



Multilayer with periodic grating based high performance SPR waveguide sensor

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ABSTRACT

We propose a high performance periodic grating coupled multi-layered surface plasmon resonance (SPR) waveguide based on Al + Au. High sensitivity is obtained by using grating filled with silver instead of air. Further sensor's performance is analysed by optimising width and thickness of SPR active metal layer as well as grating period also. Using finite difference time domain (FDTD) method, we have shown that sensitivity and detection accuracy can be improvised using appropriate multi-layered grating configuration.

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1. Introduction

In the recent years, optical properties of metallic structures have shown renewed interest. This influence empowers to minimise the structures or dimensions of optical devices, which is becoming probable due to the advancement in the patterning of metals [1,2]. Meanwhile SPR (Surface Plasmon Resonance) based optical sensors have marked their presence due to emerging bio-sensing application areas. SPR biosensors have been widely explored and several geometries related to SPR configuration have been developed [3,4]. To detect small changes in refractive index, for example that near to metal-dielectric, SPR technology was first introduced. In addition to that, it has several advantages like high sensitivity, fast speed response etc. Previously SPR biosensing technology used the Kretschmann configuration which constituted the prism based implementation of attenuated total reflection [5]. SPR technique is based on the electromagnetic oscillations generated due to free charge density fluctuations which propagate through metal and dielectric interface are known as Surface Plasmon [6]. Recently surface plasmons have gained more interest of researchers as it has the ability to propagate through sub-wavelength sized holes [7]. Multilayered metallic nanostructure is also in focus other than single metallic interface since it has an advantage of using same plasmonic active metals at both ends to obtain structures with improved optical responses [8]. The bi-metallic layered structure has the ability to squeeze the surface

plasmon modes in the dielectric region. The improvement in computational techniques for better understanding of plasmonic behaviour in bi-metallic structures and consistent fabrication methods have made it promising to use complex metal structures for various applications [9]. It is worth mentioning that performance of SPR sensor will be determined by dispersion properties of metals [10]. Generally, metals which show dispersion properties and have SPR characteristics like silver (Ag), gold (Au) and aluminium (Al) etc. Further each SPR metal exhibits its own SPR properties, such as aluminium exhibit narrower resonance curve while gold carries better chemical stability and absorption coefficient [3]. Although Al have some issues over chemical stability, so to overcome this issue we have simulated the multilayered grating waveguide of gold and aluminium. West et al. [11] emerged new window for alternate plasmonics materials with the aspects of fabrication. They also represented the comparative study of different type of metals, metal alloys and doped semiconductors. In continuation of that Xiao et al. [12] also stated the theory of enhanced transmission through a gold film with sub wavelength array holes. They emphasised this technology for door opening of surface plasmon based sensors. Jory et al. [13] demonstrated a prototype of SPR sensor with gratings, with angular interrogation method. In continuation to this, Hu et al. [14] also proposed a high performance grating coupled SPR sensor to achieve angular sensitivity of 187.2°/RIU. Srivastava et al. [3] proposed a periodic multilayered SPR waveguide sensor with SPR active metals. Some of them only focused on the angular interrogation which was so complex in optimising and calibration. Moreover, angular interrogation method was not so accurate vide Srivastava et al. [3]. While maintaining a periodic multilayered waveguide is

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impractical for obtaining high end accuracy and sensitivity. In view of above, we have investigated a high performance multilayered grating SPR sensor and optimised it with few SPR metals i.e. gold (Au) and aluminium (Al).

2. Theory

The proposed MSPGW (Multilayered surface plasmon grating waveguide) geometry based on surface plasmons is shown in Fig. 1. It includes a stacked layer of metal and dielectric with periodic gratings. Assuming that the waveguide is fabricated with core of silica having a refractive index of 1.5, with a periodic grating of $\Lambda = 100$ nm filled with silver. The core is sandwiched in between multilayer of metals i.e. gold and aluminium of thickness 10 and 5 nm. Metal layer is further followed by an analyte i.e. sodium chloride of having refractive index of 1.360. In this geometry, the interface between metal and dielectric is modulated with a period Λ . According to the grating equation $\sin \theta = n\lambda/\Lambda$, where (θ is the angle of diffraction, λ is the wavelength of light, Λ is the grating pitch and n is the diffraction order) [13,15]. So general equation by implying the surface plasmons [13].

$$k_n = k_0 \sin \theta \pm 2\pi n/\Lambda \quad (1)$$

where k_0 is the wavevector of incident photon and k_n is the grating plane surface wavevector. Normally surface plasmons are excited at the metal interface when their momentum matches, the momentum of the incident photon or wavevector of SPR along the said interface is equal to k_n , by keeping θ fixed and varying the wavelength. Normally for a sensing region, resonance wavelength is highly sensitive to change in the refractive index of sensing material for a sensor [16]. Further, light from a tunable laser source is passed through the proposed waveguide core using optical devices and suitable detector. As discussed above, transmission spectrum shows minimum value at a particular resonance wavelength. Similarly, a slight change in refractive index of analyte brings good shift in wavelength spectrum that forms the essentials for refractive index sensing.

In this manner, sensor is basically qualified in terms of sensitivity (S_n) and accuracy detection (DA). Due to variation in refractive index of analyte, the variation in resonance wavelength is obtained. Hence sensitivity is defined as ratio of variation in

resonance wavelength to variation in refractive index of analyte. Further detection accuracy $DA = 1/\text{FWHM}$ (Full width at half minimum) of transmission curve.

3. Results and discussions

To design the proposed sensor, first we have determined the suitable thickness of metal layers. Surface plasmons exhibit TM wave in-turn also called p-polarised light. To better understand the phenomena of p-polarised light at transmission output, we followed a general equation of transmitted power normalised with source power and written as [17]

$$P(f) = \exp\left(-\frac{4\pi}{\lambda} \text{imag}(n_{\text{eff}})L\right) \quad (2)$$

where n_{eff} is the effective refractive index of surface plasmons. Here we have taken the imaginary part of effective refractive index to show the dip of resonance wavelength. We have done a series of simulations to investigate the performance of proposed sensor through FDTD method. We used standard method i.e. band solver to calculate the result and also find out the mode effective indices of multilayer periodic gratings. We assume that refractive index of substrate $n_s = 1$ and the thickness of metal layer = 10 nm. In order to find out the impact of metal layer with periodic gratings with following variations i.e. (i) gratings with gold – analyte (ii) Al based MSPGW sensor with the proposed waveguide as per parameters mentioned above. The changes in mode effective index (n_{eff}) with respect to the wavelength are shown in Fig. 2.

The value of dielectric constants of gold, silver and aluminium is taken from Palik [18]. The effective refractive index variation with existing modes using band solver is shown in Fig. 3. We have

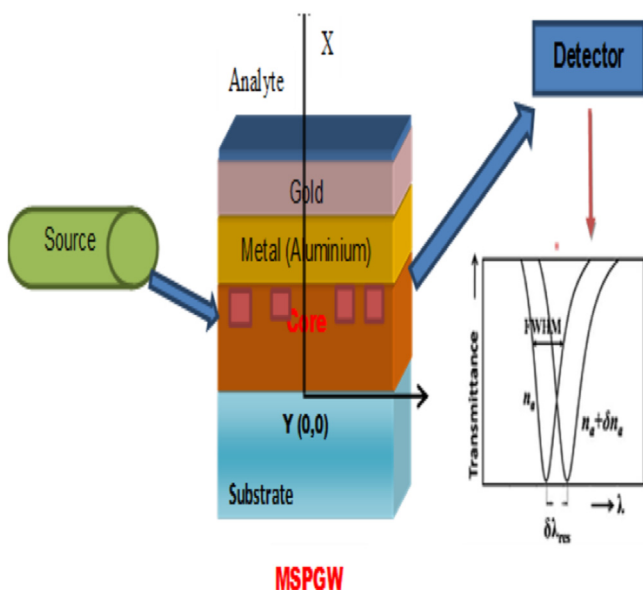


Fig. 1. Proposed configuration of MSPGW geometry.

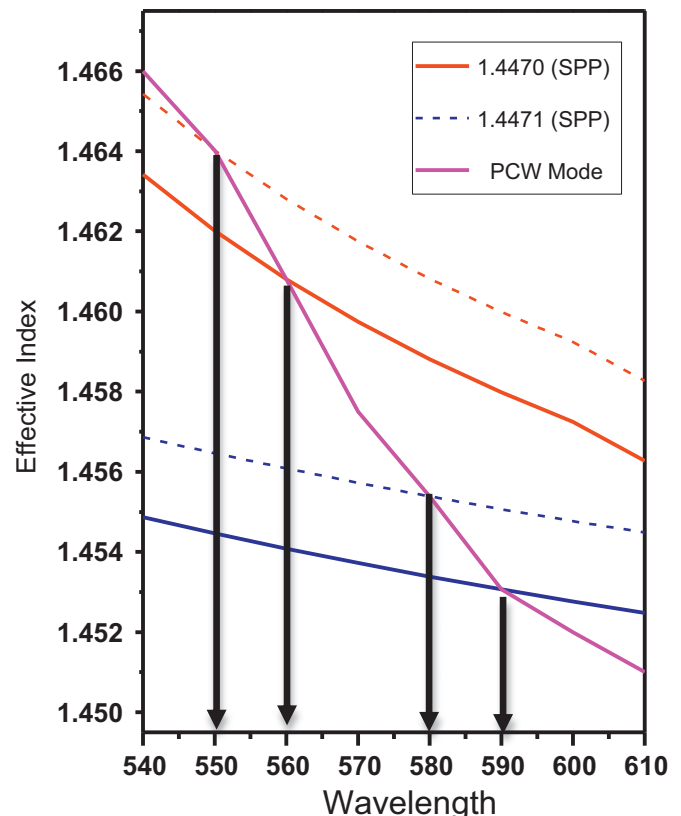


Fig. 2. Variation with effective refractive index w.r.t wavelength for exciting mode of Multilayer grating waveguide and SPP of plasmonic waveguide for gold and aluminium at $n_s = 1.4470$ and 1.4471 .

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