they might serve as programmable artificial cells for early detection and destruction of pathogens. An interesting utilization of nanorobots may be their attachment to transmigrating inflammatory cells or white blood cells, to reach inflamed tissues and assist in their healing process. Nanorobots may be applied in chemotherapy to combat cancer through precise chemical dosage administration, and a similar approach could be taken to enable nanorobots to deliver anti-HIV drugs. Nanorobots are now being used to process specific chemical reactions in the human body as ancillary devices for injured organs. Monitoring and controlling nutrient concentrations in the human body, including glucose levels in diabetic patients may be a possible application of medical nanorobots. Nanorobots might be used to seek and break kidney stones. Another important possible feature of medical nanorobots is the capability to locate atherosclerotic lesions in stenosed blood vessels, particularly in the coronary circulation, and treat them either mechanically, chemically or pharmacologically. Prostate cancer is the most common malignant tumor in men, corresponding to approximately 27% of all male cancer.

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Lanthanide diketonate supermolecues with macrocyclics can be used as markers for prostate specific antigen (PSA) detection in serum sample.

Applications in Consumer Products

Nanotechnology has a very high impact in the field of consumer products. It provides 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. Already in use are different nanoparticle improved products, especially in the field of cosmetics. The traditional chemical UV protection approach suffers from its poor long-term stability. A sunscreen based on mineral nanoparticles (e.g., titanium dioxide) offer several advantages. Titanium oxide nanoparticles have a comparable UV protection property as the bulk material, but they lose the cosmetically undesirable whitening as the particle size is decreased. The sunglasses using protective and anti-reflective ultrathin polymer coatings are in 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.

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. 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.

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. Nanoscience concepts and nanotechnology applications have the potential to redesign the production cycle, restructure the processing and conservation processes and redefine the food habits of the people. 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.

Nanotechnology may also play a vital role in sports. Materials for new athletic shoes may be made in order to make the shoe lighter. Baseball bats already on the market are made with carbon nanotubes which reinforce the resin, which is said to improve its performance by making it lighter. Other items such as sport towels, yoga mats, exercise mats are on the market and also are being used by players round the globe.

Applications in Heavy Industry

In case of heavy industry nanotechnology has also put its fingerprint. Lighter and stronger materials will be of immense use for aircraft manufacturing, leading to better performance. Spacecraft will be also benefited, where weight is a key factor. Nanotechnology would help to reduce the size of equipment and thereby decrease fuel consumption required to get it airborne. Chemical catalysis benefits from nanoparticles, due to their extremely large surface to volume ratio. The potential applicability of nanoparticles in catalysis ranges from fuel cell to catalytic converters and photocatalytic devices.

Nanotechnology has immense potential to make construction faster, cheaper, safer, and more varied. The use of nanotechnology in construction involves the development of new concept and the understanding of hydration of cement particles and the use of nano-size ingredients such as alumina and silica and other nanoparticles. 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. In the near future nanotechnology can be used to sense cracks in foundations of architecture and can send nanobots to repair them. Coating is an important area in construction. Coatings should provide a protective layer which is bound to the base material to produce a surface of the desired protective or functional properties. Nanotechnology is being applied to paints to obtain the coatings having self-healing capabilities and corrosion protection under insulation. Since these coatings are hydrophobic and repel water from the metal pipe and can also protect metal from salt water attack. Self-cleaning glasses may be prepared by coating with ZnO nanoparticles. Research is being carried out on the application of nanotechnology to glass. Titanium dioxide (TiO_2) nanoparticles are used to coat glazing since it has sterilizing and anti-fouling properties. The particles catalyze powerful reactions which breakdown organic pollutants, volatile organic compounds and bacterial membranes. The TiO_2 is hydrophilic (attraction to water) which can attract rain drops which then wash off the dirt particles. Thus the introduction of nanotechnology in the glass industry incorporates the self-cleaning property of glass. In building construction nanomaterials are widely used from self-cleaning windows to flexible solar panels to wi-fi blocking paint. The self-healing concrete blocks ultraviolet and infrared radiation. Smog-eating coatings, light-emitting walls and ceilings are the new nanomaterials being used in today's construction. Nanotechnology is thus a promise for making the smart home a reality.

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Nanotechnology helps us to fabricate fire-protective glass, which is prepared by using a clear intumescent layer sandwiched between glass panels made of silica nanoparticles (SiO_2). It turns into a rigid and opaque fire shield when exposed to heat. Most of glass in construction is used over the exterior surface of buildings. So, the light and heat entering the building through glass has to be prevented. The nanotechnology can provide a better solution to block light and heat coming through windows. Use of nanoparticles can provide better adhesion and transparency. The TiO_2 coating captures and breaks down organic and inorganic air pollutants by a photocatalytic process, which leads to putting roads to good environmental use. In regard with fire-protection the nano-cement has the potential to create a new paradigm in this area of application because the resulting material can be used as a tough, durable, high temperature coating. It provides a good method of increasing fire resistance and this is a cheaper option than conventional insulation.

The use of nanotechnology in steel helps to improve the properties of steel. The fatigue, which led to the structural failure of steel due to cyclic loading, such as in bridges or towers, can be waived by using copper nanoparticles. The nano-size steel produce stronger steel cables which can be used in bridge construction. At the same time, these stronger cable materials would reduce the costs and period of construction, especially in suspension bridges as the cables are run from end to end of the span.

Future Needs & Challenges

It is to be mentioned in this context that nanoparticles have some effects on health and environment. Let me mention some of the effects of nanoparticles on health and social issues. Nanoparticles may enter the body if building water supplies are filtered through commercially available nano-filters. Airborne and waterborne nanoparticles enter from building ventilation and wastewater systems. Also, since sensors become more common use, a loss of privacy may result from users interacting with increasingly intelligent building components. The technology at one side has the advantages of new building material. The other side it has the fear of risk arises from these materials. However, the overall performance of nanomaterials to date, is that valuable opportunities to improve building performance, user health and environmental quality.

So, the future research in materials science and nanotechnology will lead us to the main industrial challenge of sustainable competitiveness. Sustainable competitiveness appears to be a new wide concept of competitiveness embracing all goals set by the Lisbon Council. It is based on qualitative growth, bound to take into account concerns about environment, health, energy, employment, prosperity, public acceptance, culture and human dignity. The way towards sustainable competitiveness requires a system approach and an overall integration of players, skills and activities, including research and innovative funding schemes. Technological advances on materials and related technologies have the potential to improve our quality of life by means of new and enhanced products and services, thus generating wealth and employment. Research activities can provide the economic growth and the consequent wealth level needed for social and environmental improvements at the basis of a sustainable development. This implies, in particular, the reorientation of means and models of production and consumption that are no longer compatible with the concept of sustainability. Future research will then not only provide innovative solutions to existing problems but will in particular offer new opportunities through the development of innovative materials with new functionalities and potentially improving the quality of life for everybody. New approaches and production paradigms are required to meet the challenge of sustainable competitiveness. A shift from resource-based towards knowledge-based approaches; from quantity to quality; from mass-produced, single-use products to customer-tailored, multi-use products and product-services are needed. A qualitative growth can only be ensured by a global quality approach.

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