Nanotechnology & Engineering Applications

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Abstract— Nanotechnology is regarded world-wide as one of the key technologies of the 21st Century. Nano-technological products and processes hold an enormous economic potential for the markets of the future. There is much debate on the future implications of nanotechnology. The production of ever smaller, faster and more efficient products with acceptable price-to-performance ratio has become for many industrial branches an increasingly important success factor in the international competition. Nanotechnology may be able to create many new materials and devices with a vast range of applications, such as in medicine, electronics, biomaterials and energy production. Due to its interdisciplinary cross-section character, nanotechnology will affect broad application fields within the ranges of chemistry/ materials, medicine/life science, electronics/information technology, environmental and energy engineering, automotive manufacturing as well as optics/analytics and precision engineering in various ways. Also in space technology a high potential for nano-technological applications is postulated. On the other hand, nanotechnology raises many of the same issues as any new technology, including concerns about the toxicity and environmental impact of nano materials, and their potential effects on global economics, as well as speculation about various doomsday scenarios. This paper throws light on some of the application of nanotechnology and nano materials in Engineering.

Key words: Nanotechnology, Application of Nano technology, Nanomaterials, Nano electronics, Nano technology in Space, Carbon Nanotube, MEMS, NEMS

I. Introduction

Nanotechnology is the study of manipulating matter on an atomic and molecular scale. Generally, nanotechnology deals with developing materials, devices, or other structures possessing at least one dimension sized from 1 to 100 nanometres. Quantum mechanical effects are important at this quantum-realm scale.

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 nano-scale to direct control of matter on the atomic scale. Nanotechnology entails the application of fields of science as diverse as surface science, organic chemistry, molecular biology, semiconductor physics, micro fabrication, etc. The interest in nano-particles of these typical sizes is due to the fact that the magnetic, optical and electronic behaviour of bulk materials can be modified when their size approaches the nano meter scale. Nano-materials exhibit fundamentally unique properties with great potential application in electronics, computing, optics, biotechnology, medical imaging, medicine, drug delivery, structural materials aerospace, space exploration, energy etc. In the last 20 years research has focused on understanding the origin of these new properties.

There is much debate on the future implications of nanotechnology. Nanotechnology may be able to create many new materials and devices with a vast range of applications, such as in medicine, electronics, biomaterials and energy production. On the other hand, nanotechnology raises many of the same issues as any new technology, including concerns about the toxicity and environmental impact of nano materials, and their potential effects on global economics, as well as speculation about various doomsday scenarios. These concerns have led to a debate among advocacy groups and governments on whether special regulation of nanotechnology is warranted.

In 1974, Japanese scientist Norio Taniguchi coined the term 'Nanotechnology' for the first time in a conference while referring to a semiconductor process at minute scale. In 1979, K. Eric Drexler came across Feynman's talk 'There is plenty of room at the bottom'. In 1986, he wrote a book 'Engines of Creation: The Coming Era of nanotechnology' in which he presented concept of second-generation nano Machines called as 'Assemblers'. He proposed that these will serve as devices for assembling molecular structures and will let us place atoms in any reasonable arrangements allowed by basic Laws of nature. According to him, advancements in the field of technology, medicine, computation, production etc. will all depend on the ability to rearrange atoms. In 1981, an instrument called as Scanning Tunnelling Microscope (STM) was build for taking images at atomic scale. The creators, Gerd Binning and Heinrich Rohrer got Nobel Prize in Physics in 1986.Its resolution of the order of 0.1nm enabled scientists to observe and manipulate the materials at atomic level.

In the early 2000s, the field was subject to growing public awareness and controversy, with prominent debates about both its potential implications, exemplified by the Royal Society's report on nanotechnology, as well as the feasibility of the applications envisioned by advocates of molecular nanotechnology, which culminated in the public debate between Eric Drexler and Richard Smalley in 2001 and 2003. Governments moved to promote and fund research into nanotechnology with programs such as the National Nanotechnology Initiative.

II. Fundamental concepts

Nanotechnology is the engineering of functional systems at the molecular scale. This covers both current work and concepts that are more advanced. In its original sense, nanotechnology refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, high performance products.

One nanometer (nm) is one billionth, or 10^{-9}, of a meter. By comparison, typical carbon-carbon bond lengths, or the spacing between these atoms in a molecule, are in the range 0.12–0.15 nm, and a DNA double-helix has a diameter around 1- 2 nm. On the other hand, the smallest cellular life-forms, the bacteria of the genus Mycoplasma, are around 200 nm in length. By convention, nanotechnology is taken as the scale range 1to 100 nm following the definition used by the National Nanotechnology Initiative in the US. The lower limit is set by the size of atoms (hydrogen has the smallest atoms, which are approximately a quarter of a nm diameter) since nanotechnology must build its devices from atoms and molecules. The upper limit is more or less arbitrary but is around the size that phenomena not observed in larger structures start to become apparent and can be made use of in the nano device. These new phenomena make nanotechnology distinct from devices which are merely miniaturised versions of an equivalent macroscopic device; such devices are on a larger scale and come under the description of micro technology.

To put that scale in another context, the comparative size of a nanometer to a meter is the same as that of a marble to the size of the earth. Or another way of putting it: a nanometer is the amount an average man's beard grows in the time it takes him to raise the razor to his face.

Two main approaches are used in nanotechnology. In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition. In the "top-down" approach, nano-objects are constructed from larger entities without atomic-level control.

Areas of Engineering & physics such as nanoelectronics, nanomechanics, nanophotonics and nanoionics have evolved during the last few decades to provide a basic scientific foundation of nanotechnology.

III. FULLERENES & CARBON NANOTUBES

Carbon exists in different allotrope forms like graphite, diamond etc. Fullerenes are also allotropes of carbon. Richard Smalley, Robert Curl, James Heath, Sean O'Brian and Harold Kroto at Rice University discovered first fullerene molecule in 1985. Spherical fullerenes resemble football in appearance. Fullerenes doped with some elements form superconducting materials. Fullerenes having cylindrical shapes are called as carbon nanotubes. Due to their unique physical properties, they are found very useful in domains of material science and electronics. Carbon nanotubes (CNT) with diameters of few nanometers as fullerene derivatives represent pure carbon compounds and occur in different modifications, e.g. single walled (SWCNT) or multi-walled (MWCNT). CNT possess unusual mechanical characteristics (on molecular level approx. 50 times stronger than steel and outstanding thermal and electrical conductivity). Due to their special properties, CNT possess numerous application in space, e.g. space structures, thermal control devices, sensor technology, electronics and biomedicine. In particular the huge potential for mass savings in space structures makes CNT very interesting for Engineering applications.

IV. AEROSPACE & AUTOMOTIVE APPLICATIONS

Due to the outstanding functional characteristics of nanostructured materials, which are mainly based on a large surface- to-volume-ratio and on quantum effects, numerous potential applications arise in space.

A. Materials for space structures

A range of applications of nanomaterials lies in the construction of spacecrafts and space structures due their improved mechanical characteristics (higher firmness and stability and concurrently a lower density) compared with conventional materials. Nanomaterials could in particular contribute to the reduction of the lift-off masses of spacecrafts leading to substantial cost savings and also ensure safer and more flexible space missions.

B. Metal-Matrix-Composites

By reinforcement of metals with ceramic fibers, in particular silicium carbide, aluminium oxide or aluminum nitride, their thermomechanical properties can be improved. Such metal matrix composites (MMC), e.g. SiC in aluminum alloys or TiN in Ti/Al alloys, due to their high heat resistance, firmness, thermal conductivity, controllable thermal expansion and low density, possess a high potential for aerospace applications and are examined at present, regarding the replacement of magnesium and aluminium in various structures of spacecrafts and aeroplanes. As it has been reported, the strength of MMC could be increased up to 25 % through nanostructuring and beyond that, superplasticity and a better resistance against material fatigue can be obtained in comparison to conventional MMC.

C. Nanoparticle Reinforced Polymers

The mechanical properties of polymers can be improved by dispersion of nanoparticles into the polymer matrix. As polymer matrices for example epoxide, nylon, polyphenole or polyimide can be used. Due to its high n mechanical firmness and resistance against heat and radiation, nanoparticle reinforced polymers have potential applications for various components in space, among other things as housings of solid-propellant rockets, as heat protection material in rocket nozzles, electrical isolations or fire protection applications. Also within the range of aviation, nanoparticle reinforced polymers are investigated intensively at present as lightweight structure materials for airplane bodies.

D. Nanocrystalline metals and alloys

The thermomechanical characteristics of metals and alloys can also be improved by controlling the nano/microstructure of the materials. Melting points and sintering temperatures can be reduced up to 30 %, if the material is made of nano powders. Another advantage is the easy formability of the materials through super plasticity. Nanocrystalline aluminum alloys were developed for space applications as alternatives for titanium in components of liquid rocket engines, since they are lighter and less susceptible to embrittlement by hydrogen.

E. Automotive Nano-Technology

Lighter and stronger materials will also be useful for creating vehicles that are both faster and safer. They protect engine parts from wear and tear thereby increasing the lifespan and efficiency. MEMS (Micro Electro Mechanical Systems) techniques allow both electronic circuits and mechanical devices to be manufactured onto a single silicon microchip. NEMS (Nano Electro Mechanical Systems) is the next miniaturized version of MEMS. MEMS technology allows for the miniaturization of the electronic components used in aircrafts or vehicles. For example, MEMS accelerometers have replaced the previously bulky accelerometers used for air-bag deployment in automobiles. Similarly, MEMS gyroscopes and MEMS inertial sensors are being used in automobiles and for consumer electronics. The newer MEMS chips are both tiny and cost- effective.

The basic areas where nanotechnology can benefit automobiles are – lighter and stronger materials for better safety of the passengers, improved and miniaturized electronic systems, improved engine and fuel efficiency, lower component failure, smart materials for self-repair and greater service life.

V. NANO ELECTRONICS

Sensors are devices that convert a physical parameter to a signal that can be measured electrically. Once the physical parameter has been converted to an electrical equivalent, it can be easily used as an input to a computer or microprocessor for manipulating, analyzing and displaying. Most commonly used sensors are pressure, temperature, position, speed etc. Unlike the bulky and expensive traditional sensors, the new age, miniscule nano sensors can help lower materials cost, weight, and power consumption in manufacturing processes.

Pressure sensors are used for many applications and their location varies accordingly. Pressure sensor can be used to determine when an air filter is dirty. This can be done by measuring the pressure difference between the air at the filter intake and air on the other side of the diaphragm. They can also be used to calculate mass airflow rate, engine speed and air temperature by measuring the pressure from intake fold. The pressure sensor devices used in tire pressure monitoring system (TPMS) can be installed inside the tire (internal sensor) or mounted on the valve stem (external sensor). The sensors measure the pressure in each tire and transmit the data wirelessly to a central receiver in the vehicle, which analyzes the information and displays it to the driver. The information varies from simple warning lights when pressure gets too low, to readouts of pressure measurements. Some systems may also include pressure information about the spare tire. The sensor is made of a double layer membrane of 70nm $SiO2$ and 70nm of $Al2O3$. The SWNT is embedded between the two layers and contacted by a source and a drain metal electrode. A nearby gate electrode is used to bias the SWNT in a transistor configuration. The top and bottom oxide layers are used to encapsulate the SWNTs to protect them from the environment.

Temperature sensors provide a key parameter to the electronic module to enable feedback of the system's current state of operation. The most common applications of temperature sensors are sensors for measuring coolant temperature, intake air temperature, and transmission oil temperature and, cylinder head temperature.

The coolant temperature sensor measures the temperature of the coolant and interfaces with the electronic control module (ECM). An ECM, also known as power-train control module (PCM) is a type of electronic control unit that determines the amount of fuel, ignition timing and other parameters that an internal combustion engine needs to keep running. The coolant temperature sensor provides feedback to the ECM regarding the temperature of the coolant at a single point on the engine. Similarly, the cylinder head temperature sensor provides the temperature of the metal at a single point on the engine. Using this temperature data and previous engine calibration information, the ECM controls the operation of the engine management system to achieve optimal engine control. Engine intake air temperature is also a key temperature used by the ECM. Similar to the coolant sensor, this sensor also interfaces with the ECM. Most temperature sensors on vehicles are located underneath near the front bumper bar.

VI. FUTURE SCOPE

Nano sensor applications have the potential to redefine the automotive industry. Vehicle dynamic control (VDC), rollover detection and antitheft systems are other important areas where CNT based sensors can be potentially applied. It is expected that many applications of CNT-based sensors will be explored in future as the interest of the nanotechnology research community in this field increases. The future cars based on nanotechnology will be lighter, stronger, faster, safer, and more intelligent than the driver and eco-friendly.

A sunscreen based on mineral nano particles such as titanium dioxide or zinc oxide offer several advantages. These nano particles have a comparable UV protection property and are transparent in appearance thereby avoiding the undesirable whitening, which comes with other sunscreens.

Clothes that are water and stain resistant and wrinkle free can be manufactured using nanotechnology. Nano sensors are being weaved along with the clothes that can be used to monitor a person's health.

VII. CONCLUSIONS

The increasing commercialization of manned and unmanned space travel and ever more ambitious missions for the scientific investigation of the solar system as well as, far space, require the development of more efficient, more economical and more resistant space technologies and systems in the future. Nanotechnology could contribute significantly to solutions and technological breakthroughs in this area. The low weights, Nano-Satellite have significant role to play in the cost reduction, experimentation, reduction in the development and testing time for the new technologies and will significantly change the satellite development activity in the future.

Automotive industry has been greatly influenced by nanotechnology and the fundamentally new capabilities offered by it. CNTs play a major role in the advancement of nanotechnology in various applications. The exceptional properties of CNT allow them to be used in sensors, which help in increasing the sensitivity and dynamic range of sensors. Nano sensors are used to acquire information about vehicle parameters such as pressure, vehicle altitudes, temperature, heat, humidity, speed, exhaust gas, engine knock and torque apart from enabling new desirable features. CNT-based sensors are replacing old technologies with cheaper and more reliable devices.

With nanotechnology, the products obtained will be cheaper and more efficient. Further advances in usage of nanotechnology and developing new nanomaterials may provide solutions to problems that would not have been thought to be possible a couple of decades ago.

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