Characterization of a Surface Plasmon Resonance Sensor using the Intensity Interrogation Technique

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Abstract - We investigate the possibility of enhancing the performance of a surface plasmon resonance (SPR) sensor based on the intensity interrogation technique (IIT) where we could obtain a maximum sensitivity of 362.2RIU^{-1}.

I. INTRODCUTION

Surface Plasmon Resonance (SPR) is a label-free Refractive Index (RI) sensing technique [1][2][3].The wavelength interrogation technique (WIT) is popular and widely used, it is based on scanning the sensor's response at a given wavelength range, the wavelength at which reflection is at minimum, is called wavelength of resonance, the shift of this wavelength is monitored to infer the refractive index of the surrounding medium. The wavelength interrogation technique is known for its accuracy, it also exhibits good linearity and a wide dynamic range, and most importantly immune to light intensity fluctuations. However, high cost is its major drawback, due to the expensive lab devices required to perform spectral analysis, which also make this technique unsuited for in site continuous measurements. On the other hand, intensity interrogation technique (IIT) does not require spectral analysis, as it is based on intensity measurement of the beam reflected off the metal layer at a fixed wavelength, light intensity of the reflected beam is directly related to refractive index of the analyte. However, being based on intensity measurement, this technique is vulnerable to light source fluctuations and to light absorption by the surrounding medium. In this paper we propose a design of an optical sensor for water analysis based on SPR and we try to exploit the IIT for the performance optimization of the proposed sensor.

II. Theory

The proposed structure, shown in Fig.1, is a capillary fiber made of teflon AF2400, the core is filled with water and the inner surface is coated with a gold layer. The refractive indices of teflon, gold and water are denoted n_t, n_g and n_w respectively. The hollow core allows us to have a maximum overlap between the analyte and the light mode propagating inside. The guided mode inside the core will be coupled to the plasmon propagating in the gold layer surface.

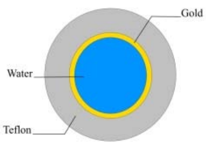

Fig.1. Proposed structure for our SPR sensor

In order to maintain total internal reflection guidance in our case, the use of materials having refractive index lower than that of water such a teflon AF is mandatory. The transfer matrix method (TMM) [4] is used to calculate the reflection coefficient of the metal layer for a given wavelength range λ, the wavelength of which reflection is minimum is the wavelength of resonance λ_{res}. This is where the incident beam of the guided mode, undergoes a maximum loss of energy to the plasmon. Sensitivity of the wavelength interrogation technique (WIT) is given by:

$$S^{WIT} = \frac{d\lambda_{res}}{dn_w} \quad (1)$$

We define the Sensitivity of the intensity interrogation technique (IIT) by the reflection coefficient R derivative with respect to the refractive index of water n_w, divided by the loss term: (1-R)

$$S^{IIT} = \left(\frac{dR}{dn_w}\right)/(1-R) \quad (2)$$

Intensity fluctuations dependence of the IIT can be minimized by establishing referenced sensing, where we measure the output to input optical signals ratio instead of directly measuring the output signal, this way the fluctuation term will be eliminated. Light absorption by water can also be minimized by working at a wavelength range where the absorption is at minimum and by making the fiber length as short as possible.

The dynamic range (*DR*) is also an important parameter which can be defined here by the refractive index range of the analyte to be detected at which the sensor response, R, is attributed to a unique refractive index value of the analyte.

III. Results

In Fig.2, the reflection coefficient R is plotted with respect to wavelength for a zero refractive index perturbation in water Δn=0 (red) and for Δn=0.005RIU (blue).We note that the refractive index perturbation Δn causes a wavelength shift of $\Delta\lambda_{res}$=25nm in the dip of resonance, and a change in the reflection coefficient ΔR along the wavelength range of interest, the latter is wavelength dependent.

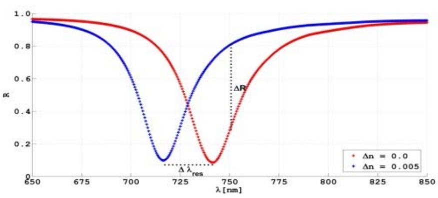

Fig.2. The spectral response of the proposed SPR sensor structure.

Fig.3 shows the wavelength of resonance λ_{res} represented with respect to refractive index perturbation in water Δn. The sensor spectral response exhibits good linearity with S^{WIT}=5000*nm/RIU*.

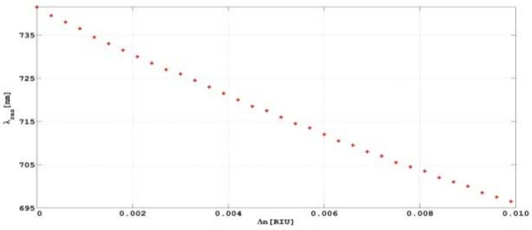

Fig.3. The wavelength of resonance λ_{res} represented with respect to refractive index perturbation in water Δn from 0 to 0.01*RIU*.

In Fig. 4, the reflection coefficient R and sensitivity S^{IIT} are represented with respect to Δn for two wavelength values: λ=730nm located near the dip of resonance and λ=775nm located relatively far from it (Fig. 2). For λ=730nm, the sensor exhibits a low *DR* value of 0.0021RIU and a limited linearity (Fig.4.a), while having a maximum sensitivity of S^{IIT}_{max}=-338 RIU^{-1} near Δn =0 (Fig.4.c). On the other hand, for λ=775nm, the dynamic range is wider *DR*=0.01RIU and linearity is better (Fig.4.b). However sensitivity is lower with S^{IIT}_{max}= 227 RIU^{-1} (Fig.4.d).

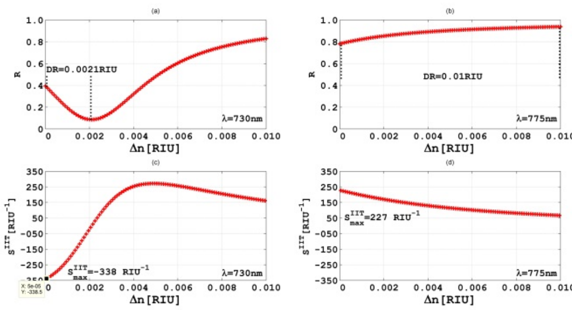

Fig. 4. Reflection coefficient *R(a)(b)* and Sensitivity S^{IIT} (c) (d) of the Sensor at the two wavelength samples: λ=730nm and λ=775nm respectively.

In Fig.5, we look for the wavelength for which the sensor has the highest sensitivity. In Fig.5.a, S^{IIT}_{max} is plotted with respect to wavelength, we note that the optimal sensitivity is located at λ=725.5nm where S^{IIT}_{max}=-362.2RIU^{-1}, this is higher than S^{IIT}_{max}=-190RIU^{-1} found in [2]. Fig.5.b shows that *DR*=2.9×10^{-3} RIU for λ=725.5nm, we can also note how *DR* decreases when λ approaches the wavelength of resonance (Fig.2). In Fig.5.c and Fig.5.d, R and S^{IIT} are plotted with respect to Δn for the optimal wavelength λ_{opt} =725.5nm, results confirm those found in 5.a and 5.b, with the optimal sensitivity S^{IIT}_{max}=-362.2RIU^{-1} noted at Δn=0.

In Fig.6, the relative position of the optimal wavelength λ_{opt} is demonstrated with respect to λ_{res} for Δn=0. We find that λ_{opt} is 16nm far from the resonance wavelength, and that the width of the resonance dip at λ_{opt} is 33nm, which is very close to the full width half maximum *FWHM*=31.5nm.

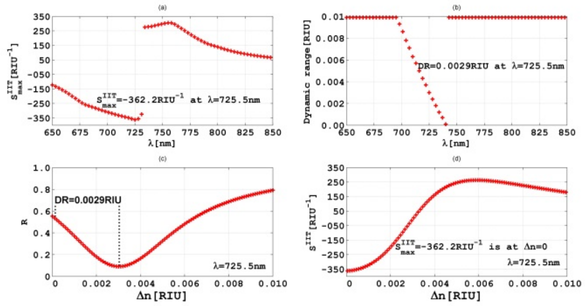

Fig.5. Maximum sensitivity calculation of the SPR sensor (a) The maximum sensitivity S^{IIT}_{max} is calculated at each wavelength value. (b) The Dynamic range *DR* is calculated at each wavelength value, (c) Reflection coefficient R plotted with respect to Δn for λ =725.5nm. (d) Sensitivity S^{IIT} plotted with respect to Δn for λ =725.5nm.

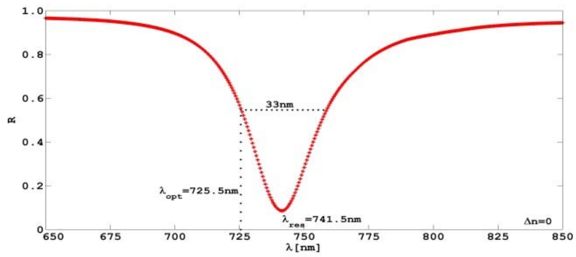

Fig.6. The spectral response of the proposed SPR sensor, for Δn=0, indicating the position of the optimal wavelength λ_{opt}=725.5nm with respect to the resonance wavelength λ_{res}=741.5nm. At λ_{opt}, the width of the resonance dip is 33nm while the full width half maximum of the dip *FWHM*=31.5nm.

IV. Conclusion

In this work we study the performance of a SPR sensor based on the intensity interrogation technique using the transfer matrix method. We find that sensitivity is wavelength dependent with the maximum sensitivity -362.2RIU^{-1} noticed at λ=725.5nm, which is located 16nm from the wavelength of resonance λ_{res} =741.5nm at a dip width of 33nm, knowing that *FWHM*=31.5nm for Δn =0. For wavelengths located relatively far from λ_{res}, a good *DR* and linearity are exhibited by the sensor. However sensitivity is low. On the other hand, for wavelengths located near λ_{res}, the sensor shows high sensitivity with a narrow dynamic range and limited linearity. However this shouldn't be a problem for applications that involve miniature refractive index changes or measurements in the molecular level such as in immunosensing applications.

References

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