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The Sensing of Refractive Index Based on a Metal-Insulator-Metal Array

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Abstract: A refractive index sensor based on a metal-insulator-metal array structure has been proposed. In both the visible and near-infrared spectrum regions, the incident wave can transmit through a seamless gold film near a specifically designed frequency due to the excited surface plasmon resonance. A nearly 100% transmission through an 80 nm-thickness Au film can be archived. The simulation results show that it is also sensitive to the refractive index change surrounding the sensor. These findings could open a new and simplified alternative approach to make sensor more miniature.

Key words: metal-insulator-metal array structure; surface plasmon resonance; miniaturization; sensitivity
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0 Introduction

Promoted by the demand of biochemical detecting, environmental monitoring and so on, the refractive index(RI) sensors [1-2] are being rapidly developed. Consequently, detection of a single molecule is feasible since the sensitivity up to 10^{-8} RI unit has been demonstrated. Much attention [3-6] recently was focused on how to miniature the sensors for achieving the portable sensing. The surface plasmon resonance (SPR) [7], which is the resonance excitation of the surface plasmon polariton at a metal-dielectric interface by evanescent optical waves, is one of the most promising ways to get the miniaturization. There is a reflectivity resonant dip can respond to the RI change nearby the interface in real time. Therefore, the SPR can provide rich information on the specificity, affinity, and kinetics of molecular interactions and/or the concentration of analyte to be detected. Different from the conventional SPR, many metal micro-nano structures [8-20] (eg. nanoparticles, nano-holes and metal-insulator-metal with periodic grooves) have been utilized to constitute the miniaturized SPR sensors. In this paper, a miniaturized RI sensor based on a metal-insulator-metal(MIM) array structure is proposed. Furthermore, the simulation result shows that the sensor exhibits a high sensitivity responding to the ambient RI change.

1 Structural Design and Simulation

The proposed MIM array structure for sensing RI is illustrated in Figure 1. A glass substrate is covered by a gold film with a thickness of h_c. Above the gold film, there is a two-dimensional array of cubic quartz (the height is denoted as h_b), which is sputtered by another gold cube with a thickness of h_a. The whole MIM array structure is illuminated by a normal incident plane wave. The top to bottom boundary condition is the perfectly matched layer(PML) absorbing boundary conditions. In the following sections, the transmission spectra of the MIM array structure and the corresponding distribution of electromagnetic fields at the resonant frequencies are numerically calculated by using a commercial FDTD package. The sensitivity for the MIM array structure of sensing the RI is also given.

From the simulation results, it is clear that the incident wave is nearly perfectly transmitted through the

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MIM array structure due to the incident light energy coupled into the surface plasmons, while out of the resonances the incident wave is almost reflected and absorbed. Consequently, there is a series of resonance wavelengths where a narrow transmission peak can be observed. The resonant wavelength is determined by the structure parameters and varies according to the change of ambient RI. By altering the structure parameters, the resonant wavelength can cover a large dynamic spectrum range from visible to near-infrared. A minor variation in the ambient RI (Δn) will lead to a dramatic change of resonance wavelength($\Delta\lambda$) ,and the sensitivity of the MIM array structure is defined as $S_\lambda = \Delta\lambda / \Delta n$.

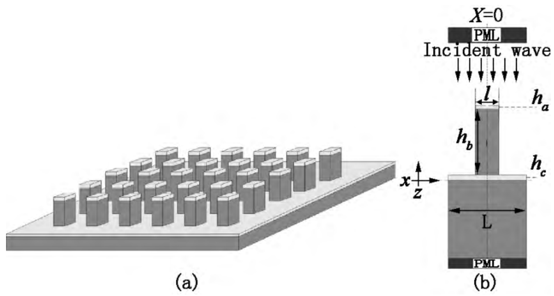

Figure 1 Schematic of the MIM array structure.

The transmission spectra for different quartz pillar heights h_b are shown in Figure 2. The h_b is increased from 350 nm to 650 nm with a step of 100 nm while other parameters is kept unchanged. The array period L and the side length of gold cube l are 460 nm and 400 nm, respectively. The thicknesses of the top gold cube h_a and the bottom gold film h_c are 60 nm and 80 nm, respectively. It is found that the transmission peak becomes narrower and higher as the quartz pillar height is increased. The distribution of electric field inside the MIM array structure at the resonant wavelength is given in Figure 3.

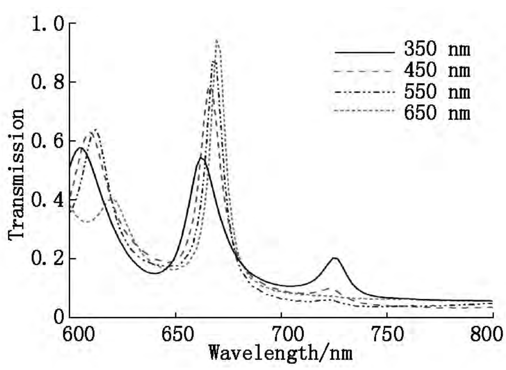

Figure 2 Transmission spectra for different quartz pillar heights h_b.

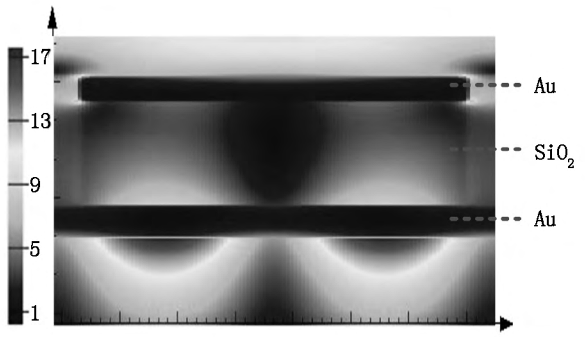

Figure 3 The distribution of electric field intensity $|E|^2$ at the resonant wavelength 672.2 nm.

The electric field intensity is greatly enhanced sincethe surface plasmon excited around the interface between the bottom gold film and the quartz. As a result, the incident wave is nearly perfectly transmitted at the resonant wavelength 672.2 nm.

The transmission spectra for the varied array periods L are shown in Figure 4. The thicknesses of the top gold cube h_a and the bottom gold film h_c are 60 nm and 80 nm, respectively. The height of quartz pillar h_b is and the side length of gold cube l is 400 nm. The array period L is varied from 400 nm to 550 nm with an interval of 50 nm. Obviously, an increased array period results in a narrowed resonant bandwidth and decreased peak intensity. Meanwhile, there is a remarkable red shift for the resonant wavelength due to the weakened plasmon resonance coupling. This desirable feature provides us a potential way to alter the resonant wavelength into different spectrum regions and thus meet different light sources and detection systems.

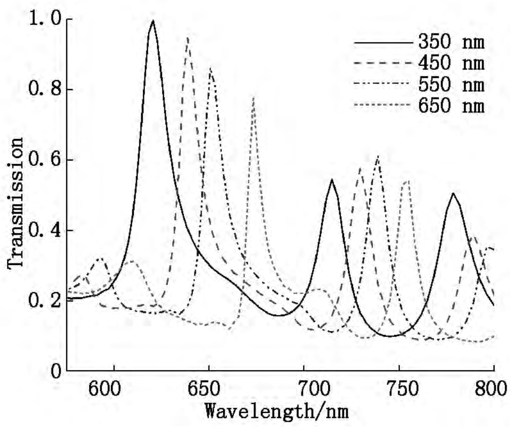

Figure 4 Transmission spectra for the varied array periods

Figure 5 shows the transmission spectra for the different thicknesses of the top gold cube h_a and the bottom gold film h_c, respectively. The array period L is

460 nm,the side length of gold cube l is 400 nm and the height of the quartz pillar is 650 nm. In Figure 5 (a),the thickness of the top gold cube $h_a = 30,60,90,120$ nm while h_c is fixed at 80 nm. In Figure 5(b), the thickness of the bottom gold film $h_c = 15,30,60,80$ nm while h_a is fixed at 60 nm. With increasing the thickness h_a or h_c,the position of the resonant transmission peak shifts to the infrared region.

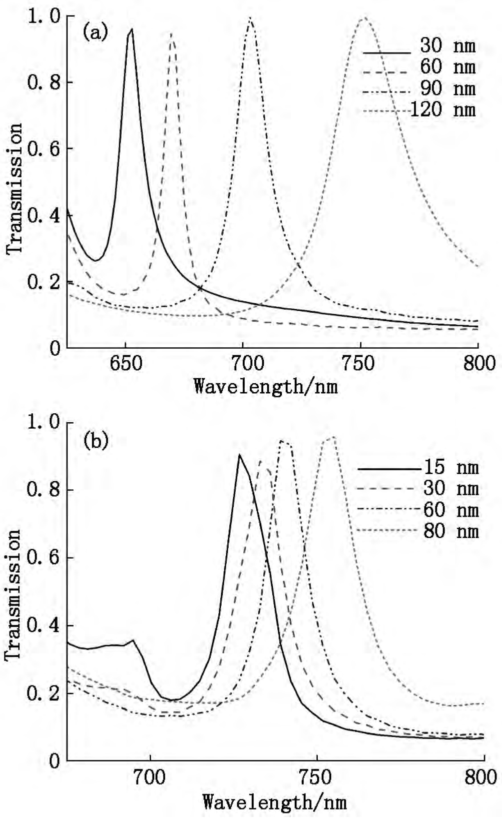

Figure 5 Transmission spectra for(a) the varied h_a and (b) the varied h_c.

Here this paper consider the sensitivity of the proposed MIM array structure. The array period L,the side length of gold cube l,the height of the quartz pillar are set as 460 nm, 400 nm, 650 nm, respectively. The thicknesses of the top gold cube h_a and the bottom gold film h_c are 60 nm and 80 nm,respectively. Figure 6(a) shows the transmission spectra for different ambient RI,which is tuned from 1.30 to 1.36 with a step of 0.02. It is obvious that a minor change in the ambient RI can lead to a dramatic change of resonant wavelength. The plot of corresponding resonant wavelength as a function of ambient RI is shown Figure 6(b). It indicates that the MIM array structure is linearly responding to the ambient RI change. The sensitivity is calculated by using the formula

$$S(\lambda,n_1,n_2) = \lim_{\Delta n \to \infty}(\lambda(n_1) - \lambda(n_2))/(n_1 - n_2).$$

The obtained sensitivities are as follows: $S_1 = (749.6 - 734.2)/(1.32 - 1.30) = 770$ nm/RUI, $S_2 = (764.8 - 749.6)/(1.34 - 1.32) = 760$ nm/RUI and $S_3 = (780.4 - 764.8)/(1.36 - 1.34) = 780$ nm/RUI.

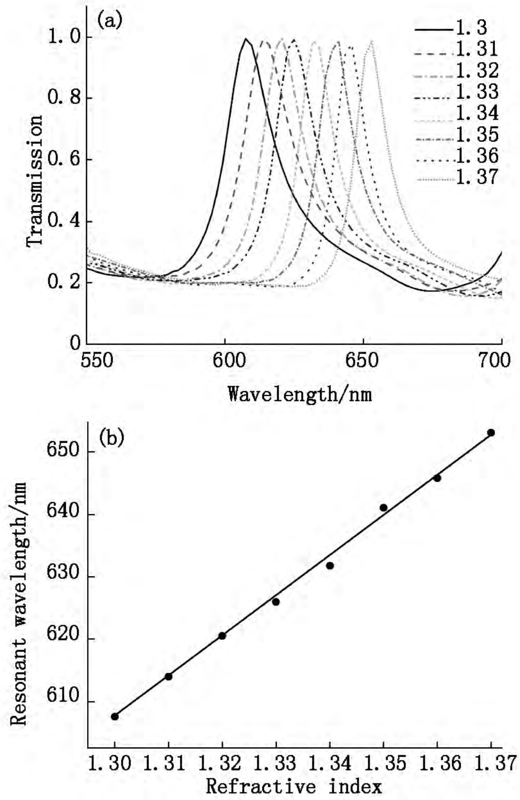

Figure 6 (a) Transmission spectra for different liquid refractive index,(b) the resonance wavelength with respect to the liquid refractive index.

2 Conclusions

In conclusion,a RI sensor based on a MIM array structure is proposed and its high sensitivity is numerically simulated by using a commercial FDTD package. The resonant wavelength of the transmission spectra is determined by the structure parameters,the paper have got a narrowed resonant bandwidth by use a appropriate structure parameters. The resonant wavelength of the transmission spectra is responding to the change of ambient RI. The sensitivity of the proposed sensor structure can reach to 780 nm/RUI in the visible range.

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基于金属-介质-金属阵列的折射率传感

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摘要: 提出一种基于金属-介质-金属阵列结构折射率传感器. 在可见光及近红外光区域内,由于表面等离子效应,入射波在特定频率时可以通过一个无缝的金,在 80 nm 厚的金膜上可以得到近 100% 的透射率. 仿真结果表明传感器对周围液体的折射率变化也很敏感,这些发现可以得出一个新的、简化的替代方法,使传感器更加小型化.

关键词: 金属-绝缘体-金属阵列结构; 表面等离子体共振; 小型化; 灵敏度

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