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Nano Biosensors

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ABSTRACT

Nano biosensors have emerged as powerful analytical tools at the forefront of biosensing technology, offering unparalleled sensitivity and specificity in detecting biochemical substances at nanoscales. Comprising a bio-receptor sensing element and a transducer component, nano biosensors convert biological and biochemical signals into quantifiable physical signals using optical, electronic, thermal, or magnetic methods. The effectiveness of these sensors is contingent upon the precise attachment of the biological component to the transducer, ensuring stability and selectivity in analyte detection. By incorporating nanomaterials, nano biosensors enhance stability, sensitivity, and catalytic activity, revolutionizing biosensing capabilities. This article elucidates the working principles, classification, and applications of nano biosensors, emphasizing their pivotal role in diverse fields such as agriculture and biomedical diagnostics. From detecting soil pathogens to diagnosing severe diseases like cancer and diabetes, nano biosensors offer unprecedented opportunities for precise and efficient detection, marking a significant advancement in biosensor technology.

INTRODUCTION

A nano biosensor is an analytical tool that measures or probes biochemical substances at nanoscales. It typically consists of a "bio-receptor" sensing element that interacts with the intended analyte to produce a detectable physical signal that is then transformed by a transducer component. This allows biological and biochemical signals to be converted and quantified using optical, electronic, thermal, or magnetic methods. A sensor is characterized as a device that can both identify and quantify the presence of an analyte in a sample. The sensor is made up of a transducer, a readout system, and a detection system known as a receptor. The acceptor, which is a biological component in biosensors, is mounted on the converter in several ways. The way the biological component, or bioreceptor layer, is attached to the transducer is a major factor in biosensor performance. The primary objective is to preserve (and even enhance) the biological component's stability while forming a strong bond between it and the sensory surface (converter). The sensor's selectivity, which shows how well the device can separate the analyte from other substances in the sample, is a crucial component. The sensor's ability to detect and measure analyte with the least amount of interference from other materials in the sample increases with its selectivity. The second crucial component is sensitivity. High sensitivity indicates that a discernible shift in the sensor's output signal can be seen even with small adjustments to the analyte concentration (Huang *et. al.,* 2021). By adding nanomaterials to the structure of biosensors, the level of stability needed for biomaterials is increased, which improves sensitivity, catalysis, low-potential reaction potential, and the speed at which electrons move from the active reaction centre to the electrode surface. One crucial factor in the creation of third-generation biosensors is the elimination of chemical intermediates in electron transfer by the use of nanomaterials in biosensor structures. Because of their enormous specific surface area and high free surface energy, nanoparticles play a significant role in the surface adsorption of biomolecules.

WORKING PRINCIPLE

The biosensor consists of three main parts:

1. Biological recognition element: It is a biologically derived material that interacts with the analyte under study by binding to it or recognizing it. It can be a tissue, microorganisms, organelles, cell receptors, enzymes, antibodies, nucleic acids.

2. Transducer or detector element: The transducer, also known as the detecting element, changes the signal produced by the analyte's interaction with the biological element into one that is easier to measure and quantify. It functions through optical, piezoelectric, electrochemical, and other physicochemical processes.

3. Signal processing electronics: Responsible for the display of the results in a user-friendly way. The biological layer is accountable for the precise interaction with the analyte, while the transducer aids in translating the resulting information into a measurable effect.

CLASSIFICATION

A biosensor has a biological layer that is sensitive and can be connected to a transducer in a number of physical and chemical methods. The transducer converts the frequency and pace of interaction between the analyte and the receptor into a detectable physical phenomenon. Biosensors can be categorized based on the kind of conversion mechanism that is employed.

- **Optical techniques**

The interaction between analyte and receptor can induce alterations in optical characteristics, including changes in absorption and emission intensity or frequency, resonance frequency of surface electrons, refractive angle, and more. Biosensors utilize diverse spectroscopic techniques to capture various spectrochemical properties, encompassing absorption, fluorescence, phosphorescence, Raman scattering, surface electron resonance, refraction, diffusion, and others.

- **Electrochemical techniques**

Electrochemical detection serves as an alternative conversion mechanism utilized in biosensors. These techniques can function autonomously or alongside optical detection methods like the notably sensitive fluorescence optical technique. Given that numerous analytes lack inherent fluorescence and the labelling process with fluorescent markers is often challenging, electrochemical conversion proves highly advantageous. By amalgamating the sensitivity of electrochemical measurements with the specificity offered by the bioreceptor, a detection threshold comparable to that of fluorescent biosensors is achieved.

- **Sensitive techniques to mass**

Another method of conversion employed in biosensors involves the measurement of slight mass variations resulting from the interaction between analyte and bioreceptor. This approach relies on piezoelectric crystals, which exhibit oscillations at a specific frequency under the influence of an electrical signal. The oscillation frequency is contingent upon both the electrical frequency applied and the mass of the crystal. Consequently, when the mass increases due to chemical bonding, the oscillation frequency of the crystal alters, and this change is electrically quantified to assess the added mass. Another mass-sensitive technique involves analyzing the deflection of cantilevers caused by the interaction between receptor and ligand.

NANO-BIOSENSORS IN AGRICULTURE

Presently, nano biosensors are emerging as promising alternatives to conventional biosensors, offering distinct properties and advantages. They demonstrate heightened sensitivity, efficiency, and specificity, coupled with improved detection capabilities. Nano biosensors hold significant potential across various domains, including agriculture, bioprocess control, bio-defense, and food quality control. These include evaluation of Disease and Soil Quality, for storage of seeds, detection of contaminants and other molecules, efficient detection of DNA and protein etc. Using nano sensors, one can detect soil diseases brought on by bacteria, viruses, and fungi, among other microorganisms found in soil. By quantifying the amount of oxygen that good and bad microbes use while they respire in soil, nano sensors are able to identify soil diseases (Ghaffar *et. al.*, 2020).

BIOMEDICAL & DIAGNOSTIC APPLICATIONS OF NANO BIOSENSORS

Nano biosensors have garnered considerable attention in research, particularly for their applications in detecting severe diseases such as cancer and diabetes. Assessing telomerase activity, crucial in cancer diagnosis, can be expedited through nano biosensors, notably those employing magnetic nanoparticles. Similarly, for diabetes detection and monitoring, traditional methods often lack sensitivity and efficiency. Nanorobot sensors offer a solution by providing proteomic-based data to identify biochemical changes linked with hyperglycemia, facilitating prompt and precise diabetes treatment. Additionally, nano biosensors enable the detection of microbial pathogens and their toxins in patients, marking a significant advancement in medical diagnostics.

Pathogens can also be detected indirectly by evaluating their metabolic activity. This can be done by monitoring the rate at which they consume nutrients in a solution, where nano-sensors can measure the microbial pathogen's metabolic activity. Numerous nano-biosensors have been designed to detect pathogens such as *Mycobacterium avium* subspecies paratuberculosis (MAP), and pathogenic bacterial toxins including botulinum toxin, as well as enterotoxins produced by *Staphylococcus aureus* and *Escherichia coli* (Rai *et. al.,* 2012).

CONCLUSION

Nano biosensors play a crucial role in detecting and quantifying analytes in various samples. A sensor comprises a receptor for detecting the analyte, a transducer for converting this detection into a measurable signal, and a readout system. The effectiveness of biosensors heavily relies on the precise and stable integration of the biological element with the transducer. Key attributes of sensors include selectivity and sensitivity, which ensure accurate detection with minimal interference and significant response to small changes in analyte concentration. The incorporation of nanostructures into biosensors has led to significant advancements. Nanomaterials enhance the stability of biological components, increase sensitivity, catalyze reactions, enable low-potential reactions, and facilitate rapid electron transfer, simplifying the overall device structure and improving performance. Nano biosensors are particularly promising in agriculture and biomedical diagnostics. In agriculture, they enable efficient detection of soil quality, contaminants, DNA, and proteins. They also facilitate the identification of soil diseases by measuring the metabolic activity of microorganisms. In biomedical applications, nano biosensors enhance the detection of severe diseases like cancer and diabetes by offering high sensitivity and specificity. They also allow for the detection of microbial pathogens and their toxins, representing a significant advancement in medical diagnostics. The development and application of nano biosensors continue to revolutionize the fields of agriculture, bioprocess control, bio-defense, food quality control, and medical diagnostics, providing more efficient, sensitive, and specific detection methods.

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