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Applications of nanotechnology in air pollution and remediation

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Abstract
Latest innovations in nanotechnology have transformed a number of scientific and industrial areas including the environmental remedies. The issue of environmental pollution has become a hot issue in today's world. Environmental pollution, mainly caused by toxic chemicals, includes air, water, and soil pollution. This pollution results not only in the destruction of biodiversity, but also the degradation of human health. Pollution levels that are increasing day by day need better developments or technological discoveries immediately. Nanotechnology offers many advantages to improve existing environmental technologies and create new technology that is better than current technology. In this sense, nanotechnology has three main capabilities that can be applied in the fields of environment, including the cleanup (remediation) and purification, the detection of contaminants (sensing and detection), and the pollution prevention. The present paper is described for air pollution and remedies on nanotechnology applications.

Keywords: nanotechnology, environment, air pollution and remediation

Introduction
Nanotechnology is the use of matter on an atomic, molecular, and supramolecular scale for industrial purposes. The earliest, widespread description of nanotechnology referred to the particular technological goal of precisely manipulating atoms and molecules for fabrication of macro scale products, also now referred to as molecular nanotechnology A more generalized description of nanotechnology was subsequently established by the National Nanotechnology Initiative, which defined nanotechnology as the manipulation of matter with at least one dimension sized from 1 to 100 nanometers. This definition reflects the fact that quantum mechanical effects are important at this quantum-realm scale, and so the definition shifted from a particular technological goal to a research category inclusive of all types of research and technologies that deal with the special properties of matter which occur below the given size threshold.

Applications
Air remediation using nanosize semiconductor photocatalyst
Some materials such as titanium dioxide (TiO2), zinc oxide (ZnO), iron (III) oxide (Fe2O3) and tungsten oxide (WO3) may serve as photo catalysts. This photo catalyst has many uses, including as a white pigment which gives colour to paper and paint, ultraviolet light-absorbing material on the sunscreen, protective antimicrobials and automatic cleaners. In relation to the environment and water remediation, photo catalysts are able to oxidize organic pollutants into nontoxic materials.
In general, the use of TiO2 in advanced methods of photochemical oxidation for the remediation of water is due to its low levels of toxicity, high photoconductivity, high photo stability, and that it is an easily available and inexpensive material. Figure 1 shows a nanosize semiconductor photocatalyst.

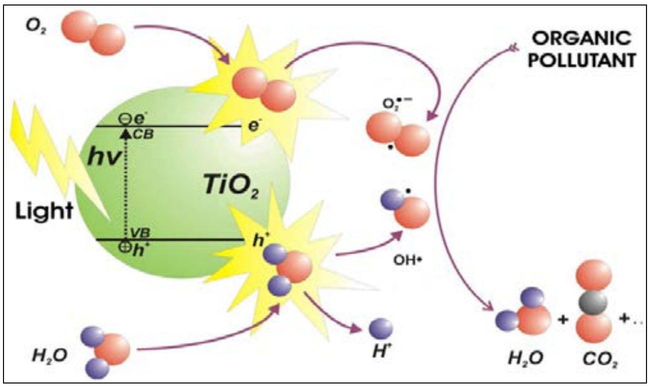

Fig 1

Using the principle of a semiconductor, organic molecules can be oxidized by light. At a sufficient level of light, the charge transfer process will occur from the valence band to the conduction band causing the surrounding substance to be oxidized. Through the development of nanotechnology, semiconductor photocatalysts are modified in terms of reactivity and selectivity.One semiconductor photocatalyst has been applied for water remediation under the United States Environmental Protection Agent (US EPA) SITE program 19. The photocatalyst is able to remove contaminants from ground water containing 1,1-dichloroethane, cis-1,2-dischloroethane, 1,1,1-threechloroehtane, xylenes and toluene. In a pilot scale, it was also found that TiO2 was capable of eliminating benzene, toluene, ethylbenzene and xylene (BTEX) contents from groundwater. The surface of TiO2 catalysts which can be developed using nanotubes is shown to be more effective at eliminating the material in comparison with the usual structure of TiO2 powder 21. In addition to the use of TiO2, which is already commonly used in industry, ZnO photocatalysts are currently being developed as well. As a concept, ZnO is expected to have two functions, namely to detect and remediate contaminants. During laboratory experiments, a ZnO photocatalyst was successfully used to detect and eliminate 4-chlorocatechol 22.

Removal of volatile organic compounds from air

In addition to nitrogen oxides and sulfur oxides, many chemicals are formed by atmospheric reactions, such as soot 39, nitrous acid 40, polyaromatic compounds 41–43 and volatile organic compounds (VOCs). Clean air regulations have become increasingly stringent as those particles are potentially damaging to human health. Most modern air purification systems are based on photocatalysts, adsorbents such as activated carbon or ozonolysis. However, conventional systems are not very good at getting rid of organic pollutants at room temperature. Japanese researchers have now developed a new material that is very effective for removing VOCs, nitrogen and sulfur oxides from air at room temperature 44. It involves highly porous manganese oxide with gold nanoparticles that are grown into it.

To prove the effectiveness of this catalyst, Sinha and Suzuki 44 performed tests using three major components of organic indoor air pollutants: acetaldehyde, toluene and hexane. The results showed that all three pollutants in the air were very effectively removed and degraded by this catalyst compared with the conventional catalyst systems. One reason for the success is porous manganese oxide which has a much larger surface area than all previously known compounds. This large surface area causes better adsorption of volatile molecules. In addition, the adsorbed pollutants are decomposed effectively. Degradation on the surface is very effective because of the presence of free radicals. The presence of gold nanoparticles helps to reduce the barrier of radical formation that is usually very high. This process has opened the possibility for other nano-metal components to be applied.

Isopropyl alcohol adsorption

In addition to being used as a solvent, isopropyl alcohol (IPA) is often used in the manufacture of optoelectronic devices and semiconductors. Owing to the lack of air pollution control, IPA vapour is released into the atmosphere without any treatment. The release of IPA vapour can cause harm to human health as it is irritating and carcinogenic.Hsu and Lu 45 conducted a study of SWNTs oxidized by a solution of HNO3 and NaClO that was used as an adsorbent to adsorb IPA vapour. Physicochemical properties of SWNTs were improved after being oxidized by HCl, HNO3 and NaClO solution leading to a pore size reduction whereas the surface area of micro- pores, the surface of functional groups and the active surface of the base increased. Consequently, SWCNTs are able to absorb more IPA vapour from the air stream. SWNTs/NaClO had the best performance to adsorb IPA followed by SWNTs/HNO3.

Nanotechnology for Sensors and Detectors of Pollution

It has long been understood that long-term exposure to particulate matter and heavy metal pollution is a significant leading factor in causing health problems in the form of heart conditions, lung cancer and other problems. In urban areas, particulate sizes are typically in the range of 100–300 nm in diameter 46 while heavy metals could be found in various ranges of concentration. In addition, heavy metals cannot be broken down by microorganisms (i.e. they are not biodegradable). A high degree of difficulty in the recovery of heavy-metal-contaminated land raises pressure in developing onsite sensors that can detect heavy metal ions before their concentration reaches dangerous levels 48. Figure 2 shows sensors and detectors of pollution.

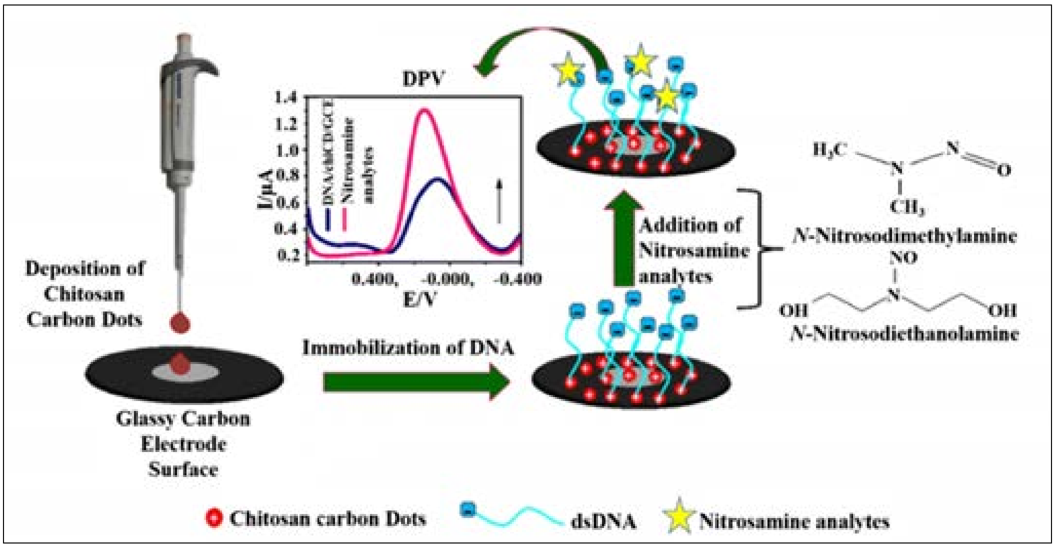

Fig 2

Rapid and precise sensors able to detect pollutants at the molecular level may enhance the human ability to protect the sustainability of human health and the environment. Large increases in process control, ecosystem monitoring and environmental-based decision-making can occur if the available contaminant detection technology is more sensitive and less expensive. One of the desired technologies is a continuous monitoring tool that is able to provide information, especially information of pollutants in very short analysis time 47. A nanocontact sensor has been developed and this sensor has the potential to detect some metal ions without preconcentration required. In particular, this sensor is suitable for the onsite detection of heavy metal ions, including radioactive elements. Nanocontact sensors can be made in miniature size and automatic mode so that they are easy to use onsite or taken to the land. In addition, the use of these sensors is also inexpensive (cost-effective) because they ate made with conventional microelectronics manufacturing equipment using simple electrochemical techniques 49.

Nanotechnology-Based Biosensors

Nanotechnology-based biosensors that employ biomaterials have been developed 50. Liu *et al*. 51 have found a way to increase the nanoprobe sensitivity of the test strips which will allow the creation of a portable biosensor. Portable biosensors are able to quickly detect people who have been exposed to chemicals. In the Pacific Northwest National Laboratory (PNNL), Wang *et al*. 52 produced a nanoparticle 'label' that is able to enhance the ability of sensors to detect and interpret biomarker signals. The approach is based on the electrochemical immunoassay method. This method involves the use of specific antibodies to attract the biomarkers of disease. The provision of 'label' on the second antibody with a nanoparticle amplifies the biomarker signals.

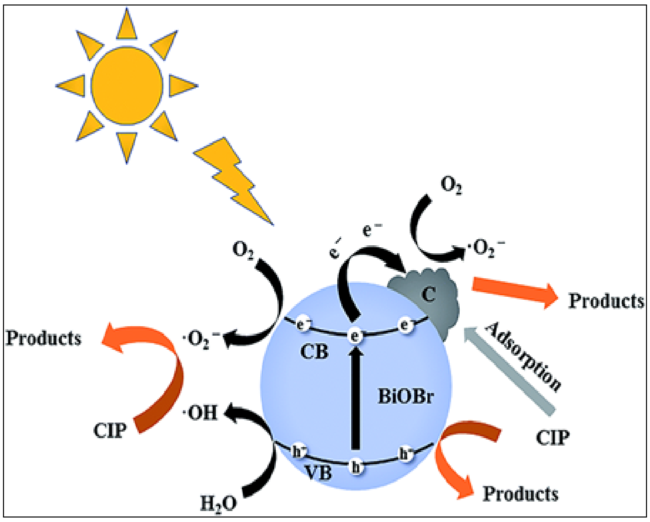

Fig 3

Nanowires and nanotube-based sensors

Nanowires or nanotubes offer tremendous capabilities as materials for chemical and biological sensors 54. SWNTs have shown a faster response and higher sensitivity than the conventional probes that are currently used in the detection of gas molecules such as NO2 and NH3. In this case, gas molecules are directly bonded to the surface of SWNTs and influencing the electrical resistance of the sensor. Another advantage of SWNTs as sensors is the ability to achieve high sensing sensitivity at room temperature. In general, conventional solid sensors are operated at temperatures of 200–600°C. Although SWNTs are highly promising alternatives to nanosensors, SWNTs also have some limitations. First, the current method of the SWNT synthesis produces a mixture of metallic and semiconducting nanotubes, and nanotube is the only material that can be used as a sensor. Second, in order to detect various chemical and biological species, the surface of nanotubes needs to be modified with a specific functional chemical group. Moreover, the flexibility of the chemical detection relies of the type of functional group doped on the nanotube surface. In contrast, some nano-semiconductors such as Si nanowires (SiNWs) do not have this Kind of limitation. Boron-doped SiNWs have been used for protein and antibody detection in real-time electrical detection. The small size and the ability of semiconductor nanowire to detect many types of analytes in real-time sensors can be used to develop detectors of chemical and biological agents that are pathogenic in the air, water and food.

Cantilever Sensors

A cantilever sensor is a device made of a silicon cantilever array coated with nano-coating that is sensitive to specific pollutants 55. A cantilever is typically 10–500 µm in length, but it has a thickness of less than several micrometres. Interactions between pollutants with the nano-coated cantilever array because the array to bend as a result of changes in surface pressure. The small bending will be measured by a laser beam which can result in the quantitative measurement of the detected mass of pollutants. Cantilever sensors have been developed to detect VOCs, heavy metals, pesticides and harmful bacteria such as salmonella. Figure 3 shows a schematic diagram of cantilever-based biosensors.

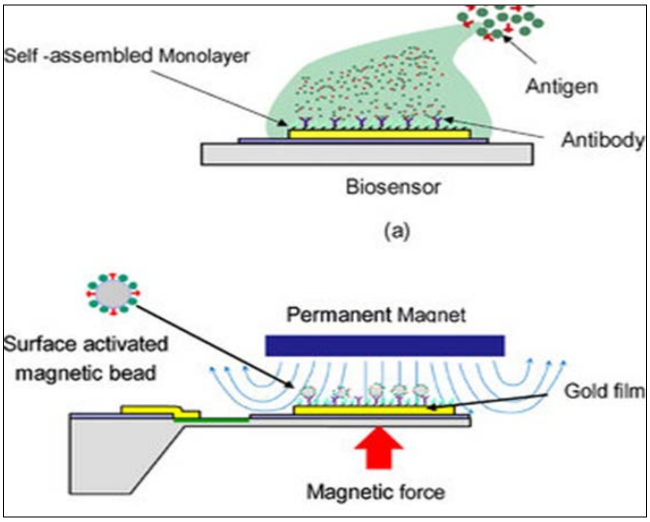

Fig 4

Nanotechnology for Pollution Prevention

Prevention of pollution refers to a reduction in pollution sources and other practices that utilize raw materials, energy, utilities and other resources effectively in order to reduce or eliminate waste generation. Nanotechnology offers many innovative strategies to reduce waste production in various processes such as improving manufacturing processes, reducing hazardous chemicals, reducing greenhouse gas emissions and reducing the use of biodegradable plastics. The discussion below is just a few of many approaches that can be done to reduce environmental pollution. Nanotechnology is actively involved in this sector, both for producing advanced materials that have low pollution levels and improving production efficiency in industrial processes (e.g. nanocatalysts).

Environmentally Friendly Materials (Environmentally Compliant Materials)

The application of nanotechnology is able to create an environmentally friendly substance or material, replacing widely used toxic materials. For example, liquid crystalline display (LCD) computer screens that are more energy efficient and less toxic have largely replaced the screen cathode ray tubes (CRTs) which contain many toxic materials. LCDs also do not contain lead and consume less energy compared with CRT computer screens. The use of CNTs in computer screens may further reduce the impact on the environment by eliminating toxic heavy metals, reducing material and energy needs drastically, as well as improving performance according to customer needs. The example of display technology that uses CNTs is field emission displays (FEDs).

In addition, the application of nanotechnology in composite materials has the potential to produce a material with better mechanical and other properties. This is because nanotechnology has the ability to produce structures that are lighter and smaller without degrading the quality of existing properties. The advantage of this technology is the increased robustness, reduced system costs and whole replacement, as well as reduced environmental impact. Examples of environmentally friendly materials that can be produced using nanotechnology are: biodegradable plastics made from polymers with a molecular structure that is easy to decompose; nanocrystalline composite materials that are not toxic to replace the lithium–graphite electrodes in rechargeable batteries; and glass with self-cleaning ability. An example of a glass product with self-cleaning capability that has been made widely available in the market is Activ^{TM} Glass, a commercial product from Pilkington.

Conclusion

Nanotechnology has been developed to achieve the purpose of maintaining environmental sustainability. In this case, environmental sustainability is not limited to human environmental issues, but also human health problems. Technologies that have been developed include technologies which can enhance and improve the conventional technological capabilities and new technologies which replace the conventional technologies. The application of nanotechnology in the environmental field is not limited to the conditions where environmental contamination has occurred. Nanotechnology can also be applied to prevent the creation of pollution. Its applications include the synthesis of green materials, coatings and biocides to prevent the release of hazardous substances into the environment.

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