Biosensors - Classification, Applications, New Trends and Technical Challenges

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Abstract— Since biosensors offer considerably higher performance in terms of selectivity and sensitivity than most of the other available diagnostic tools, they have become one of the most essential analytical tools in the present scenario. Due to their rapid growth and development, the importance of biological and biochemical processes in fields like medicine, biology and biotechnology have gained momentum much more than expected. Owing to their applications in diverse areas like the food industry, agricultural industry and environmental screening, there is a serious need to understand and resolve the existing technological challenges and explore new trends in the field of biosensors.

Key words: Biosensors, Classification

I. INTRODUCTION

Biosensor applications have widened considerably over the last few years majorly because of the ease of their applications to various areas. Before we get into the details of the growth of biosensor technologies and the technological challenges faced by them, we first need to be sure about what are biosensors?

As per the recently proposed IUPAC definition, "A biosensor is a self-contained integrated device which is capable of providing specific quantitative or semi-quantitative analytical information using a biological recognition element (biochemical receptor) which is in direct contact with a transducer element." Hence, each biosensor has a biological element that acts as a sensor and an electronic part which transducers and detects the signal. Therefore, a biosensor, as the name suggests, is an amalgam of biology, electro-chemistry, micro-electronics and physics.

The inception of biosensors was around 1962, when L.L.Clark, known as the father of biosensor concept, successfully worked his way out of an experiment where he measured the dissolved oxygen in the blood using Clark's oxygen electrode, which was the enzyme glucose oxidase entrapped in dialysis membrane. Later, this was used to measure blood sugar and content of urea in body fluids like blood and urine. And, as such biosensors emerged as highly reliable analytical devices which can perform fast and accurate analysis.

The two integral components that comprise of a biosensor include the following:

1) A biologically sensitive element, called the bioreceptor. It is immobilized to allow it's interaction with the analyte resulting in biochemical interaction.
2) A transduction element, which is used to convert the output of the reaction between the receptor and the analyte into a measurable electrical parameter like voltage, current, etc.

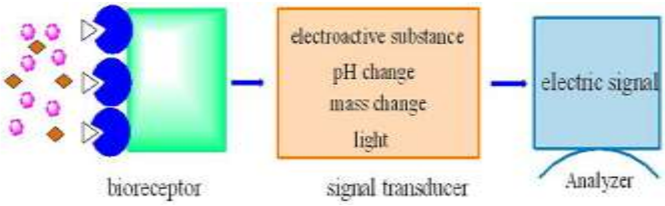

Fig. 1: Biosensor

A. Advantages

Advantages of biosensors, which have augmented their applications by a terrific amount over the past few years include:

1) They are quite specific in nature.
2) Their response time is quite small (usually less than a minute), which makes them quite rapid in their performance.
3) They are highly stable and sensitive
4) It is possible to have total control over these devices.
5) Can even gauge non-polar molecules, which are insensitive to almost all other devices.
6) They are indeed very practical and user-friendly analytical devices.

B. Bioreceptors

The bio-components commonly used to interact with the target analyte include:

– enzymes like lyases, hydrolases, isomerases.
– antibodies.
– nucleic acids.
– microbes/ cells.
– lectins(plant proteins which bind sugar moities).
– complex materials like organelles, tissues.
– organic molecules and membranes.

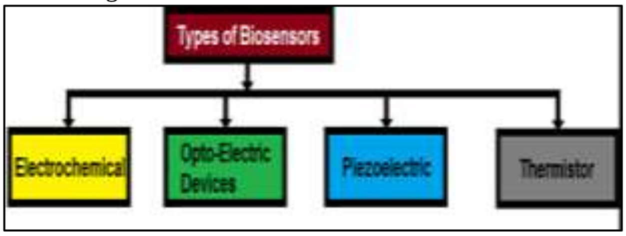

Fig. 2: Types

II. CLASSIFICATION OF BIOENSORS

Biosensors are categorized as per their principle of transduction and the bio-sensitive element used for the detection process. According to the method of transduction they are basically classified as electrochemical, optical, piezoelectric and calorimetric biosensors. Electrochemical biosensors are further grouped as amperometric, conductometric and potentiometric sensors.

A. Electrochemical Biosensors

The working principal of this group of biosensors is that the chemical reaction between the bio-molecule and the respective analyte produces or consumes ions or electrons. This reaction hence, produces an electrical signal which is proportional to the concentration of the analyte.The most common detection methods for electrochemical biosensors involve measurement of current, voltage, conductance, impedance or capacitance. On the basis of this electrochemical biosensors are further classified into three categories:

1) Amperometric Biosensors

They measure the change in current observed when the electroactive elements react biochemically, while a constant potential is being applied. The working electrode is usually a nobel metal or a screen printed layer coated with a bioelement. The conversion of electroactive elements at the electrode result in a change in current which is measured to give the intensity of the bio-signal.

2) Potentiometric Biosensors

These transducers involve the measurement of the potential difference the reference electrode and the working electrode under a condition of null or zero flow of current. This potential difference is found to be proportional to the logarithm of the concentration of the electrochemically active materials.

3) Conductometric Biosensors

The bioelectrochemical reaction under investigation often results in a considerable change in the conductivity or resistivity of the medium between the electrodes. This is forms the basis of conductometric transduction. Such sensors also known as impedimetric sensors, although are not as popular as the others, are often used to measure the salinity of marine environments.

B. Optical Biosensors

1) The reaction between the sensing element and the target often results in fluorescence, absorption or light scattering. These changes are then monitored using a basic system which consists of a light source, an optical fiber, a sensing element and a detector. When the reaction occurs, the output is a change in both physio-chemical and optical properties. To gauge these optical signals, the difference between the incident and the output light is measured, which is related to the concentration of the analyte. A few advantages of optical biosensors are:
   - Quite suitable for in vivo applications since they are non-electrical in nature.
   - Allow detection of various analytes using multiple wavelengths.
   - The set-up does not require a reference electrode or a reagent and hence, is much more practical and portable.
   - No additional electrical safety hazards or electrical interference.

C. Piezoelectric (Acoustic) Biosensors

These biosensors are based on the coupling between the bioelement and the piezoelectric component, which acts as a mass to frequency transducer. Many piezoelectric materials like quartz, tantalate, tourmaline, lithium-niobate exhibit piezoelectric properties but usually quartz is preferred over the others. These piezoelectric elements in their crystal form have the ability to produce and transmit acoustic waves. The resonating frequency of these acoustic waves depends on the physical properties of the piezoelectric components, which inturn change when there is a change in the mass due to the interaction of the sensing element and the analyte. These interactions set up mechanical vibrations that can be translated into electrical signals proportional to the concentration of the analyte. These mass-sensitive biosensors find potential applications in the field of environmental and clinical analysis.

D. Calorimetric(Thermometric) Biosensors

The fact that all biological reactions are exothermic in nature can be used to develop biosensors which are independent of the chemical properties of the sample under observation. In any calorimetric biosensor, once the analyte and the bioelement come in touch, the reaction heat which is directly related to the concentration of the analyte is captured and measured. The total heat generated or absorbed in the bioelectrochemical reaction is proportional to the molar enthalpy and the number of molecules involved in the reaction. The gauging of temperature is done using an enzyme thermistor. These biosensors , although still in their growth phase, find use in cosmetics, food and pharmaceutical analysis.

III. APPLICATIONS

The advent of cheap, quick and user-friendly biosensors has had a considerable impact in varied fields. A few of which include:

A. Biomedical

The most popular application in this area is the use of biosensors to measure the concentration of glucose, uric acid, lactic acid and various other pathogenic microbes in blood samples.

B. Agricultural industry-

Due to their selective and sensitive properties, biosensors are used to detect the presence of organophosphate in pesticides and measure ammonia and methane levels. Other considerable applications include the wastewater quality control using biological oxygen demand (BOD) analyzers based on micro-organisms like bacteria erythropolis.

C. Food Industry

Biosensors are often used in quality-assurance laboratories to ensure food safety by detecting pathogenic organisms in various food items like meat, fish or other poultry products.

D. Environmental screening

Biosensors find applications in environmental pollution monitoring. They are quite often used for testing and screening of various potential toxicating elements and therefore also in formulating means to mitigate their effects.

IV. TECHNOLOGICAL CHALLENGES

The awareness and use of biosensors is restricted majorly due to the following factors:

- The life span of biomolecules is limited.
- In certain applications, bioelements require pre-treatment before use.

- Certain biosensors are quite expensive.
- They lack long-term stability.
- Miniaturization of biosensors in certain cases poses technical challenges.
- In some biosensors, readout times are very long, even more than 20 seconds.
- Some biosensors are not rugged enough, thus inhibiting their use in industry.
- Cells of biosensors can easily become intoxicated.
- Most enzyme sensors remain limited to chemistries such as change in color, pH or oxidation state.

In spite of the technological challenges faced by biosensors, product and technology innovations and improvements, seem to continue at a high pace. Some of these new trends in the field of biosensors are discussed below.

V. Recent innovations

Biosensors are one of the key interdisciplinary research areas involving continuous research and development, with the number of applications increasing as each new biosensor is developed. These innovations of biosensors have ensured their penetration into new markets such as military bio-defense, security, environmental monitoring, narcotic detection and process industry. Most of the ongoing research is focused on improving the immobilization techniques of the biological elements in order to increase selectivity, sensitivity and stability of the biosensors and hence, boost their applications.

A. Silicon Biosensors

Recently, there has been a gradual increase in the use of micro-fabrication technologies in the development of new biosensors. This trend has lead to the growth of silicon-based biosensors. Porous-silicon(PS), a nanostructured material, has gained immense attention for use as a bio-sensing substrate due to both its optoelectronic properties and biocompatibility. Such biosensors have the capability of detection of various analytes including but not limited to glucose, DNA and antibodies. Despite, of the numerous advantages of silicon microbiosensors, a few challenges like formation and functionality of porous silicon layer are still to be dealt with.

B. Fast-Detection Biosensors

The excessive research in the field of biosensors recently led to the development of a biosensor that can detect bacteria at levels as low as 1 cell per 5 ml of water, in only a few seconds. The device basically uses carbon nanotubes (CNT's) containing fragments of DNA, that preferentially bond with the specific bacteria generating small , detectable electrical signals. CNT's are well ordered and hexagonal arrangements of carbon atoms, rolled as tubes. They form the basis of next-generation biosensors because of their advantages such as small size, high strength, high electrical and thermal conductivity, long term stability and fast response. Because of these properties the researchers consider that these fast-detection CNT biosensors have the potential of revolutionizing the sensor area.

C. Cell-On-Chip Biosensors

Rapid growth in the field of nano- and micro-fabrication technologies has lead to the successful implementation of Cell-on-chip biosensors, which offer potential improvements in the analysis of proteins, viruses, cells and DNA. The major focus of this innovation was to develop the means to identify cells in the immune system that suppress tumor growth. These devices are based on immunochemical methods for the measurement of antigen-antibody reactions on modified surfaces and hence, are capable of identifying interactions between single cells and detecting measurable signals from biological activities. Thus, due to their advantages like low cost and easy fabrication, cell-on-chip biosensors are without doubt the future of cellular biology analytical tools.

VI. Conclusion

Biosensors represent promising analytical tools which are applicable in areas such as food industry, clinical diagnosis, environmental screening and other fields where reliable and rapid analysis is required. Although, this technology is still in its developing phase, it seems to have an edge over other technologies due to its various advantages. Some biosensors have been successfully implemented in the commercial sphere and the growth seems to continue. Currently, they are used in more than 47 end-user applications in contrast to the 32 end-user applications six years ago. This rapid augment in applications of biosensors and its expansion into the market is strongly aided by developments within the biosensor field. The major driving forces of this growth in the field of biosensors are the requirements for low cost, sensitive, selective and fast response analytical devices. In spite of factors such as lack of validation and standardization and a plethora of other technological challenges, the next generation of biosensors based on nanostructures, seems to have taken the field to a much higher level altogether and this process of innovation is bound to accelerate in the future.

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