Surface Plasmon Resonance Sensor in Plastic Optical Fibers. Influence of the Mechanical Support Geometry on the Performances

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Abstract. A performance analysis on Surface Plasmon Resonance (SPR) sensor based on D-shaped Plastic Optical Fibers (POFs) is reported. It is a very low cost sensor for determining refractive index variations at the interface between a metallic layer and a dielectric medium. This POF-SPR optical platform can be used in many bio and chemical applications. The advantage of using POFs is that the sensor platforms based on POF are simpler to manufacture than those made using silica optical fibers. For low-cost sensing systems, POFs are especially advantageous due to their excellent flexibility, easy manipulation, great numerical aperture, large diameter, and the fact that plastic is able to withstand smaller bend radii than glass. In this work the authors investigate the role of the geometric shape of the resin block, used to obtain a D-shaped POF. In fact, different resin blocks can produce different performances. Two different POF-SPR sensors, based on two different geometric shapes of the resin block, with numerical and experimental results, are presented.

Keywords: Surface Plasmon Resonance · Plastic Optical Fibers · Optical sensors · D-shaped plastic optical fiber

1 Introduction

The SPR is an optical phenomenon that appears at a metal-dielectric interface, widely used in a large number of sensors for label-free detection [1–4]. The Kretschmann configuration is widely used in practice, but the setup usually require expensive optical equipment. Incorporating optical fiber makes it possible to reduce the sensor cost and dimensions, with the possibility to integrate the SPR sensing platform in telecommunication systems [5–8]. Using a molecularly imprinted polymer (MIP) layer as an artificial receptor, the rapid and selective detection of different analytes, as for example

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trinitrotoluene (TNT) or L-nicotine, in aqueous matrices has been demonstrated [9, 10]. Also, MIP-POF-SPR optical platform has been demonstrated to be potentially useful for the determination of 2-furaldehyde (2-FAL) directly in transformer oil, without any previous extraction procedure [11]. In comparison with biosensors based on biological receptors, the polymeric receptors have an improved reproducibility and shelf-life, and a lower cost, so that they are suitable for mass production of sensors [12]. The planar gold surface and the useful refractive index ranging from 1.33 to 1.42 are two good factors for successful bio/chemical sensors implementation. Moreover the flat surface of the optical platform, characteristic of the D-shaped platform here proposed, makes it possible the reproducible deposition of the receptor, particularly in the case of MIP.

The performances of the optical sensor platform (sensitivity and signal-to-noise ratio) are very important to the implementation of the platform in bio/chemical applications.

In this work the authors investigate the role of the geometric shape of the resin block. In fact, different resin blocks can produce different performances. To this aim, a numerical model of the sensor, with different sensing regions, has been developed and subsequent experimental testing has been conducted to confirm the simulation results.

2 Optical Sensor System

The fabricated optical sensor system was realized removing the cladding of a plastic optical fiber along half the circumference, by mechanically polishing the plastic optical fiber without jacket embedded in a resin block, spinning on the exposed core a buffer of Microposit S1813 photoresist, and finally sputtering a thin gold film using a sputtering machine [13]. In this work the authors investigate the role of the geometric shape of the resin block. We have realized two different SPR-POF sensor platforms based on two different geometric shapes of the resin block (see Fig. 1).

The chosen plastic optical fiber has a PMMA core of 980 μm and a fluorinated polymer cladding of 20 μm, the gold film is 60 nm thick and the thickness of the photoresist buffer layer is about 1.5 μm. The realized sensing region is about 10 mm in length (see Fig. 1).

The gold film so obtained presents a good adhesion to the substrate, verified by its resistance to rinsing in de-ionized water, and it is also easy to functionalize with bio/chemical receptors.

The experimental setup is arranged to measure the light spectrum transmitted through the SPR-POF sensor and is characterized by a halogen lamp, illuminating the optical sensor system and a spectrum analyzer (see Fig. 2). The employed halogen lamp exhibits a wavelength emission range from 360 to 1700 nm, while the spectrum analyzer detection range is from about 330 to 1100 nm. An Ocean Optics USB2000 + VIS-NIR spectrometer, controlled by a computer, has been used. The spectral resolution of this spectrometer ($\delta\lambda_{DR}$) was 1.5 nm (full width at half maximum).

Fig. 1. Sensors with two different geometric shapes of the resin block

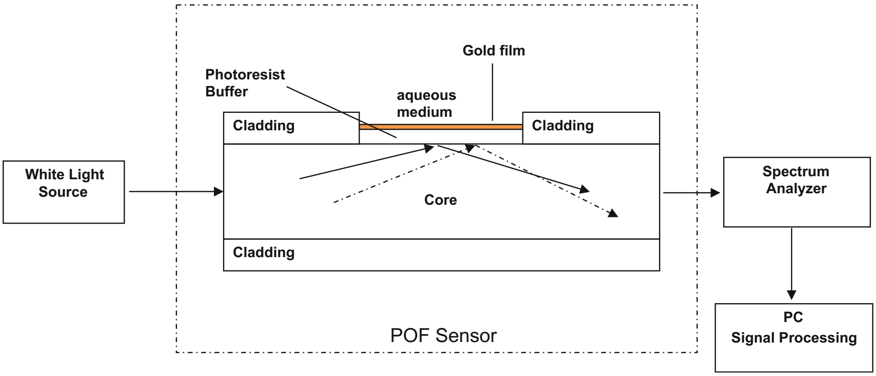

Fig. 2. Schematic view of the experimental setup and section of the SPR platform

3 Sensor's Parameters in Spectral Mode Operation

In SPR sensors with spectral interrogation, the resonance wavelength (λ_{res}) is determined as a function of the refractive index of the sensing layer (n_s). If the refractive index of the sensing layer is altered by δ_{ns}, the resonance wavelength shifts by $\delta\lambda_{res}$. The sensitivity (S_n) of an SPR sensor with spectral interrogation is defined as [13–15]:

$$S_n = \frac{\delta\lambda_{res}}{\delta n_s}\left[\frac{nm}{RIU}\right] \quad (1)$$

Owing to the fact that the vast majority of the field of an SPW is concentrated in the dielectric, the propagation constant of the SPW is extremely sensitive to changes in the refractive index of the dielectric itself. This property of SPW is the underlying physical principle of affinity SPR bio/chemical sensors. In the case of artificial receptors, as molecular imprinted polymers (MIPs), the polymeric film on the surface of metal selectively recognizes and captures the analyte present in a liquid sample so producing a local increase in the refractive index at the metal surface. The refractive index increase gives rise to an increase in the propagation constant of SPW propagating along the metal surface which can be accurately measured by optical means. The magnitude of the change in the propagation constant of an SPW depends on the refractive index change and its overlap with the SPW field. If the binding occurs within the whole depth of the SPW field, the binding-induced refractive index change produces a change in the real part of the propagation constant, which is directly proportional to the refractive index change.

The resolution (Δn) of the SPR-based optical sensor can be defined as the minimum amount of change in refractive index detectable by the sensor. This parameter (with spectral interrogation) definitely depends on the spectral resolution ($\delta\lambda_{DR}$) of the spectrometer used to measure the resonance wavelength in a sensor scheme. Therefore, if there is a shift of $\delta\lambda_{res}$ in resonance wavelength corresponding to a refractive index change of δn_s, then resolution can be defined as [13–15]:

$$\Delta n = \frac{\delta n_s}{\delta \lambda_{res}} \delta \lambda_{DR} = \frac{1}{S} \delta \lambda_{DR} [RIU] \tag{2}$$

The Signal-to-Noise Ratio (SNR) of an SPR sensor depends on how accurately and precisely the sensor can detect the resonance wavelength and hence, the refractive index of the sensing layer. This accuracy in detecting the resonance wavelength depends on the width of the SPR curve.

The narrower the SPR curve, the higher the detection accuracy. Therefore, if $\delta\lambda_{SW}$ is the spectral width of the SPR response curve corresponding to some reference level of transmitted power, the detection accuracy of the sensor can be assumed to be inversely proportional to $\delta\lambda_{SW}$.

The signal-to-noise ratio of the SPR sensor with spectral interrogation is, thus, defined as [13–15]:

$$SNR(n) = \left(\frac{\delta \lambda_{res}}{\delta \lambda_{SW}} \right)_n \tag{3}$$

where $\delta\lambda_{SW}$ can be calculated as the full width at half maximum of the SPR curve (FWHM). SNR is a dimensionless parameter strongly dependent on the refractive index changes.

4 Numerical and Experimental Results

Two different POF sensors, based on two different geometric shapes of the resin block, are numerically and experimentally tested: first, the D-shaped POF configuration with a square (cubic) resin block (see Fig. 1); second, the D-shaped POF configuration with a round (cylindrical) resin block (see Fig. 1).

Figure 3 shows the simulation of the Poynting vector, for a round (cylindrical) resin block (see the layout with the geometry in Fig. 3, after the polishing process). The model was made with beam propagation method (BPM). In the simulation we have considered one wavelength and one mode, the fundamental mode (because it contains the maximum energy). Figure 3 shows how the power increases in the middle of the sensing area, because of the lens effect at the entrance (convergent lens). At the end of the sensing area the lens effect is divergent and it is possible that some modes are lost in the cladding (exceed the critical angle).

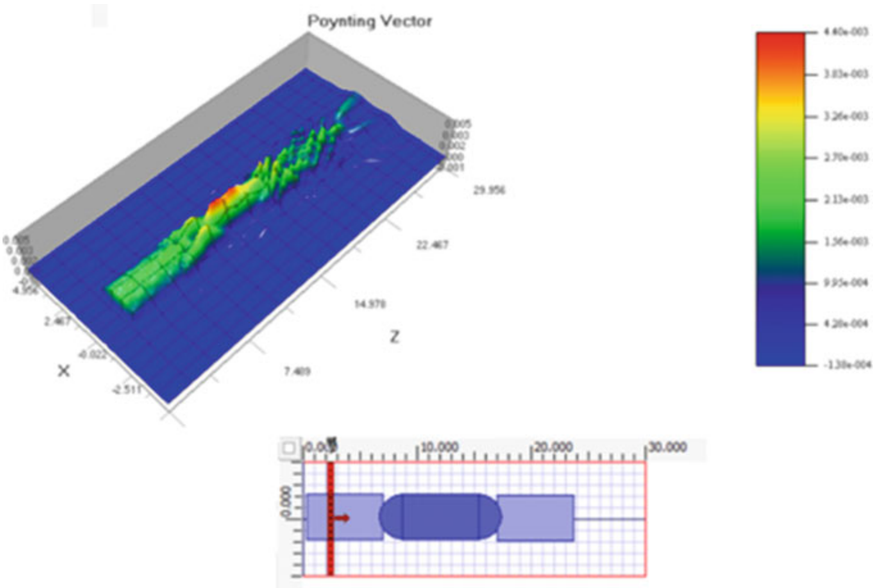

Fig. 3. Numerical results (based on BPM) for POF sensor with round (*cylindrical*) resin block

The preliminary experimental results are plotted in the Fig. 4. SPR transmission spectra of these two different sensors with two different geometric shapes of the resin block, when a water solution (1.332 RIU) is present on a gold layer, are reported in Fig. 4. The results clearly demonstrate that the geometric shape of the resin block has a relevant role in the performances of the optical platform. In particular, the square (cubic) resin block presents a deeper resonance than the round (cylindrical) resin block. This phenomenon is very important to the signal-to-noise ratio (SNR) of the SPR sensor.

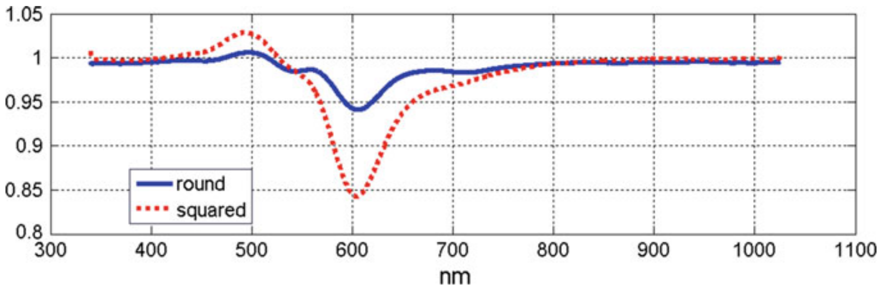

Fig. 4. Experimentally obtained SPR transmission spectra, normalized to the air spectrum, for two POF sensors with different geometric shapes of the resin block (*round* and *square*), when a water solution (1.332 RIU) is present on a gold layer

5 Conclusions

In this work the role of the geometric shape of the resin block (used to obtain a D-shaped POF) is investigated. This has been suggested by a numerical simulation carried out considering that the sensor actually consists of different sensing regions, possibly formed during the preparation of the sensor, in particular during the removal of the cladding. Subsequent experimental testing has been conducted to confirm the simulation.

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