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Analysis of Integrated Optical Structure for Sensor Applications

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***Abstract*—The analysis of Bio-sensors are to gain an understanding of Integrated optical structure to convert biological sample response into an measurable electrical signal. The present technology developed in Integrated optical structure based Surface Plasmon Resonance (SPR) sensors. SPR sensors are very small size, low cost and ruggedness. It can improved by designing and analysis for optical structure platform. In this review Optical Integrated Structure waveguide as a dielectric material with high Refractive Index enclosed on all sides and metal bounded on all sides by materials with lower Refractive Index, i.e. base material substrate and the medium to be sense. Optical bio-sensors are prone to noise which arise due to mechanical vibrations, spatial intensity fluctuations of the light source, thermal drift and change in refractive index of the bulk analyte solution. The main applications are detection of bio samples such as a analyte. The analysis of optical sensor growth in the field of SPR sensor, Lab On Chip design and new materials to afford the benefits. In this paper review basic fundamentals of SPR principle technology and sensing analysis briefly discussed and also leading to the integration of sensitive SPR to Lab-On-Chip designs.**

***Index Terms*— Refractive Index (RI), Surface Plasmon Wave (SPW), Total Internal Reflection (TIR), Surface Plasmon Resonance (SPR), Lab On Chip and BeamPROP.**

I. INTRODUCTION

The new era optical sensors are developing that allows efficient bio-samples into measurable signal, usefull to environmental, drug analysis, pesticides, and medical diagnostics. In the past few decades integrated optical structure based Surface Plasmon Resonance sensors offered many advantages compared to other technologies. Now a days Optical biosensors are using the excitation of Surface Plasmon Wave (SPW), normally the term Surface Plsmon Resonance (SPR). The optical sensors are different interaction mechanism exploited to transfer the variation of the absorption of the biological mediator into an optical signal Example SPR. The method of the SPR is very sensitive to a refractive index changes in sensing medium. This changes happens due to linking of analyte (in a fluid sample) to their affinity legends (that immobilized on the chip surface plane) when the fluid liquid sample comes get in touch with to the sensor surface plane. Hence,

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material which is get in touch with the liquid sample (top layer of sensor), in terms of refractive index and absorption of molecules, is influential and important [1],[2]. Now a days the new technique SPR sensing configuration for measuring Biological and chemical quantities have been described. In this review we are analysed basic theoretical analysis of effective index waveguide based SPR bio sensor technique.

II. Theory of Surface Plasmon Resonance

Surface Plasmon Resonance is an indicate a ”collective of oscillations” to exist at the boundary between two media with dielectric constants of opposite signs, for example, metal and dielectric [3]. The charge density wave is related with an electromagnetic wave, the field vectors which arrive at their maximum at the boundary and decay evanescently into both media. This Surface Plasma Wave (SPW) is a TM-polarized wave (magnetic vector is at a 90 degree angle to the direction of propagation of the SPW and equivalent to the plane of boundary). The propagation constant of the surface plasma wave propagating at the interface between a semi-infinite dielectric and metal is given by the following expression:[1]. SPPs are transverse magnetic (TM) waves that propagate along the interface between materials with negative and positive permittivity’s (Example, a metal / dielectric layers). According to the Drude Theory, the spreading relation β of an SPP, which effectively correlates the relation between the wave vector next to the boundary and the angular frequency ω , can be described by equation 1 [4].

$$\beta = \frac{c}{\lambda}\sqrt{\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}} \qquad (1)$$

Where c is the speed of light, ε_m is the permittivity of metal and ε_d is the dielectric of metal. The above equation will describe Surface Plasmon Polaritions wavelength. Consequently, the real part of the dispersion function is extremely sensitive and changes proportionally to change in the refractive index [5]. The principle of SPR, however, only occurs as soon as the lights wavevector component equivalent to the metal surface matches that of the SPP. This condition is only satisfied at distinct angles of incidence, appearing as a drop in the reflectivity of incident light [7],[5] shown in figure 1.

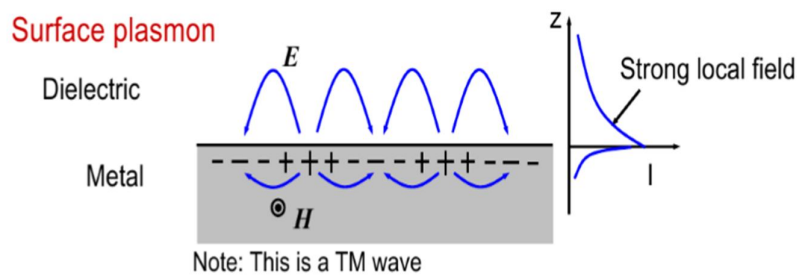

Figure1. E-filed of Surface Plasma’s propagating on a surface parallel to interface , exponential dependence of the field E perpendicular to interface

Where light incident on the waveguide layer end - face at the direction is guided in the waveguide by Total Internal Reflection (TIR) at the waveguide layer and substrate boundaries at the propagation angle of the light and the intensity of the guided light is calculated by a intensity detector as shown in figure 2.

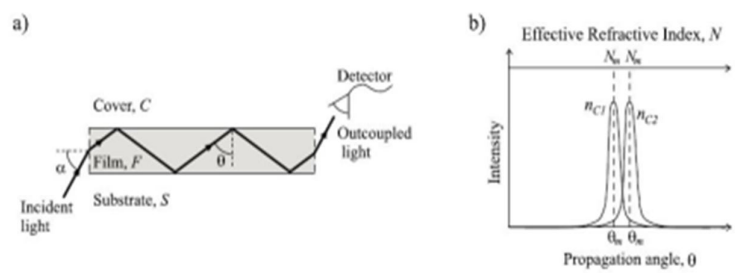

Figure2. Basic Surface Plasmon Resonance sensing principle Operation of the waveguide sensor

A. Light Guided in Slab Waveguide

The dielectric planar waveguide, light lead in the waveguide by Total Inside / Internal Reflection (TIR) at the waveguide substrate and waveguide cover up correspondingly as shown in Fig 2. The TIR achieved for light propagating in medium with refractive index higher than the adjacent medium and incident angle of the light boundary [2]. Two media is higher than the critical angle $\theta_{Critical}$, the angle of the light changing from a normal propagating wave across the boundary to totally internal reflected.

$$\theta_{critical} = \arcsin\left\{\max\ \frac{n_c, n_s}{n_s}\right\} n_{film}\ Max\ n_c\, n_s$$

Thus, to achieve TIR in the planar slab waveguide both boundaries and the planar slab waveguide Refractive Index should be higher than the Refractive Index of the substrate. The fundamental sensing principle of the planar dielectric waveguide sensor is to evaluate changes in Refractive Index of Metal N_m due to changes in Refractive Index Cover N_c and the principle is illustrated in below Fig 2. Light can be coupled into the waveguide at the end surface of the waveguide layer in excess of angles, and guided in the waveguide film by Total Internal Reflection (TIR) at the cover up film and substrate-boundaries at a variety of angles.

The light is attached to out of the waveguide at the other end surface of the film where the intensity is calculated by a detector. The calculated scale of intensity versus angle is referred to as a sensorgram. By the waveguide mode angle M corresponding to N_m a waveguide mode is excited in the waveguide which gives rise to a peak intensity in the measured sensorgram and a change in N_c results in a change of N_m and thus in the waveguide mode angle.

III. Optical Waveguide-Based SPR System

Basically the Integrated optical structure sensor constructs a dielectric three layer planar waveguide, shown in figure 3.

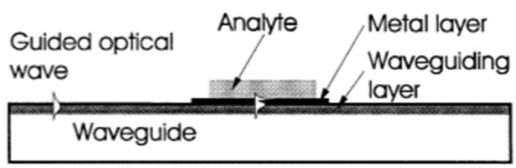

Figure3. Waveguide-based SPR system

Where it is possible to change the cover medium with single are multi layer for example from one solution to another. The waveguide sensor is along with other optical sensors referred to as evanescent field sensors due to the evanescent wave extending into the medium. Considering the phase shift of the reflected light at the cover interface it is seen, that a given value of N_c influences the phase shift, thus, for a change in N_c the phase shift of the optical path length Δ_s has to change in order to compensate for the changing thereby maintain a waveguide mode shown in figure 4.

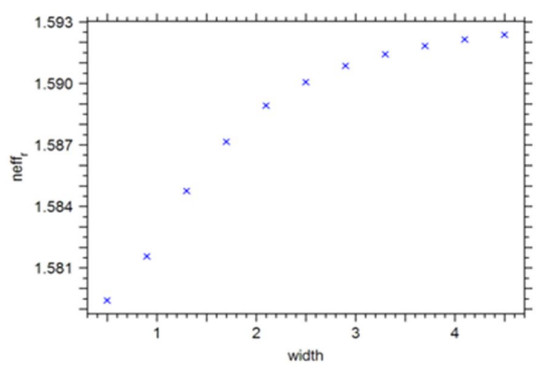

Figure 4. Effective refractive indices varying Width

The fundamental sensing principle of the planar dielectric waveguide sensor is to compute changes in N_m due to changes in N_c and the principle is illustrated in Fig 2 a. Light can exist attached into the waveguide at the

end surface of the waveguide film above a choice of angles, and be guided in the film by TIR at the cover and the film / substrate-boundaries at a choice of angles. The light is attached out of the waveguide at the other end surface of the film where the intensity is calculated by a detector. The calculated spectrum of intensity verses angle is referred to as a sensorgram. The sensorgram can also be shown as Fig 2 b. At the waveguide mode angle M corresponding to N_m a waveguide mode is excited in the waveguide which gives rise to a peak in intensity in the measured sensorgram and a change in N_c results in a change of N_m and thus in the waveguide mode angle. The fundamental sensing principle is to measure the change in the position of the peak in intensity, illustrated in Fig.2(b) for a change in cover RI from $N_{c1}$to N_{c2}.

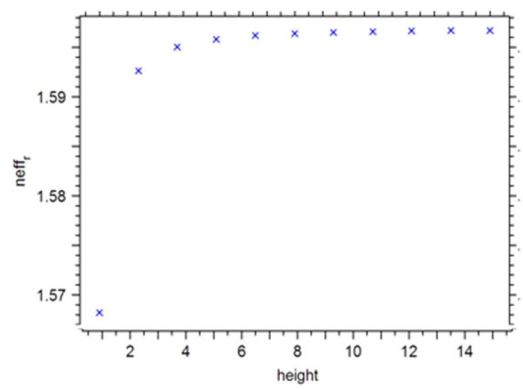

Figure 5. Effective refractive indices varying Height

A. Theoretical Calculation of N_{eff}:

The excitation surface plsmon theoretically calculated based on above equation 1. A surface plasmon-polariton is an EM (Electromagnetic) waves are propagates with in dielectric and metal and it will get quasi-free electron plasma. An surface plasmon-polariton is a transverse-magnetic (TM) wave and it is analyzed by the propagation constant and EM field distribution. To calculate theoretical N_{eff} of refractive index below equation.

$$\beta = k_0 N_{eff} \tag{2}$$

$$where\ k_0 = \frac{2\pi}{\lambda} \tag{3}$$

$$k_0 N_{eff} = \sqrt{\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}} \tag{4}$$

$$where\ \varepsilon_d = n_1^2, \varepsilon_m = n_2^2 \tag{5}$$

$$k_0 = \sqrt{\frac{\varepsilon_d' \varepsilon_m}{\varepsilon_d' + \varepsilon_m}} \tag{6}$$

$$n_{eff}^2 = \frac{\varepsilon_d' \varepsilon_m}{\varepsilon_d' + \varepsilon_m} \tag{7}$$

$$\varepsilon_1' \varepsilon_2^2 = \varepsilon_1' N_{eff}^2 = \varepsilon_2^2 N_{eff}^2 \tag{8}$$

$$\varepsilon_1' = \frac{\varepsilon_1' N_{eff}^2}{\varepsilon_2^2 N_{eff}^2} \tag{9}$$

$$\varepsilon_d = n^2 w_g$$

By deriving above equation we are taking $\varepsilon_m = \varepsilon'_m + \varepsilon''_m = 0.38 + i10.75$ and wavelength $\lambda = 1550$nm we get ε_m and N_{eff} =1.429. The theoretical analysis of Gold coating sensing structure in that calculation index profile of the wave guide replaced an equally step index multilayer in our sported calculation the dielectric constant of the Gold layer.

IV. Simulation Results

We have designed with the help of R-Soft Beam Propagation method the simple Integrate optical SPR structure based on above equation Free space wavelength 1550 nm, Background index 1.44, Cover index 1, Length 1000 nm, Slab material: Si: Re=1.6, Delta 0.16, Height 3 m, Width 1 nm, slab height 1, after simulating it is matching theoretical values shown in figure 6. We have simulated and calculated the $N_{effective}$

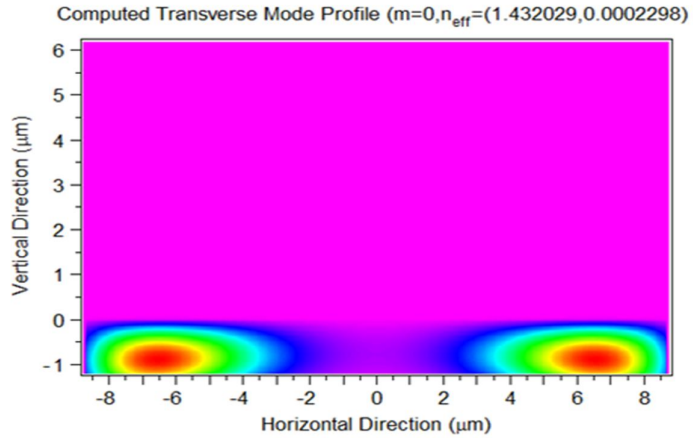

Figure 6. Effective refractive indices Index profile

of different height and width variation shown in . The effective refractive index Changing and the width, height variation shown in Figure.5 and figure 6. BeamPROP is a easy method of solving for fields in integrated optical devices. It is used to only in solving for intensity and modes within shaped (bent, tapered, terminated) different waveguide structures. The beam propagation method (BPM) technique is used for simulating the propagation of light in slowly varying optical waveguide.

The figure 7 shows the structure of waveguide based SPR sensor base material layer1 is substrate SU8 refractive Indexis 1.602 width: 5 m, height: 5 m, layer 2 is core material Height 0.07 m, i.e dielectric waveguide refractive Index is 1.313 , layer 3 is Gold (Au)Re:0.38, im:10.75, delta:0.16, length:1000 m and top of Air Refractive index is 1. Free space wave length: 1550 nm, $\varepsilon_m = \varepsilon'_m + \varepsilon''_m = 0.38 + i10.75$.

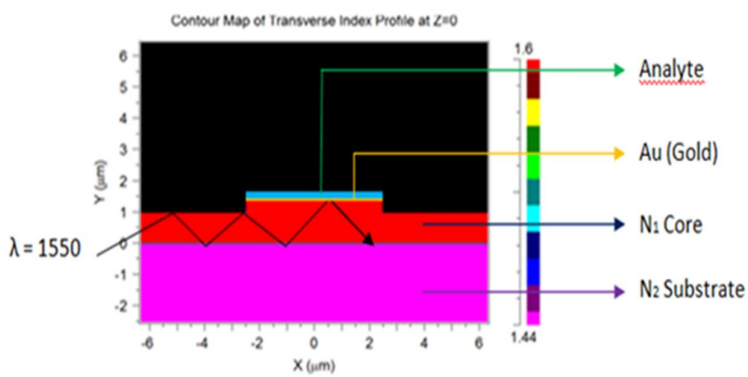

Figure 7 : Free space wave length: 1550 nm, width: 5 m, height: 5 m, Background material: Sio2,cover material: Air:1, Layer1, SU8:re: 1.6,layer2, Height: : 0.07 m, Au: Re:0.38, im:10.75,, layer3, Height: : 0.07 m, Analyte: Re:1.33, delta:0.16, length:1000 nm, Slab Height: 1

According to above equation we are taking 1550nm input wavelength the layer 1 guided index SU8 Real part N_2 = 1.6. and the Gold real part of refraction index N_1 = 0.38. Applying the these values above equation adjust the refractive index. The integrated optical Multi layered waveguide SPR sensor structure as shown in figure 7 it consists of a planet waveguide multilayer structure supporting the surface plasmon The multilayer contains an SPR active material usually Gold(Au).The other layer Analyte. Light propagate through waveguide excites surface plasmon in the multi layer structure the phase velocity of the waveguide mode and that of the surface plasmon match. the surface plasmon propagation constant depends strongly in wavelength. To operating wavelength of the sensor determined by the refractive index profile of the wave guide properties of the SPR active metal layer and the refractive index of the Analyte. In this sensor application Analyte refractive index 1.33. The input wave length varying from 1400 nm to 1600 nm range in plane slab waveguide. in order to shift 1440 to 1460 as shown in figure 8.

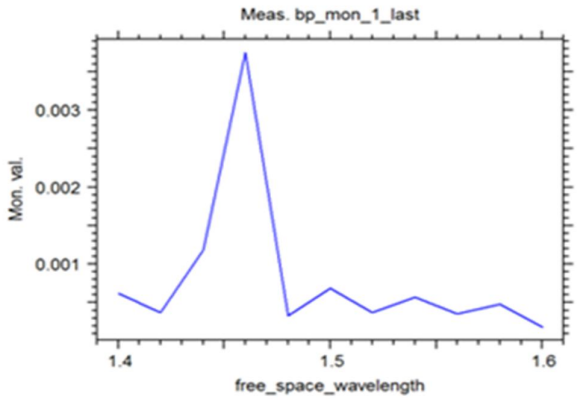

Figure 8. Excitation of wavegude based SPR without sample

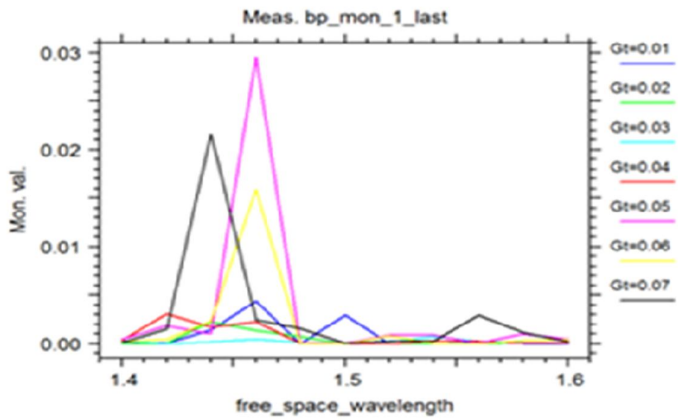

Figure 9. Excitation of wavegude based SPR with sample

To operating wavelength of the sensor determined by the refractive index profile of the wave guide properties of the SPR active metal layer and the refractive index of the Analyte. In this sensor application Analyte refractive index 1.33. The input wave length varying from 1400 nm to 1600 nm range in plane slab wave guide. in order to shift 1440 to 1460 as shown in figure 7, change in refractive index i.e. cover material see the excitation of sensing variation shown in figure 9.

V. CONCLUSION

In this review has analyzed sensor development and discussed up-and-coming trends in SPR-sensing. In order to demonstrate the potential of SPR-sensing plans, major application fields of SPR sensors have been outlined and examples of applications have been discussed. In the past 10 years optical sensors are exposure of bio interactions with applications in Health care , Drug analysis detection, pesticides, medical environmental pollution, bio-investigate discovery. The sensors are wide variety of design to detect Bio-interactions. Surface Plasmon Resonance Integrated optical structure waveguide polarization interferometer biosensors are frequently used techniques with commercial availability. Optical SPR sensors are low cost and ruggedness. Beam Propagation Method (BPM) refers to a computational technique in Electromagnetic, used to solve the Helmholtz equation under conditions of a time harmonic wave. Tool will take care inside mathematical equations. The main challenges and future work of the SPR sensors change in refractive index and improve the sensitivity. We have compared with Aluminum layered metal waveguide biosensor with the gold layered metal waveguide biosensor having some particular affinity layers for the finding of Pseudomonas and Pseudomonas-like Bio solution.

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