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Optical Fiber Biosensors: A Review

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Abstract: *Biosensors technology pervades everywhere in the various fields. Generally, biosensors consist the three main elements i.e., biorecognition elements, transducers and output signal detector etc. All the elements are crucial and important for the performance of the biosensors. Recently, optical fiber biosensors get much more attraction due to its extensive use in diverse fields. In present report we have been presented the principle of optical fiber biosensors along with its classification. Among the different types of biosensors based on the transducers optical fiber biosensors have the more advantageous. The paper also discusses the advantages and disadvantages of optical fiber briefly. As well as the applications of biosensors also discussed in short.*

Index Terms *– Biosensor, Transducer, Optical fiber bioreceptor, Application of optical fiber biosensors.*

1. INTRODUCTION

Clinical diagnosis and treatment, biomedical, bioremediation, food quality control, farming, industrial waste water control, mining, and the military military industrial complex all depend heavily on biological and biochemical processes [1-3]. However, order to convert biological information to measurable electrical impulses is currently a time-consuming and employment process. Biosensors have received a great deal of attention in this context because they can be used to convert a biochemical process into a measurable signal. The biosensor distinguishes from physical/chemical sensors in that its recognition element is biological [4,5]. The use of biosensors has increased as device technology has advanced, and they can detect what many other traditional sensing systems cannot. Many biosensors are now constructed industrially and used to develop large-scale multi-valued sensing systems [6,7].

Biosensors can be classified based on the two main categories based on the bioreceptors and transducers. In this paper we have been reported the transducers aspect of the biosensor especially optical fiber.

2. INTRODUCTION OF OPTICAL FIBER

The whole globe connects with each other by worldwide spread telecommunication system. The revolution in the telecommunication system is the worships of the invention or the birth of optical fiber [8]. Firstly, optical fiber was invented in the 1930s, but unfortunately the use of it started in the late 1960s where Theodore Maiman investigates the first laser [9]. The loss of light was much more at the first stage of the invention of optical fiber. To develop loss-less optical fiber the great efforts have been done at that time. In 1970 Kapron, Keck, and Maurer (at Corning Glass) were successful produced the first low-loss silica optical fiber [10]. This breakthrough was very much beneficial to use an optical fiber for various applications. The first few year's optical fiber was used only for the telecommunication. Over the exploring its characteristics such as enormous potential bandwidth, small size and weight, electrical isolation, signal security, low transmission loss, potential low cost etc. increases its applicability in diverse fields.

In general, optical fiber prepared by the concentric layers of core, cladding, and the coating or buffer as illustrated in figure 2.1. Core is made up of glass whereas cladding by glass or plastic. The core and cladding have different refractive indices. Core has the higher refractive index than that of cladding. The refractive index is calculated by ratio of the speed of light in a vacuum by the speed of light in another medium, as shown in the following formula [11]:

Refractive index of the medium = [Speed of light in a vacuum (C) / Speed of light the medium (V)]

$$R.I = \frac{C}{V}$$

Light propagates mainly along the core of the optical fiber. The cladding protects the loss of light from core into the surrounding air, decrease the scattering loss at the surface of the core, reject the absorption of surface contaminants and provide mechanical strength. The coating or buffer is a layer of material used to protect an optical fiber from physical damage.

2.1 PRINCIPLE OF LIGHT TRANSMISSION OPERATION

Optical fiber is the waveguide which transmits the light over the large distance without any loss of light intensity. Optical fiber propagates the light based on the principle of total internal reflection (TIR) phenomenon. According to law of optics, when the light incident at angles less than the critical angle undergoes refraction and these light radiations penetrate the cladding and are lost. The refraction phenomena in fibers follow the well-known Snell's law [12],

$$n_1 \sin\theta_i = n_2 \sin\theta_{r2},$$

Where, $\theta_i and\ \theta_{r2}$ are the incident and refraction angle and n_1, n_2 are the refractive index of launch region and core, respectively. When light passes form lower (rarer) refractive index to higher (denser) refractive index medium partial refraction and reflection takes place. Here, θ_i angle of incidence, θ_{r1} angle of reflection, θ_{r2} angle of refraction.

TIR occurs at the interface between the core and the cladding imposing some special conditions which are given as follows.

The following two conditions must be satisfied for the TIR of light in the optical fiber.

1. The refractive index (n_1) of core must be greater than that of refractive index (n_2) of cladding.
2. The incident light (θi) inside the core is higher than the angle called critical angle (θc) i.e. θi > θc.

The critical angle is depends upon the refractive indices of core and cladding materials which is described as

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

If the light strikes the interface at an angle greater than the critical angle, it will not pass via the other medium. The intensity of the reflected light at the core/cladding interface is proportional to the angle of incidence and the refractive indices of the core and cladding. Thus, by using the expression for critical angle, the maximum value of incidence angle for which light will propagate through the fiber is given by

$$\theta_0(max) = \sin^{-1}\frac{\sqrt{(n_1^2 - n_2^2)}}{n_0}$$

3. OPTICAL FIBER BIOSENSORS

There are four basic types of light property modulation used in optical fiber Biosensors: intensity, phase, wavelength, and polarization. These light properties can be modulated by changing the boundary conditions through different types of physical perturbations which include chemical, biological, mechanical, electrical, magnetic, and thermal radiation [13,14]. The general structure of an optical fiber Biosensor system is shown in the Fig.1. It consists of an optical source (Laser, LED, Laser diode etc.), optical fiber, transducer, optical detector and processing electronics.

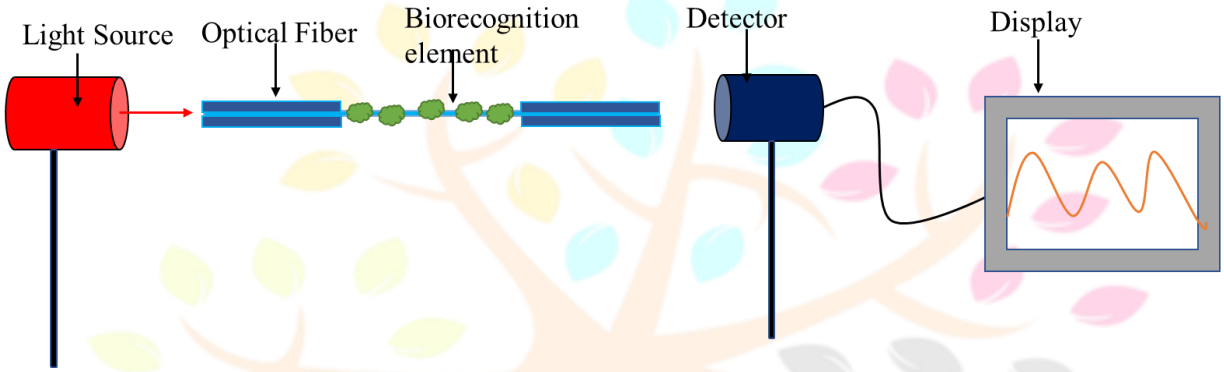

Fig.1. Optical fiber Biosensor system

3.1 LIGHT SOURCE

The selection of the light source depends on the wavelength region in which the transducer shows the maximum response. He-Ne laser, LEDs and other broadband sources may be used with multimode fibers, but single mode fibers may require coherent LED sources [15].

3.2 OPTICAL FIBER

For intensity modulation-based biosensors multimode optical fibers are generally used, single mode fibers are used in interferometric fiber biosensors where phase changes are measured. Low loss silica core fibers are preferred where fiber lengths used is large where fiber losses become considerable [16].

3.3 TRANSDUCER

The choice of the modulator is based on the kind of sensing desired form the optical fiber Biosensor. In many cases, the optical fiber itself plays an active role as a transducer.

3.4 DETECTOR

Detection is based on the type of light modulation technique used. For phase modulation, interferometric detection is used, while for polarization modulation polarization analyzer is used. However, in wavelength modulation the spectrum analyzer is used. In case of intensity modulation, the detectors used are the conventional photodiodes depending on the Wavelength of the light source and the wavelength region of the biosensor response.

3.5 ELECTRONIC PROCESSING

The electronic processing unit of the biosensor system may involve any power meter, oscilloscope, optical spectrum analyzer or computer to which the biosensor response is feed from the detector for further analysis and processing.

4. CLASSIFICATION OF OPTICAL FIBER BIOSENSORS

The optical transducer of a biosensor can be classified into the following groups: (1) direct absorption, (2) fluorescence, and (3) chemiluminescence and bioluminescence.

4.1 ABSORPTION

The most basic optical bio and chemical sensors use absorptions to detect changes in analyte concentration. The sensor works by sending light to the bio sample via an optical fiber; the amount of light absorbed by the analyte is determined by measuring the light coupled out via the same fiber or a second optical fiber. To ensure the sensing region's stability, the biological material is immobilized at the distal end of the optical fibers, allowing one to either produce or extract the analyte that absorbs light [17].

4.2 FLUORESCENCE

Bio-optrodes frequently make use of fluorescent. Fluorescence occurs when molecules absorb light at one wavelength and then emit light at a longer wavelength. Since excitation and emission only occur at different energy levels, each fluorescent molecule has a distinct fluorescence spectral fingerprint, which is crucial for the sensor application [18]. .

4.3 CHEMILUMINESCENCE AND BIOLUMINESCENCE

Chemiluminescence is like fluorescence. The thing that matters is that chemiluminescence happens by thrilling particles with a substance response (typically happening by the oxidation of specific substances like oxygen or hydrogen peroxide), though

fluorescence happens by thrilling atoms through light. In this way, on account of chemiluminescence, no outside wellspring of light is expected to start the response that kills the need of light hotspot for the sensor application [19].

5. ADVANTAGES AND DISADVANTAGES OF FIBER-OPTIC BIOSENSORS

5.1 ADVANTAGES [20,21]

1. An enormous background of optically based methods is available for chemical analysis. Almost every chemical analyte can be determined by use of its spectroscopic properties.
2. Fibers can be used to transmit light over long distances and the bioreceptor need not be in intimate contact with the optical fiber, enabling a wider range of non-invasive configurations.
3. Proper adjustment of the refractive indexes of the waveguide and the surrounding media enables the performance of surface-specific spectroscopy [35, 36]; this is difficult to apply in condensed media.
4. Fibers have a multiplex capability. Because they can guide light of different wavelengths at the same time and in different directions, multiple analyte determinations or single-analyte monitoring in single locations can be performed with a single central unit.
5. They can be used in harsh environments and are immune to electric or magnetic interference, and so can be safer than electrochemical biosensors. No reference electrode is needed and multiwavelength measurements can be used to correct for drift in optical and electrical components.
6. They can be easily miniaturized at low cost, thus finding application for in-vivo measurements.
7. A light guide can carry more information than electric wire.
8. The temperature-dependence of the fiber is lower than that of electrodes.

5.2 DISADVANTAGES [22]

1. Interference of surrounding light, albeit this can be stayed away from by utilization of reasonable light separation or balanced light sources.
2. Possible photograph dying or pointer wash out when marker stages are utilized, and restricted security of the immobilized natural part, albeit this would likewise be a disadvantage or different sorts of transducers.
3. Background absorbance, fluorescence, or Raman disperse of the fiber.
4. Long reaction times assuming mass exchange to the reagent stage is required.
5. Limited accessibility of advanced business embellishments for use with optical filaments.

REFERENCES

1. Garg, M., & Mehrotra, S. (2017). Biosensors. Principles and applications of environmental biotechnology for a sustainable future, 341-363.
2. Thieman, W. J. (2009). Introduction to biotechnology. Pearson Education India.
3. Ranjit, P., Varma, C. A. S. L., Maddela, N. R., & Reddy, K. V. (2021). Biotechnology of Twenty-First Century. Innovations in Biotechnology for a Sustainable Future, 17-42.
4. Tharani, S., Durgalakshmi, D., Balakumar, S., & Rakkesh, R. A. (2022). Futuristic Advancements in Biomass-Derived Graphene Nanoassemblies: Versatile Biosensors for Point-of-Care Devices. Chemistry Select, 7(40), e202203603.
5. Yang, J., Shen, M., Luo, Y., Wu, T., Chen, X., Wang, Y., & Xie, J. (2021). Advanced applications of chitosan-based hydrogels: From biosensors to intelligent food packaging system. Trends in Food Science & Technology, 110, 822-832.
6. Chaudhary, V. (2022). A paradigm of internet-of-nano-things inspired intelligent plant pathogen-diagnostic biosensors. ECS Sensors Plus, 1(3), 031401.
7. Zhou, Q., Pan, J., Deng, S., Xia, F., & Kim, T. (2021). Triboelectric nanogenerator-based sensor systems for chemical or biological detection. Advanced Materials, 33(35), 2008276.
8. Hecht, J. (2020). The breakthrough birth of low-loss fiber optics. Optics and Photonics News, 31(3), 26-33.
9. Hamblin, M. R., Agrawal, T., & de Sousa, M. (Eds.). (2016). Handbook of low-level laser therapy. CRC Press.
10. Keck, D. (2000). A future full of light. IEEE Journal of Selected Topics in Quantum Electronics, 6(6), 1254-1258.
11. Truesdale, C. M. (2000). Optical Fibers. *Electro-Optics Handbook*, 83.
12. Murata, H. (2020). *Handbook of optical fibers and cables* (Vol. 1). CRC Press.
13. Lee, B. (2003). Review of the present status of optical fiber sensors. Optical fiber technology, 9(2), 57-79.
14. Bosch, M. E., Sánchez, A. J. R., Rojas, F. S., & Ojeda, C. B. (2007). Recent development in optical fiber biosensors. Sensors, 7(6), 797-859.
15. Gupta, B. D. (2006). Fiber optic sensors: principles and applications. New India Publishing.
16. Lyu, S., Wu, Z., Shi, X., & Wu, Q. (2022, December). Optical Fiber Biosensors for Protein Detection: A Review. In Photonics (Vol. 9, No. 12, p. 987). MDPI.
17. Qu, H., & Skorobogatiy, M. (2012). Resonant bio-and chemical sensors using low-refractive-index-contrast liquid-core Bragg fibers. Sensors and Actuators B: Chemical, 161(1), 261-268.
18. Biran, I., Yu, X., & Walt, D. R. (2008). Optrode-based fiber optic biosensors (bio-optrode). In Optical biosensors (pp. 3-82). Elsevier.
19. Israel Biran, P. H. D., & Walt, D. R. (2002). Optrode-Based Fiber Optic Biosensors (Bio-Optrode). Optical Biosensors: Present & Future, 5.
20. Mehrvar, M., Bis, C., Scharer, J. M., Moo-Young, M., & Luong, J. H. (2000). Fiber-optic biosensors-trends and advances. Analytical sciences, 16(7), 677-692.
21. Marazuela, M., & Moreno-Bondi, M. (2002). Fiber-optic biosensors–an overview. Analytical and bioanalytical chemistry, 372, 664-682.
22. Ligler, F. S., & Taitt, C. R. (Eds.). (2011). Optical biosensors: today and tomorrow. Elsevier.