Analytica Chimica Acta 943 (2016) 17–40

Contents lists available at ScienceDirect

Analytica Chimica Acta

journal homepage: www.elsevier.com/locate/aca

Review

Fluorescence based fiber optic and planar waveguide biosensors. A review

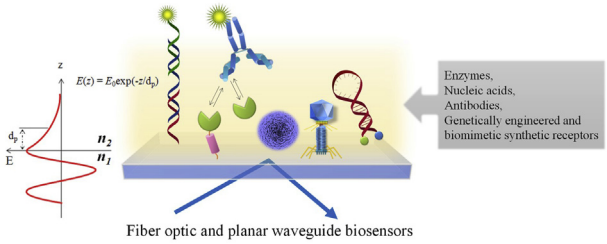
Elena Benito-Peña [a], Mayra Granda Valdés [b], Bettina Glahn-Martínez [a], Maria C. Moreno-Bondi [a, *]

[a] Department of Analytical Chemistry, Faculty of Chemistry, Complutense University, 28040 Madrid, Spain
[b] Department of Analytical Chemistry, Faculty of Chemistry, University of La Habana, 10400 La Habana, Cuba

HIGHLIGHTS

- Principles, configurations and fluorescence techniques using fiber optic and planar waveguide biosensors are discussed.
- The biorecognition elements and sensing schemes used in fiber optic and planar waveguide platforms are reviewed.
- Some major and recent applications of fiber optic and planar waveguide biosensors are introduced.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 January 2016
Received in revised form
25 August 2016
Accepted 29 August 2016
Available online 13 September 2016

Keywords:
Fiber optic and planar waveguide biosensors
Optical sensing
Fluorescence techniques
Biorecognition elements
Enzymes
Nucleic acids
Antibodies
Genetically engineered and biomimetic synthetic receptors

ABSTRACT

The application of optical biosensors, specifically those that use optical fibers and planar waveguides, has escalated throughout the years in many fields, including environmental analysis, food safety and clinical diagnosis. Fluorescence is, without doubt, the most popular transducer signal used in these devices because of its higher selectivity and sensitivity, but most of all due to its wide versatility. This paper focuses on the working principles and configurations of fluorescence-based fiber optic and planar waveguide biosensors and will review biological recognition elements, sensing schemes, as well as some major and recent applications, published in the last ten years. The main goal is to provide the reader a general overview of a field that requires the joint collaboration of researchers of many different areas, including chemistry, physics, biology, engineering, and material science.

Contents

* Corresponding author. Department of Analytical Chemistry, Faculty of Chemistry, Universidad Complutense de Madrid, Avenida Complutense, s/n Madrid, 28040, Spain.
E-mail address: mcmbondi@quim.ucm.es (M.C. Moreno-Bondi).

http://dx.doi.org/10.1016/j.aca.2016.08.049
0003-2670/

1. Introduction

Biosensors have been defined [1–3] as self-integrated devices capable of providing specific quantitative or semiquantitative analytical information on the species of interest using a biological recognition element (biochemical receptor), which is in direct spatial contact with the transducer element. Those biosensors based on the measurement of photons are classified as optical. This review is focused on optical fiber and planar waveguide fluorescence based biosensors, a type of device in which a waveguide (an optical transmitter) is used as a platform for the biochemical receptor as well as to transmit the excitation light and/or the resultant signal to a photodetector that converts the light into an electrical signal.

At present, optical biosensors are not competitive with bulky laboratory instrumentation, such as microplate array systems, for applications where a large number of samples need to be analysed simultaneously. However, they present some desirable features such as potential low cost, small size and ease of use and are well suited for some applications such as on-line monitoring or for the analysis of complex samples, as well as for the measurement of binding events in real time [4]. As a result, this is an active research area and a number of optical biosensing platforms are already in the market for application in specific areas including, environmental analysis, food safety or clinical diagnosis [5,6a,b].

Fluorescence is, without doubt, the most commonly used transducer signal in biosensors [7,8]. Several parameters can be recorded and applied for sensing including, fluorescence intensity, that can be measured at the given wavelengths of excitation and emission; decay time or emission anisotropy, which is a function of the fluorescence intensities obtained at two different polarizations, vertical and horizontal [8,9]. Therefore, a variety of possibilities exists to improve biosensor performance. For example, the excitation or the emission wavelengths of the luminophore can be adequately tuned to improve method selectivity and, in addition, the emission kinetics as well as the anisotropy properties of the luminescent compound may add specificity to the measurement in comparison to other optical methods [10]. Recent biosensor reviews [11–15] confirm that fluorescence-based transduction, in whichever of its possibilities, is one of the most popular optical detection methods used in biosensing.

This paper focuses on the working principles of fluorescence-based fiber optic and planar waveguides biosensors and will review biological recognition elements, assay formats, as well as selected applications in different areas, published in the last ten years. The main goal is to provide the reader a general overview of this exciting field which requires the joint effort of researchers of many different areas, including optics, biochemistry, electronics and fluidics.

2. Light guiding in optical waveguides and biosensor configurations

Optical waveguides are dielectric structures that transport energy between its two extremes at wavelengths in the UV–Vis and IR region of the electromagnetic spectrum. Depending on their geometry they can be classified in two main groups: cylindrical and planar. Optical fibers are included in the first group and consist of a cylindrical central dielectric core clad by a material of slightly lower refractive index (by $\approx$ 1%). A planar waveguide is formed from a dielectric slab core sandwiched between two cladding layers with lower refractive indexes [16]. In both, light propagation and guiding along the core is based on the well-known optical phenomenon of total internal reflection (TIR) [5,16].

When light propagates along an optical waveguide (Fig. 1), such as an optical fiber or a planar waveguide, light is totally reflected at the interface between the optically more dense medium and the optically rare medium if the angle of refraction is larger than a critical angle (θ_C). At each point of reflection there is a finite decaying electric field across the interface that penetrates some distance into the lower refractive index medium. This field is referred to as the evanescent wave [17].

In emission spectroscopy, the evanescent wave can be used to generate luminescence or Raman scatter. The wavelength range extends from the UV to the far infrared depending on the quality of the waveguide. Higher order modes, *i.e.* those that propagate at angles close to the critical angle, contribute in a major extent to the power of the evanescent wave [5]. Therefore, the geometry of the sensing region must be properly designed in fluorescent biosensors based on evanescent field excitation (EFE) so as to increase the excitation power along the probe length, as well as to avoid the coupling of the emitted fluorescence into guided modes that fail to propagate in the clad fiber, what is known as V-number mismatch [5,18–20]. Tapering of the sensing region has been proven to be a