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Use of nanotechnology for clean and safer future environment

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Abstract: ***Nanotechnology is the most promising technology in modern science. This technology deals with the study and practical applications of different materials of nano-scale dimension. The chemical reactivity of a material increases immensely when we take its nano-dimensional form due to large surface to volume ratio and this special characteristic of a nanostructure is used widely in different environmental applications. Nanotechnology can be used in three different ways to tackle environmental pollutions. Firstly, we may use nanosensors to detect pollutant and pathogens in the environments. Secondly, we can apply nanotechnology for pollution remediation and treatment. Thirdly, nanotechnology may also be used as a tool to prevent our environment from further damage. Different nanowires and nanostructures are found to be very useful in detecting gaseous substances. Especially single walled carbon nanotubes (SWNT) are widely used for the detection of gases like*** NH_3, NO_2 ***etc. The use of zero-valent iron (ZVI or*** Fe^0***) for in situ remedial treatment of soil and water has been expanded to include all different kinds of contaminants. Nanoparticles of*** TiO_2 ***and ZnO are very effective in converting toxic contaminants of water by solar photo catalysis remediation. Nano-membrane and nano-filters have shown promise to produce pure drinking water and fresh air in future. Nanotechnolgy has a very bright future in the field of prevention and reduction pollution from our environment. Different nano-catalysts may reduce the use of toxic reagents and we can hope for a "Green Manufacturing" process in future.***

Key Words: Nanotechnology, Eco-friendly, Sensors, Remediation, Prevention.

1. Introduction

Nanotechnology is an emerging new field in modern science. It focuses on the design, synthesis, characterization and applications of materials and devices on nanoscale. Nanotechnology has wide range of applications in physics, chemistry, biology and other interdisciplinary sectors. Nanotechnology has some advantages over the conventional technologies, devices produced by this technology need fewer amounts of materials compared to the macro devices, it consumes very small amount of energy and this technology helps to miniaturize the whole system of the device.

Nano-dimensional structure of any element or compound shows some extraordinary features which are totally different from its bulk form. The special characteristics shown by the nano-structure may be explained with the help of some simple logic. Firstly, when we make very tiny particles actually we increase the surface area of the materials immensely but the total volume of the material remains the same. This phenomenon is called increase of surface to volume ratio. So, for nanoparticles, surface to volume ratio increases which in turn increases the open surface of the material and more molecules or atoms now have the access to react with other surrounding molecules or atoms. This is why the chemical reactivity of nanostructures increases many fold compared to its bulk counterpart. Secondly, nanoparticles or structures are very small and free electrons are trapped in these isolated structures. Due to the confinement of electron in a nano-dimensional space, quantum mechanics dominates the behavior of the electron. This effect is called quantum confinement effect. As a result of this affect optical band-gap of the material changes dramatically and the optical and electrical properties of the nanostructure get modified.

Nanotechnology has huge successful applications in different areas of applied science where its noble characteristics due to its shape and size are utilized. Nanoscale materials have immense potential to improve the environment by direct applications to detect, prevent and remove the pollutant, as well as indirectly by designing cleaner industrial processes and create eco-friendly products. In the present paper some simple applications of nanotechnology which may be helpful to improve the quality of our environment were discussed.

2. Detection of pollutants

Rapid and sensitive detection of pollutants are the most essential part of making clean and non-hazardous environment. Sensor is a device build to detect a specific biological or chemical compound, usually producing electrical signal upon detection. Sensors used to detect pollutants must have molecular precision in their sensitivity. These sensors should have maximum efficiency in detecting pollutants and pathogens. Nanotechnology can improve the sensitivity of these sensors quite dramatically. Nanomaterials have specific biological and chemical properties thus sensor selectivity may improve immensely when nanomaterials are used in sensing devices. This property may also improve the accuracy level of the sensor. Nanomaterials have large surface to volume ratio which results in a large number of atomic or molecular presence on the open surface of the nanomaterials. This property particularly increases the reactivity of the material. We can use a very small amount of sensing material to detect the pollution level accurately and as the sensing material is nano-dimensional, the size of the detecting device should be very small. In this way, we can miniaturize the device which can help us for *in situ* detection in real time monitoring of large areas in the field. As the size of the sensor becoming very small due to nanomaterials, we can pack more detection sites in the same device which will allow the fabrication of super small 'multiplex' sensor.

The gas sensor has become indispensable to our human society. As human life becomes more convenient, we are more exposed to environmental threats. In 1960, liquid petroleum (LP) gas was widely used for domestic purposes, but at the same time, many gas explosion accidents occurred because of gas leaks. Gas sensors that were able to detect LP gas dramatically reduced the accident rate. Now, the gas sensors are easily found in our daily lives: fire alarms installed in the house; gas emission controllers in the car; breath analyzers for drunken drivers; etc. In the industrial area, many kinds of chemicals are used on the production line, so gas sensors are demanded for the safety of the workers and for the prevention of the accidents and machinery failures caused by exposure to inflammable, toxic, or corrosive chemicals. They are also currently being used for food quality control. There are different types of gas sensors has been developed. Chemiresistive gas sensors are the most common for wide range of sensor applications. Chemiresistive gas sensor is usually made of semiconducting materials, and the sensing involves changes in the density of charge carriers. In other words, it measures changes

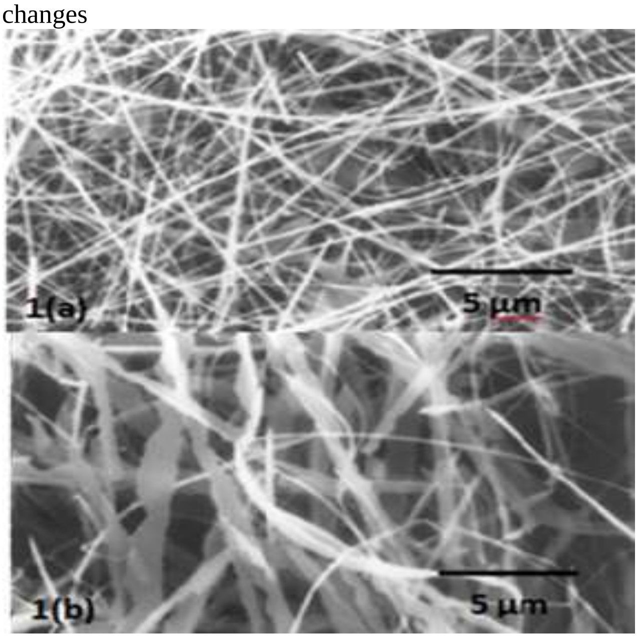

Figure1: Scanning Electron Micrograph shows (a) nanowire structure and (b) nanobelt structure of β-Ga_2O_3 . [Taken from P. Guha, S. Chakrabarti and S. Chaudhuri Physica E 23(2004) 81.]

in the conductivity of a semiconductor when it interacts with the gas to be analyzed. The most widely preferred semiconducting materials are metal oxides such as Ga_2O_3, In_2O_3, SnO_2, WO_3, TiO_2, etc., and they are sensitive to CO_2, H_2S, NH_3, O_3, NO_x, CO and carbon hydroxides. Normally this type of gas sensor is made on an insulating substrate with connections to conductive wires (Au, Pt). The element is integrated into the circuit. Briefly, the energy level rises or falls, playing an important role in detecting gases when O_2 adsorbed on the sensor element reacts with the target gas.

Gallium oxide is an important wide band gap (E_g = 4.9 eV) semiconductor material. In particular, monoclinic gallium oxide (β-Ga_2O_3) has excellent chemical and thermal stability. Its *n*-type conduction is achieved when it is synthesized under reducing conditions, due to the oxygen vacancies which acts as shallow donors [1]. β-Ga_2O_3 has various technological applications, such as transparent conducting oxides, optical emitters for ultraviolet radiation, flat-panel displays, spin tunneling junctions, and high temperature gas sensing [2-3]. Fig.1 shows nanowire and nanobelt structure of β-Ga_2O_3. β-Ga_2O_3 nanostructures are quite efficient to detect O_2, NO, CO, NH_3 and CH_4[4-6].

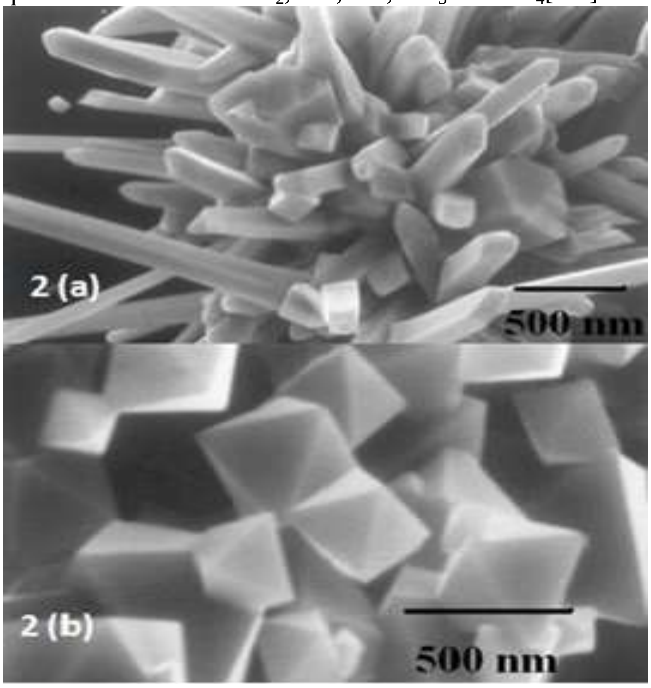

Figure2: Scanning Electron Micrograph shows (a) nano-column structure and (b) nano-octahedra structure of In_2O_3. [Taken from P. Guha, S. Kar and S. Chaudhuri Appl. Phys. Lett. 85 (2004) 3851]

Indium oxide (In_2O_3) is a wide band-gap transparent semiconductor (direct band gap of 3.55 − 3.75 eV and indirect bandgap of 2.6 eV), which can be widely used in electronic and optoelectronic devices, flat panel displays, gas sensors, and photocatalysis [7-9]. Different nanostructures of In_2O_3 like nanowire, nano-belt, nano-column, nano-octahedra were reported. Fig. 2 shows nano-column and nano-octahedra structure of In_2O_3. In_2O_3 is reported to be very sensitive towards oxidizing gases like O_3, NO_2, Cl_2 etc. It can also sense H_2, H_2S, NH_3, ethanol and acetone [10-15].

Tin oxide (SnO_2) is another wide band gap (3.6 eV) semiconductor. The electronic conductivity of SnO_2 is significantly influenced by the effects on its surface states of molecular adsorption. It has been widely explored as an effective gas sensor, traditionally in the forms of thin or thick films with low sensitivity and long response time [16]. Recently, SnO_2 nanobelts have been tested for their sensitivity to environmental pollutants such as CO and NO_2 [17].

Photochemical SnO_2 nanoribbon sensors have been fabricated for detecting low concentrations of NO_2 at room temperature under UV light [18]. Polycrystalline SnO_2 nanowire sensors were also developed for sensing ethanol, CO, and H_2 gas [19]. SnO_2 nanohole array sensors have exhibited a reversible response to H_2 [20].

Tungsten oxide (WO_3) is an n-type semiconductor and it shows good response in NH_3 and NO. Elements such as Au, Mo, Mg etc. enhances the selectivity of WO_3 sensor and doping with Cu or surface modification with Au and Pt enhance sensitivity to NH_3 [21-26].

Titanium oxide (TiO_2) is another n-type semiconductor with high temperature stability and endurance in harsh environments. Thermal expansion coefficient matched with alumina used as thin film gas sensor substrate. Its nanostructure is very useful in detecting organic alcohols, NH_3 and NO [27-31].

Single walled carbon nanotubes (SWNTs) have demonstrated to exhibit a faster response and higher sensitivity towards gaseous molecule such as NO_2 and NH_3 than that of existing solid state sensors [32]. In this case, direct binding of the gaseous molecule to the surface of the SWNT is the mechanism involved in sensing, upon which the electrical resistance of the SWNT dramatically increases or decreases. Moreover, this sensitivity was registered at room temperature, whereas conventional solid-state sensors operate at very high (200 to 600^0C) temperatures in order to achieve enhanced chemical reactivity between molecules and the sensor material. Although SWNTs are promising candidates as nanosensors, they have some drawbacks. First, existing production methods produce a mixture of metallic and semiconducting NTs, only the latter being useful as sensors. Second, in order to be able to sense a variety of chemical and biological species, the surface of NTs needs to be modified to have specific functionalities to bind those species. Flexible methods to modify the surface of NTs to bind large variety of analytes are not well established yet.

3. Pollution Remediation and Treatment

Soil and groundwater contamination arising from manufacturing processes are a matter of great concern. Affected sites include contaminated industrial sites, landfills, and abandoned mines. Pollutants in these areas include heavy metals and organic compounds. Nanotechnology can develop techniques that will allow for more specific and cost- effective remediation tools. Currently, many of the methods employed to remove toxic contaminants involve laborious, time-consuming and expensive techniques. A pre-treatment process and removal of the contaminated area is often required, with a consequent disturbance of the ecosystem. Nanotechnology allows developing technologies that can perform *in situ* remediation. In addition, thanks to its ability to manipulate matter at a molecular level, nanoscience can be used to develop remediation tools that are specific for a certain pollutant, therefore increasing affinity and selectivity, as well as improving the sensitivity of the technique.

Drinking water quality and its contamination from pollutants is another matter of concern. Mercury and arsenic are in particular two extremely toxic metals that pose very high health risks. Remediation methods that allow fast, economic and effective treatment of water polluted with such contaminants is highly needed. Nanotechnology can introduce new methods for the treatment and purification of water from pollutants.

The use of zero-valent (Fe^0) iron nanoparticles for the remediation of contaminated groundwater and soil is a good example of how environmental remediation can be improved with nanotechnology [33]. When exposed to air, iron oxidizes easily to rust; however, when it oxidizes around contaminants such as trichloroethylene (TCE), carbon tetrachloride or dioxins these organic molecules are broken down into simple, far less toxic carbon compounds. Since iron is non-toxic and is abundant in the natural environment, some industries have started using an 'iron powder' to clean up their new industrial wastes. However, the simple 'iron powder' is not effective for decontaminating old wastes that have already soaked into the soil and water. This effect is due to the low reactivity of iron powders. Another matter of concern is the decrease of reactivity of iron powders over time, possibly due to the formation of passivation layers over the surface of the iron granules.

Nanotechnology has offered a solution to this remediation technology in the form of iron nanoparticles. These nanoparticles are 10 to 1000 times more reactive then commonly used iron powders [33]. They have a larger surface area available for reacting with the organic contaminant and their small size (1-100 nm) allow them to be much more mobile, so they can be transported effectively by the flow of groundwater. The nanoparticles do not change by soil acidity, temperature or nutrient levels, so they can remain in suspension maintaining their properties for extended periods of time to establish an *in situ* treatment zone. Experimental results collected both in laboratory and in the field have shown that nanoscale iron particles are very effective for the complete transformation and detoxification of a wide variety of common environmental contaminants, such as chlorinated organic solvents and pesticides. When nano-sized iron powders are used, no toxic by-products are formed, a result of the increased reactivity and stability of the nanoparticles compared to the granular iron powder [34]. Contaminant levels around the injection level is considerably reduced in a day or two and nearly eliminated within a few days [33]. Nano-iron particles remain active in a site for six to eight weeks before they become dispersed completely in the groundwater and become less concentrated than naturally occurring iron.

Nanoparticles that are activated by light are also investigated for their capability of removing contaminants from various media, especially water. The semiconductors TiO_2 and ZnO are of particular interest, since these are readily available and inexpensive, so their use for remediation has been studied for many years. The vision is to create some solar photocatalysis remediation systems, where TiO_2 or ZnO are used to convert toxic contaminants, such as chlorinated detergents, into benign products using sun radiation. There is evidence that those semiconductors can photodegrade numerous toxic compounds [35], but the technology requires improvements in term of efficiency, since TiO_2 or ZnO only adsorb UV light which represents only 5% of the solar spectrum. In this context, nanotechnology could bring an improvement in the form of nanoparticles with surfaces modified with organic or inorganic dyes to increase the photoresponse window of TiO_2 and ZnO from UV to visible light [36].

Nanotechnology can also be employed for the fabrication of nano-filters and nano-membranes with specific properties to be used for decontaminating water and air. In principle, 'nano-traps' designed for a certain contaminant can be produced, for instance having a specific pore size and surface reactivity [37-38].

4. Pollution Prevention

Reduction of waste in manufacturing processes; reduction in the use of harmful chemicals; reduction in the emission of 'greenhouse'-effect gases during fuel combustions; use of biodegradable plastics: these are only few of the many approaches that can be taken to reduce the pollution of the environment. Nanotechnology is already actively involved in this sector, either as a technology to produce advanced materials that pollute less, or as a method to increase the efficiency of certain industrial processes.

A catalyst is a substance that increases a chemical reaction rate without being consumed or chemically altered. One of the most important properties of a catalyst is its 'active surface' where the reaction takes place. The 'active surface' increases when the size of the catalysts is decreased. The higher is the catalysts active surface, the greater is the reaction efficiency. Also, research has shown that the spatial organization of the active sites in a catalyst is important as well [39]. Both properties can be controlled using nanotechnology. In the environmental field, nanocatalysis is being investigated for desulphurizing fuels, with the aim of developing 'clean' fuels containing very low sulphur products.

'Green manufacturing' is a generic name to broadly cover methods and technologies that are directed towards developing new chemical and industrial procedures; reduction in the use of unsafe compounds; development of 'green' chemicals that are more environment-compatible; and efficient use of energy. The application of 'green nanotechnology'[39] to manufacturing includes bottom-up, atomic-level synthesis for developing improved catalysts; inserting information into molecules to build new materials through highly specific synthetic routes; scaling down material usage during chemical reaction by using nanoscale reactors; and improving manufacturing to require less energy and less toxic materials.

5. Conclusions:

Nanotechnology has the potential to offer numerous opportunities to prevent, reduce, sense and treat environment contamination. However it has its own drawbacks. Nanomaterials fabrication requiring large amounts of water and energy, the chemicals required are often highly toxic, as are many nanomaterials themselves. There is no full ecotoxicological profile for any of the nanomaterials available today and the existing scientific results identify potential serious health and environmental concerns. Much more research and ecotoxicological modeling is therefore required before we should consider large-scale environmental release of nanomaterials for use in remediation or other purposes.

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