A novel plasmonic nanosensor based on electro-magnetically induced transparency of waveguide resonator systems

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Abstract

We propose a plasmonic refractive index-sensitive nano-sensor based on the electromagnetically induced transparency (EIT) of waveguide resonator systems. The structure consists of one tooth-shaped cavity as well as the bus and stub metal-insulator-metal waveguides. By adjusting the structural geometry, it is demonstrated that the controllable transmission of EIT response can be obtained with the finite-difference-time-domain simulations. It is found that the transmission spectra dip can be strongly controlled by changing the refractive index filled in the stub waveguide. The calculated results show that the sensitivity of tbe plasmonic nanosensor is 733 nm/RIU.

I. INTRODUCTION

Nanoplasmonic devices are emerging as a new focus of scientific research because of their unique ability to manipulate light, particularly in subwavelength optics fields. In the devices, surface plasmons (SPs) [1,2] are utilized to enhance the optical field intensity and overcome the classical diffraction limit. Recently, many devices based on SPs have been proposed and applied widely, such as plasmonic imaging systems [3,4], nanocavity [5], absorbers [6,7], transistors [8, 9, 10] and sensors [11,12]. Among the devices, plasmonic nanosensor is one of the most important and successful applications because of its high sensitivity. It is now widely used in biology, chemistry and environment monitor. Nanosensor with better performance is still expected.

Recently, some new sensors with novel structures and excellent characteristics have been reported. Liu *et al.* have presented a compound rectangle hole structure. The structure can excite electromagnetically induced transparency (EIT) response [13]. The EIT peak depends on the refractive index changing of the sample surface. It is indicated that the sensitivity and figure of merit (FOM) of the sensor are 588 nm/RIU and 3.8. Meanwhile, Lu *et al.* have reported a sensor based on the Fano resonance in metal-insulator-metal waveguide-coupled resonator systems [14]. The sensor shows that the sensitivity and FOM are about 900 nm/RIU and 500. The new type sensors offer a suggestive way to realize the plasmonic nanosensor with better performance.

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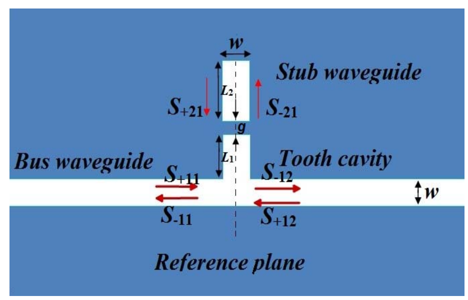
In this paper, a plamonic nanosensor, sensitive to the refractive index, is proposed with the EIT resonator systems. The structure consists of one tooth-shaped cavity as well as the bus and stub metal-insulator-metal waveguide. It is found that the EIT dip strongly relies on the refractive index filled in the stub waveguide. The calculated results show that the sensitivity is 733 nm/RIU.

II. Numerical model and simulations



(a) (b)

Figure 1. (Color online) Schematic for the tooth-shaped plasmonic resonator based on the induced transparency system;

Fig. 1 shows the basic scheme of the plasmonic metal-insulator-metal waveguide resonator structure. The materials in the blue and white areas are chosen to be silver and air (n=1), respectively. The dielectric function of silver obeys the Drude model as $\varepsilon_m = \varepsilon_\infty - \omega_p^2 / \omega(\omega + i\gamma)$. Here $\omega_p = 1.38\times10^{16}$ Hz and $\gamma = 2.73\times10^{13}$ Hz are the bulk plasma and damping frequencies of the oscillations, respectively. ε_∞ stands for the dielectric constant at infinite frequency with a value of 3.7 [15].

A tooth-shaped cavity is formed by a plasmonic slot cavity with length L_1 being connected to the bus waveguide directly. A stub waveguide of length L_2 is on the top of the tooth-cavity with a distance $\boldsymbol{g}$. The width of the metal-insulator-metal waveguide in the whole structure is fixed at 50 nm so that only the fundamental TM mode can be supported [16]. When a TM-polarized plane wave is coupled into the bus waveguide from the left side, surface plasmon polariton (SPP) waves can be excited at the metal-insulator interfaces and confined in the insulator layer. The propagations of SPPs are simulated by using commercialized EM simulation software EastFDTD with finite-difference-time-domain (FDTD) method [17].

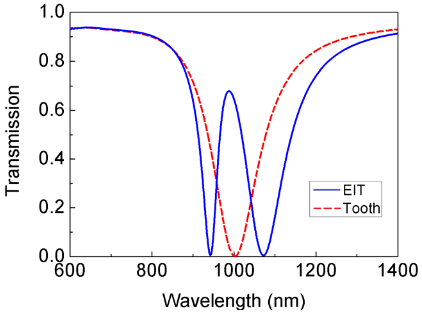


Figure 2. (Color online) The transmission spectra of the tooth-shaped cavity resonator system without (red dash curve) and with (blue solid curve) stub waveguide

The transmission spectra of the plasmonic resonator system are presented in figure 2. The red dash and blue solid curve are the transmission spectra with L_2 is zero and 300 nm, respectively. The other parameters are L_1 = 150 nm, g = 20 nm and w = 50 nm. When L_2 is zero, the coupling between tooth-shaped cavity and the stub waveguide does not exist. The calculated results show that there is a transmitted dip at the resonance wavelength (1000nm) of the tooth-shaped cavity. When L_2 = 300nm, it is found that there is a narrow transparency peak at 1000nm and two distinct transmitted dips locate at 942 nm and 1072 nm, respectively. It can be seen that the EIT peak results from the coupling between the tooth-shaped cavity and the stub waveguide.

Fig. 3 illustrates the redshift of the "shorter" wavelength (SW) dip with different refractive indices (n) filled in the stub waveguide. In order to obtain good performance for the nanosensor, the length of the stub waveguide is set as L_2=250 nm. With n increasing from 1.00 to 1.03, the wavelength of SW dips changes from 829 nm to 851 nm. The sensitivity of the nanosensor is 733 nm/RIU.

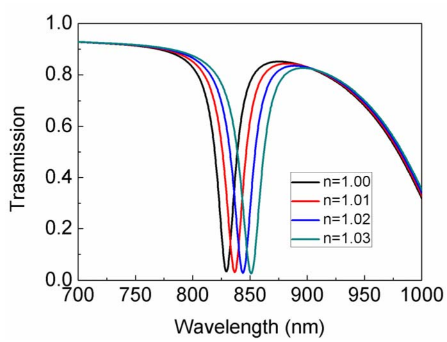


Figure 3. (Color online) Transmission spectra with different refractive indices (n) and L_2 = 250 nm.

III. Conclusion

In this paper, a novel plasmonic refractive index-sensitive nanosensor has been proposed and numerically investigated. The structure consists of one tooth-shaped cavity as well as the bus and stub metal-insulator-metal waveguides. The calculated results show that the SW transmission spectra dip of the EIT transmission spectra can be easily modulated by changing the refractive index filled in the stub waveguide. With the high sensitivity of 733 nm/RIU,,the proposed nanosensor may have significant applications in the field of highly-integrated optoelectronics.

Acknowledgements

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