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Low cost highly sensitive miniaturized refractive index sensor based on planar waveguide

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ABSTRACT

A simple, compact, low cost and highly sensitive refractive index sensor based on single mode leaky planar waveguide is reported. An optical waveguide fabricated on glass substrate has been proposed to construct the sensor. In this structure Cytop works as guiding layer while Teflon forms the cladding layers. Propagation of light in Cytop layer is strongly affected by the refractive index of external medium placed on top of Teflon layer. If the refractive index of the medium is close to or greater than that of Cytop, there is leakage of power from Cytop layer to external medium which affects the transmittance of the waveguide. The structure can be designed to have strong variation in transmittance with the refractive index of external medium and, thus, can be utilized as a highly sensitive refractive index sensor for biomedical applications. In this paper we have carried out the designs of such refractive index sensor for various biological and chemical applications. We design a sensor having sensitivity of the order of 10^4 dB/RIU. Fabrication of the sensor can be carried out by using spin coating technique. Long sensing range, high sensitivity, simple manufacturing process and compactness make the sensor attractive for diverse applications.

1. Introduction

Optical techniques have several applications in biomedical fields, such as photodynamic therapy [1], functional imaging [2], optical biopsy [3] and laser-induced thermotherapy [4]. Light or laser beams are transported and distributed in biological tissues in all of these applications. When light enters a biological tissue or a chemical liquid, the optical properties of material like absorption coefficients, reflection, irradiance levels, and the scattering phase functions determine the light transmission and distribution. These properties strongly depend on the refractive indices of tissues or liquids. Also, the refractive properties of tissues reflect their structural organization, which can be used as an intrinsic marker for a disease. Therefore, to understand the light behavior in biological tissues and in chemical liquids, it has become imperative to have accurate data of the refractive indices of the tissues or liquids. Optical waveguide sensors, based on optical fibers or planar waveguides, are widely used for this purpose. Optical fiber based sensor are sometimes difficult to handle, due to their fragile nature. Fabrication process of the fibers specially designed for this purpose is also not so simple. Integrated-optic sensors, therefore, have attracted rapidly growing interest. Various types of integrated optical sensors have been reported in literature including interferometric [5–7], refractrometric [8], evanescent field [9], fluorescent or absorbance [10] based, and surface-plasmon resonance based

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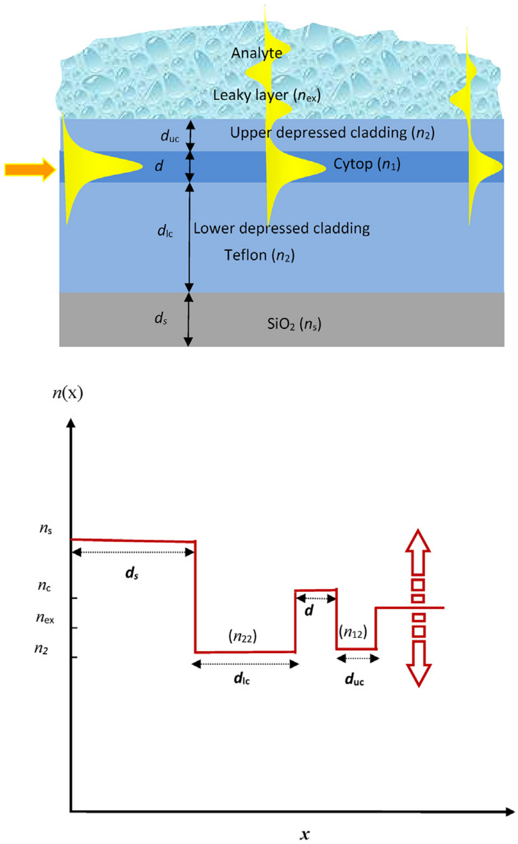

Fig. 1. (a) Schematic representation of proposed refractive index sensor, (b) Corresponding refractive index profile of waveguide employing variation in n_{ex}.

sensors [11]. The choice of technique employed is a tradeoff between fabrication cost, practicality, robustness and simplicity of manufacturing process. Although some of the refractometric biosensing systems or sensors have been commercially successfull but their use has been mostly limited to research laboratories due to their cost and complexity. In this paper, we present a leaky planar waveguide based refractive index sensor. The sensing structure is a Teflon-Cytop-Teflon waveguide formed on a glass substrate. Any change in the refractive index of the external medium affects light guidance in the cytop layer and this forms the working principle of the sensor. We observe resonant coupling of power from cytop layer to the external medium (sample to be sensed) for a particular value of refractive index of the external medium. The sensor has high sensitivity around this value of refractive index of external medium. We have designed refractive index sensors for biochemical applications and have studied tolerance with respect to various design parameters.

2. Waveguide structure and method of analysis

We have considered the waveguide structure as shown in Fig. 1. The waveguide structure has been formed on SiO_2 glass substrate of refractive index n_s. The width of the core of the waveguide having refractive index n_c is d. The core of the waveguide is surrounded by upper cladding and lower cladding having widths d_{uc} and d_{lc} respectively. The refractive index of upper cladding and lower cladding is n_2. The analyte is put on the top of the waveguide structure and is treated as external medium of refractive index n_{ex}. For the values of n_{ex} close to or greater than n_c, the structure becomes leaky. Hence some portion of the light propagating through waveguide is trapped by high refractive index material. So, we get a modulated output and by measuring the fraction of input power that comes out of the output end, we can find out the refractive index of the liquid. Transfer matrix method (TMM) has been used to analyze the structure [12]. Multilayer representation of planar leaky waveguide is shown in Fig. 2. To implement TMM, electric field in the p^{th} layer having refractive index n_p can be expressed as:

$$E_p = \begin{cases} A_p \cos k_p[x - d_{p+1}] + B_p \sin k_p[x - d_{p+1}]; & k_p^2 > 0 \\ A_p \cosh k_p[x - d_{p+1}] + B_p \sinh k_p[x - d_{p+1}]; & k_p^2 < 0 \end{cases} \quad (1)$$