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Nanosensors: Applications and Challenges

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Abstract: ***This paper discusses nanosensor developments and applications. It illustrates progress in environmental field by considering a number of applications of nanosensors and their products. This paper shows that the innovative biosensors, gas and chemical sensors are having a growing impact in the present scenario. Many of the US-based companies have frequently raised significant finance and subsequent funds from government agencies involved with defence, homeland security and healthcare. Many of the world's largest, high-technology companies are pursuing nanosensor developments. This paper briefly discusses nanosensor applications and provides an insight into the present day state of nanosensor commercialization.***

Keywords: NanoSensors, Nano-Wires, Nanotubes, Applications

1. Introduction

Nanotechnology deals with the design, synthesis, analysis, characterization, and application of materials and devices whose smallest functional unit in at least one dimension is on the nanometer scale. Materials and devices engineered at the nanometer scale need controlled manipulation of individual molecules and atoms in how they are arranged to form the bulk macroscopic substrate. Nanotechnology is a branch of science that deals with manipulating matter on the atomic scale. It is so called because this field deals with engineering on the scale of a billionth of a meter, also known as a nanometer. One of the early applications of nanotechnology is in the field of nanosensors [1-4].

Sensors are the devices that can detect and sense certain signals. The signals can be biomedical, optical, electronic, electrical, physical or mechanical. A sensor can be defined as a transducer that converts a measurement into a signal that carries information while nanosensors are the tiny sensors reduced in size from few nanometers to 10 to 100 nanometers. They make use of the unique properties of nanomaterials and nanoparticles to detect and measure materials and components in the nano scale. For example, nanosensors can detect chemical compounds in concentrations as low as one part per billion [5,6] or the presence of different infectious agents such as virus or harmful bacteria[7,8].

Different types of nanosensors like Carbon nanotube based sensors work by monitoring electrical changes in the sensor materials. For example if a molecule of nitrogen dioxide (NO_2) is present it will strip an electron from the nanotube, which causes the nanotube to be less conductive. If ammonia (NO_3) is present it reacts with water vapour and donates an electron to the carbon nanotube, making it more conductive. By treating the nanotubes with various coating materials, they can be made sensitive to certain molecules and immune to others.

Like chemical nanosensors, mechanical nanosensors also measure electrical changes. Car airbags depend upon MEMS systems. The nanosensors used in MEMS systems monitors changes in capacitance. These systems have a miniscule weighted shaft attached to a capacitor. The shaft bends with changes in acceleration which is measured as changes in capacitance. Recent advances in ionic polymer conductor composites (IPCC) and ionic polymer metal composites (IPMC) as biomimetic distributed nanosensors, nanoactuators, nanotransducers and artificial muscles have taken over the current scenario. Technologies such as nano-electromechanical system, nano-opto-electromechanical system, nanophotonics and the combination of nanotechnology with microtechnology offer prospects to yield sensors for a wide range of chemical, biochemical and physical variables in applications which include healthcare, defence and homeland security, environmental monitoring and light sensing and imaging.

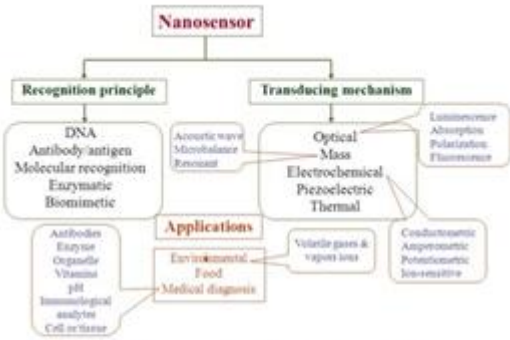

Figure 1: Representation of Recognition Process and application of nanpsensors

2. Nanosensors Applications

Nanosensors have multiple applications in the environmental field. One of the major concern of environmental agencies is the ability to sense for harmful chemicals and biological agents that are present in the air and water. Nanosensors will innovate the ways with which the quality of air and water is measured due to their size, thickness, and accuracy of measurements. An example of this is detecting mercury, zinc or harmful materials in any medium (such as air and water) through the use of dandelion-like Au/polyaniline (PANI) nanoparticles in conjunction with surface-enhanced Raman spectroscopy (SERS) nanosensors[9].

A new approach to air sampling is to measure air quality, particularly for pollutants, with the help of nanosensors. Nanosensors have already been used to measure solar irradiance, aerosol cloud interactions, climate forcing, and other biogeochemical cycles of East Asia and the Pacific region. Such instrumentation has been useful in tracking air pollution in Beijing during the summer Olympic Games [10]. Nanosensors have also been used by an Israeli start-up company that will monitor and analyze emissions from vehicle engines in order to meet the ever increasing strict standards of American and European Environmental agencies (Brinn, 2006).

Nanomaterials in one dimension such as nanowires and nanotubes can be used as nanosensors, as compared to bulk planar devices. They can function both as transducers and wires to transmit the signal. Their small size can enable multiplexing of individual sensor unit in a small device.

- **Semiconductor nanowire used as detection elements in Sensors :** These sensors are capable of detecting of chemical vapors. When molecules bond to nanowires made from semiconducting materials such as zinc oxide, the conductance of the wire changes. The amount that the conductance changes and in which direction depends on the molecule bonded to the nanowire.
- **Semiconducting carbon nanotubes:** To detect chemical vapors, you can first functionalize carbon nanotubes by bonding them with molecules of a metal, such as gold. Molecules of chemicals then bond to the metal, changing the conductance of the carbon nanotube.
- **Carbon nanotubes and nanowires that detect bacteria or viruses:** These materials can be used also to sense bacteria or viruses. First you functionalize the carbon nanotubes by attaching an antibody to them. When the matching bacteria or virus bonds to an antibody, the conductance of the nanotube changes. One promising application of this technique is checking for bacteria in hospitals. If hospital personnel can spot contaminating bacteria, they may be able to reduce the number of patients who develop complications such as staph infections.
- **Nanocantilevers:** These devices are being used to develop sensors that can detect single molecules. These sensors take advantage of the fact that the nanocantilever oscillates at a resonance frequency that changes if a molecule lands on the cantilever, changing its weight.

Another use of nanoparticles is in the detection of volatile organic compounds (VOCs). Researchers have found that by embedding metal nanoparticles made of substances such as gold in a polymer film, you create a VOC nanosensor [11].

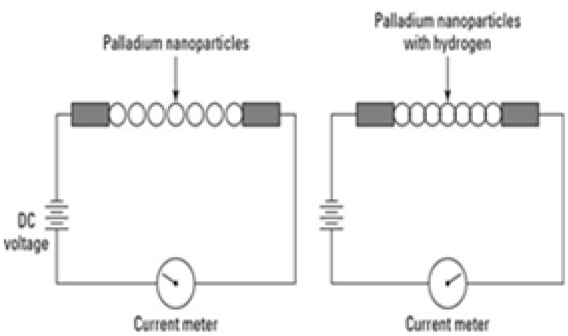

Figure 2: VOC Nanosensors

Sensors are also being developed to detect molecules that indicate that a particular disease is present in a blood sample.

Nanosensors can also be used in monitoring water distribution and water quality. Due to the loss of water from leaky pipes and mains, the Environmental Protection Agency has designed an innovative way to improve the water supply infrastructure via a highly cost-effective monitoring system. This “Smart Pipe” prototype is built from a multisensor array that will monitor water flow and quality using nanosensors. It will allow for real-time monitoring of flow rates, pipe pressures, stagnant points, slow flow sections, pipe leakage, backflow, and water quality without altering flow conditions in the already-existing infrastructure [12].

These are just some applications of nanosensors that are used in the environmental field. There are numerous others applications in sensing environmental disturbances. Nanomaterials-based sensors have several benefits in sensitivity and specificity, offers advantages in cost and response time, over sensors made from traditional materials. Nanosensors can have increased specificity because they operate at a similar scale as natural biological processes. Low cost makes nanosensors suitable for high-throughput applications. Nanosensors provide real-time monitoring compared to traditional detection methods such as chromatography and spectroscopy which take long time to obtain results and often require investment in capital costs as well as time for sample preparation[13].

Challenges

There are several challenges for nanosensors, including drift, developing reproducible calibration methods, applying preconcentration and separation methods. Also integrating the nanosensor with other elements of a sensor package in a reliable manner is a big challenge. Nanosensors being a relatively new technology, limits its application in biological systems. Some nanosensors may impact cell metabolism and homeostasis, changing cellular molecular profiles and making it difficult to separate sensor-induced artifacts from fundamental biological phenomena.

3. Conclusion

The purpose of this paper is to provide a technical review of recent nanosensor research. It considers a range of emerging nanosensing technologies and some specific areas of application. This paper shows that nanosensor technology is developing rapidly and is the subject of a global research effort. An increasing amounts of research has gone into nanosensors, whereby modern nanosensors have been developed for many applications. Nanoscience has much potential for applications in the defense and military sector, healthcare, food, environment, and agriculture. However, the primary efforts surrounding nanosensors largely remain in research and development. Some nanosensors in development for defense applications include nanosensors for the detection of explosives or toxic gases.

Surprisingly, some of the most challenging aspects in creating nanosensors for defense and military use are political in nature, rather than technical. There are not well defined regulations on nanosensor testing or applications in the sensor industry. Also a high degree of precision is needed to manufacture nanosensors, due to their small size and sensitivity to different synthesis techniques, which creates additional technical challenges to be overcome.

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