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Factors Toward The Development Of A Robust Surface Plasmon Resonance Based Sensor

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Abstract

Plasmonics is one of the very promising branches of photonics, which have been integrated into many applications due to its potentials in miniaturizing optical devices, and the fabrication of high sensitive sensors. The high sensitivity of surface-plasmon resonance (SPR) sensors allows the detection of small variations in the surface. Many researches were conducted in order to design a highly sensitive optical sensor based on surface plasmon resonance, commonly for medical applications and the early detection of disease. This work reviews the factors that were studied in order to enhance the sensitivity, such as the SPR mode, and the effect of structure symmetricity.

Keywords*:* Plasmonics, surface plasmon resonance.

1. INTRODUCTION

Due to technological advancements, and the availability of high performance computing devices, many scientific and technological branches have been revolutionized, notable among them photonics. Plasmonics is one of the very promising branches of photonics, which deals with the study and application of surface plasmons[1][2][3].At the metal-dielectric interface, surface plasmon waves are generated at optical wavelengths. The discovery of surface plasmon phenomena has given scientists the ability to control the structure and properties of materials at an exceptional levels, since surface plasmons have numerous attractive features such as, resonant behavior, and the ability to confine light at nanometer scales which have been applied in biomedical applications. In addition to the high field intensity at the metal-dielectric interface, and slow group velocity. These features attracted scientist and engineers for taking advantage of plasmonics in many applications starting from solar cells, up to nanolithography and near field microscopy[4].When the electromagnetic waves couples with the oscillating conduction electrons of the metal,

the surface plasmon polariton (SPP) is formed, these particles starts propagating along the metal-dielectric interface with amplitudes decaying into both layers. SPP is used to overcome diffraction limit. This leads to the fabrication of photonic devices at very smaller scales than those currently achieved. The task of designing surface plasmon resonance (SPR) based sensor requires taking many aspects into consideration, such as the sensitivity. Several methods have been developed to enhance the SPR sensor sensitivity[5].This includes the proper choice of the operating wavelength, type and thickness of the metallic film, and the structure of the holes [6].
In this paper, the sensitivity optimization techniques that was proved theoretically and experimentally are listed. The paper is structured as follows: the effect of surface plasmon resonance mode is discussed in section 2. Symmetricity of structure in section 3. In section 4 the thickness of the metal film is discussed. Where in section 5 the effect of composing a multi-layered structure is explained. Finally, section 6 illustrate the wavelength region for optimum sensitivity.

2. SPR MODE

The propagated surface plasmon (PSP) and the localized surface plasmon (LSP) are the two modes or platforms that base an SPR sensor, the SPR mode is taken into consideration when it comes to biosensing applications. The PSP sensor is based on a thin film gold planar [7], which reaches its maximal sensitivity for very small molecules. However, this mode achieved low detection limits for larger molecules. The LSP sensor uses more spatially confined nanostructures such as the nanospheres and the nanorods, which has achieved a remarkable values of sensitivity. The sensitivity of the LSP mode can be enhanced depending on the nanoparticle shape and dimension. Combining the two modes into a single structure can overcome the problems with the PSP mode, but the sensitivity of the combined structure is still less than the LSP mode. The combination can be used in commercial applications due to ease and accuracy of fabrication[8]. The structure of the sensor for optimum sensitivity that is based on the selected mode is described next.

3. SYMMETRICITY OF THE STRUCTURE

The performance of any SPR sensor is determined in terms of two aspects. First, the resonance angle shift as per refractive index changes must be as large as possible. Second, the sharpness of the SPR curve that is known as the full width at half maximum (FWHM). The sharpness of the curve minimizes the error in determining the resonance angle. Researchers defined a performance parameter called intrinsic sensitivity which directly proportional to the FWHM. Intrinsic sensitivity of the SPR sensor is mathematically calculated using equation (1)[9]:

$$\frac{Shift\ in\ resonance\ angle}{FWHM} \tag{1}$$

One of the methods used to modulate the wavelength and the resonance angle of the

SPR sensor is the symmetricity of the structure. Many researchers approved that the asymmetric structure enhance the FWHM of the reflectivity curve, and therefore improve the quality of the signal. For example, the asymmetric structure of the SPR sensor using the ZnO as an intermediate layer exhibited a much higher sensitivity[10]. Additional criteria for optimizing the sensitivity, which is the thickness of the metal film is discussed next.

4. METAL FILM THICKNESS

In a study conducted by Hyuk Rok Gwon and others[11], it was found that the sensitivity is highly dependent on thickness of the metal film. Hence, Kolomenskii[12]the optimum thickness that result in a maximum sensitivity can be analytically calculated using equation (2):

$$Dopt = \left({}^{1}/_{2kp}\right)\left({}^{\varepsilon 2r}/_{\varepsilon 1r}\right)^{1/2} \ln\left\{\frac{(4kp\ np^{2}\ \alpha\varepsilon 0)}{[I1i\ (|\varepsilon 1r| + \varepsilon 2)\ \times\ (a^{2} + \varepsilon 0^{2})]}\right\} \tag{2}$$

The SPR sensor can be structured using multi-layers instead of having single dielectric layer and single metallic layer, types of multi-layered structures is discussed in the next section.

5. MULTI-LAYERED STRUCTURE

In a multi-layered SPR system, each metal-dielectric interface can sustain bound surface plasmon polariton. Interactions between the two adjacent plasmonic surfaces reaches couple modes, whenever the distance between the two surfaces is smaller than the decay length of the interface mode. Multi-layered system can be either one of the two[13]:

i. A single thin metallic layer surrounded by two thick dielectrics, a dielectric-metal-dielectric interface
ii. A thin dielectric layer surrounded by two metallic surfaces, a metal-dielectric-metal interface

In a study proposed by Xihong Zhao and others [14], the adjustment of the SPR resonant wavelength in addition to the sensitivity enhancement of the SPR sensor is achieved by structuring the multi-layered system. It was also proposed that compacting the size of the multi-layered system, results in enhancing the refractive index detection range in addition to the sensitivity. The surface plasmon to be formed, a wave must be directed to the surface, the wavelength also affects the sensitivity as discussed next.

6. WAVELENGTH REGION

Increasing the wavelength reduces the angle shift and sharpen the SPR curve, precisely wavelength region influences the sharpness of the curve rather than the resonance wavelength. Hence, the intrinsic sensitivity is larger in the IR region.This result is based on taking the imaginary part of the metal and dielectric into account, therefore the plasmon vector is composed of real part which determines the shift in resonance angle, in addition to the imaginary part which determines the sharpness of the curve[9].

7. CONCLUSION

In conclusion, it is expected that designing a localized surface plasmon resonance based sensor using compact multi-layered system with a metal thickness that satisfies Kolomenskii equation, with asymmetric structure that operates in the IR region, will result in a high sensitive SPR sensor. This paper will be extended with a simulation of an SPR sensor satisfying the above characteristics, in addition to performance evaluation.

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