Biosensors in Nanotechnology

A B S T R A C T

Nanotechnology is playing an increasingly important role in the development of biosensors. The sensitivity and performance of biosensors is being improved by using nanomaterials for their construction. The use of these nanomaterials has allowed the introduction of many new signal transduction technologies in biosensors. Portable instruments capable of analyzing multiple components are becoming available. This work reviews the status of the various nanostructure-based biosensors. Biosensors, developed by integrating the biological and physicochemical/mechanical properties (of transducers), which can have enormous implication in healthcare, food, agriculture and biodefence. Nanobiosensors, which exploit some fundamental nanoscopic effect in order to detect a specific bio-molecular interaction, have now been developed to a point where it is possible to determine in what cases their inherent advantages over traditional techniques (such as nucleic acid microarrays) more than offset the added complexity and cost involved constructing and assembling the devices.

1. Introduction

Nanotechnology involves the study, manipulation, creation and use of materials, devices and systems typically with dimensions smaller than 100 nm. Nanotechnology is playing an increasingly important role in the development of biosensors. Sensitivity and other attributes of biosensors can be improved by using nanomaterials in their construction. Nanomaterials, or matrices with at least one of their dimensions ranging in scale from 1 to 100 nm, display unique physical and chemical features because of effects such as the quantum size effect, mini size effect, surface effect and macro-quantum tunnel effect. Use of nanomaterials in biosensors allows the use of many new signal transduction technologies in their manufacture. Because of their submicron size, nanosensors, nanoprobes and other nanosystems are revolutionizing the fields of chemical and biological analysis, to enable rapid analysis of multiple substances in vivo. Here we review the major aspects of the nanotechnology-based biosensors.

Some microorganisms cause diseases that have disastrous effects on humans and can cause widespread damage. The ability of some microorganisms to evolve rapidly allows them to adapt and grow under stressful conditions. With this property of microorganisms and the advances in genetic engineering technology, the use of these harmful microbes to cause intentional damage to the life and property cannot be ruled out. Under such a scenario the control measures that we currently possess, seemtime-consuming and inappropriate. The best emerging technology to counteract this problem is the use of biosensors that provide us with a tool to rapidly detect the presence and amount of microorganisms in any given environment. International Union of Pure and Applied Chemistry **(IUPAC) defines biosensor as**

"*A device that uses specific biochemical reactions mediated by isolated enzymes, immune-systems, tissues, organelles or whole cells to detect chemical compounds usually by electrical, thermal or optical signals*".

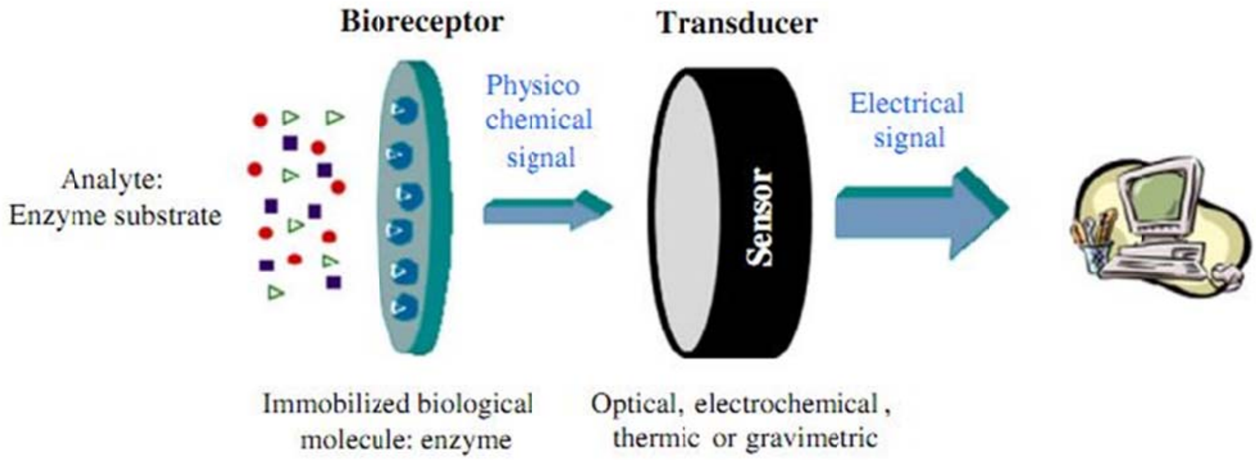

Fig. 1. Scheme of a biosensor.

Basic Characteristics of a Biosensor

1. LINEARITY: Maximum linear value of the sensor calibration curve. Linearity of the sensor must be high for the detection of high substrate concentration.

2. SENSITIVITY: The value of the electrode response per substrate concentration.

3. SELECTIVITY: Interference of chemicals must be minimized for obtaining the correct result.

4. RESPONSE TIME: The necessary time for having 95% of the response.

In recent years, with the development of nanotechnology, a lot of novel nanomaterials are being fabricated, their novel properties are being gradually discovered, and the applications of nanomaterials in biosensors have also advanced greatly. For example, nanomaterials-based biosensors, which represent the integration of material science, molecular engineering, chemistry and biotechnology, can markedly improve the sensitivity and specificity of biomolecule detection, hold the capability of detecting or manipulating atoms and molecules, and have great potential in applications such as biomolecular recognition, pathogenic diagnosis and environment monitoring. Here we review some of the main advances in this field over the past few years, explore the application prospects, and discuss the issues, approaches, and challenges, with the aim of stimulating a broader interest in developing nanomaterials-based biosensor technology.

2. Different types of Biosensors using Nanotechnology

The nanotechnology products can be classified into three categories based on the number of dimensions "pushed" to the nanometer scale:

- Thin films, such as coatings of implants for biocompatible purposes, anticoagulant coatings of stents, and coatings of pills and other therapeutic agents, have only one dimension pushed to the scale of few tens or hundreds of nanometers, while the other two dimensions can still extend up to millimeters;
- NMs, such as carbon nanotubes (CNTs), silicon nanowires, nanorods, and fibers, have two dimensions pushed to the nanometer scale; and
- NMs, such as quantum dots, gold, magnetic and polymeric nanoparticles, and liposomes, have all the three dimensions pushed to the nanometer scale.

Various kinds of nanomaterials, such as gold nanoparticles, carbon nanotubes (CNTs), magnetic nanoparticles and quantum dots, are being gradually applied to biosensors because of their unique physical, chemical, mechanical, magnetic and optical properties, and markedly enhance the sensitivity and specificity of detection.

During the last decade, NMs have been widely used in the fields of in vitro diagnostics, imaging, and therapeutics. They have enabled the simultaneous multiplex detection of many disease biomarkers and the diagnosis of diseases at a very early stage. They have also opened the possibility to explore the detection of ultra-trace concentrations of target analytes and have led to ultra-sensitive, rapid, and cost-effective assays requiring mini-mum sample volume. The NMs are being seen as the most promising candidates for the development of high-throughput protein arrays. The size, shape, composition, structure, and other physical/chemical properties of NMs can be tailored in order to produce the desired materials with specific absorptive, emissive, and light-scattering properties. The bioconjugated NPs have also been employed for signal amplification in assays and other biomolecular recognition events. However, the most promising application of nanotechnology will be in the field of point-of-care diagnostics, which will enable the primary-care physician and patients to perform assays at their respective settings. The long-term stability of NPs in addition to their brightness and sharp bandwidth will be of tremendous significance to devise new methods for ultra-sensitive biomarker discovery, validation, and clinical use. The gold NPs (GNPs) tagged with short segments of DNA can be employed to detect the genetic sequence in a sample, while the use of nanostructures (nanopores, nanowires, nanopillars, and nanogaps)-based devices can further provide the single-molecule detection capability. The identification and characterization of single-stranded genomic DNA or RNA without amplification has already been shown. NMs such as QDs and NPs are good imaging agents due to their enhanced performance and functionality. They can be targeted to the specific disease sites in the body by conjugating them to biomarker-specific vectors. The NMs-based imaging agents provide additional information pertaining to the physiology and function apart from the anatomical information, which enables more accurate and early disease diagnosis, such as the highly sensitive detection of early stage cancer, thereby leading to better therapy. Similarly, the effectiveness of treatments can be monitored more rapidly andaccurately. The plasmonic NPs and drug delivery will be employed for targeted therapeutics, where the first impacts will certainly be in treating cancer. The use of NPs improves the bioavailability and pharmacokinetics of therapeutics. They take the drugs directly to the target sites of disease in the body by avoiding exposure of healthy tissues, which increases the availability of a drug at the target site and reduces the treatment dose. These developments in nanotechnology will be highly beneficial in shifting the late-stage diagnosis (involving expensive and socially burdensome treatment) to early-stage diagnosis (relatively less expensive and less invasive). The most widely used NMs in NBBD are described below.

2.1 Carbon NanoTubes (CNTs)

During the past decade, CNTs have been one of the most extensively used NMs in biosensors, diagnostics, tissue engineering, cell tracking and labeling, and delivery of drugs and biomolecules. They are hollow cylindrical tubes composed of one, two, or several concentric graphite layers capped by fullerenic hemispheres, which are referred to as single-, double-, and multi-walled CNTs respectively. They have unique structures, excellent electri cal and mechanical properties, high thermal conductivity high chemical stability, remarkable electrocatalytic activity minimal surface fouling, low overvoltage, and high aspect ratio (surface to volume). CNTs-based biosensors and diagnostics have been employed for the highly sensitive detection of analytes in healthcare, industries, environmental monitoring, and food quality analysis. They have been predominantly used in electrochemical sensing, mainly for glucose monitoring but also for the detection of fructose galactose, neurotransmitters, neurochemicals, amino acids immunoglobulin, albumin, streptavidin, insulin, human chorionic gonadotropin, C-reactive protein, cancer biomarkers cells, microorganisms, DNA, and other biomolecules.

2.2 Graphene

Graphene, an atomically thin layer of sp2 -hybridized carbon is another most extensively used NM for diagnostics and biosensors in the last few years due to its interesting and exciting properties, such as high mechanical strength, high thermal conductivity, high elasticity, tunable optical properties, tunable band gap, very high room temperature electron mobility, and demonstration of the room temperature quantum Hall effect. It is a transparent material with a very low production cost and low environmental impact. It has been extensively employed in electrochemical, impedance, fluorescence, and electro-chemiluminescence biosensors for the detection of a wide range of analytes such as glucose, cytochrome c, NADH, hemoglobin, cholesterol, ascorbic acid, dopamine, uric acid, hydrogen peroxide, horseradish peroxidase, catechol, DNA, heavy metal ions, and gases.

Source:
http://nptel.ac.in/courses/118107015/16