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DESIGN AND SIMULATION OF ALL-OPTICAL NOT GATES BASED ON NANO-RING INSULATOR-METAL – INSULATOR PLASMONIC WAVEGUIDES

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Abstract

In this work, the all-optical plasmonic NOT logic gate was proposed using Insulator-Metal-Insulator (IMI) plasmonic waveguides Technology. The proposed all-optical NOT gate is simulated and realized using COMSOL Multiphysics 5.3a software. Recently, plasmonic technology has attracted high attention due to its wide applications in all-optical signal processing. Due to its high localization to metallic surfaces, surface plasmon (SP) may have huge applications in sub-wavelength to guide the optical signal in the waveguides which result in overcoming the diffraction limit problem in conventional optics. The proposed IMI structure is consists of dielectric waveguides plus metallic claddings, which guide the incident light strongly in the insulator region. Our design consists of symmetric nano-rings structures with two straight waveguides which based on IMI structure. The operation of all-optical NOT gate is realized by employing the constructive and destructive interface between the straight waveguides and the nano-rings structured waveguides. There are three ports in the proposed design, input, control and output ports. The activation of the control port is always ON. By changing the structure dimensions, the materials, the phase of the applied optical signal to the input and control ports, the optical transmission at the output port is changed. In our proposed structure, the insulator dielectric material is glass and the metal material is silver. The calculated contrast ratio between (ON and OFF) output states is 3.16 (dB).

Keywords: Surface plasmon (SP), Insulator-Metal-Insulator (IMI), all-optical NOT gates, all-optical signal processing.

I. Introduction

Recently, the need for huge bandwidth is highly increased to overcome the limitations of conventional electronic and photonic devices. All-optical signal processing plays a major role to realize ultra-speed processing, high data rate and overcoming the problems of heat and diffraction limit in conventional electronic and photonic devices respectively. Currently, the basic practical implementations of high data rate plasmonic devices are stepping out from the research laboratories. To realize all-optical signal processing technology, all-optical devices are the basic requirements especially the logic gates which are the main parts of all-optical systems. Surface plasmon (SP) exists at the boundary between the dielectric and metal materials of the design. The most important characteristic of surface plasmonpolariton (SPP) is the ability to couple the electromagnetic waves to make the propagation of free electrons oscillations at the dielectric-metal interface[I]. Overcoming the diffraction limit problem makes the surface plasmonpolariton (SPP) has a different application in highly integrated optical circuits[II]. Many all-optical devices in sub-wavelength have been proposed, such as switches[III], logic gates [IV-VI], modulators [VI], sensors [VII, VIII], and nanowires [IX]. Our proposed structure includes two nano-rings with two straight linear waveguides based on the IMI structure to demonstrate a plasmonic NOT gate.

II. Analyses and Numerical Results

Generally, the boundary between two semi-infinite materials having opposite charges negative and positive dielectric constants which guide the transverse magnetic (TM) waves effectively. Because the width of IMI plasmonic waveguides is smaller than the applied wavelengths, only the low orders transverse magnetic (TM) modes can be propagated. The equation of dispersion of (TM) mode in the waveguide is given by [X, XI]:

$$\varepsilon_d \kappa_m + \varepsilon_m \kappa_d \tanh\left(\frac{\kappa_d}{2}\right) = 0 \tag{1}$$

κ_d is defined as: $\kappa_d = \left(\beta^2 - \varepsilon_d \kappa_0{}^2\right)^{\frac{1}{2}}$ and κ_m is defined as: $\kappa_m = \left(\beta^2 - \varepsilon_m \kappa_0{}^2\right)^{\frac{1}{2}}$. ε_d is the insulator dielectric constant, ε_m is the metal-dielectric constant. The free space wave vector κ_0 is defined as: $\kappa_0 = \frac{2\pi}{\lambda}$. β is the propagation constant represented by the effective index of the waveguide $\eta_{eff} = \frac{\beta}{\kappa_0}$.

Drude model [XI]is used to calculate the dielectric constant (ε_m)of metal as:

$$\varepsilon_m(\omega) = \varepsilon_\infty - \frac{\omega_p{}^2}{\omega(\omega + \iota\gamma)} \tag{2}$$

at the infinite angular frequency, the dielectric constant ε_∞ is 3.7, the frequency of the bulk plasma ω_p is 1.38×10^{16} Hz, which is the natural frequency of free conduction electrons oscillations, the oscillations damping frequency γ is 2.73×10^{13} Hz, and ω is the angular frequency of the incident electromagnetic radiation. A plane wave with

TM polarization is applied to excite the SPPs [XII]. The transmission of the proposed system is defined as $T = {P_{tr}}/{P_{in}}$ where P_{in} is the input power, while P_{tr}represents the output power of transmission [XII, XIV].

III. All-Optical NOT gate

The proposed structure of the plasmonic NOT gate is shown in Figure. 1. The operation wavelength (λ) is 1310 nm, the nano-rings structure radii are (R) = 40 nmand (r) = 25 nm, the width of the straight waveguide (w) is 15 nm, and the coupling distances (d) between the nano-rings structures and straight waveguides is 5 nm. In our proposed NOT logic gate, there are three ports, input, output, and control ports, the control port is always in (ON) state. According to the NOT gate truth table that is shown in Figure.2, when the state of the input port is (OFF) state, the state of the output port is (ON) state. The magnetic field profile of the proposed structure in the case of (ON) output state and its optical transmission as a function of wavelength are shown in Figure. 3 and 4 respectively. The magnetic field profile of the proposed structure in the case of (OFF) output state and its optical transmission as a function of wavelength are shown in Figure. 5 and 6 respectively. The optical transmission of the proposed structure at different conditions is shown in Figure. 7. The realization details of the proposed all-optical NOT logic gate is presented in Table 1.

Table 1: The realization details of the proposed all-optical NOT logic gate

Input Port State	Phase Angle Degree	Control Port State	Phase Angle Degree	Optical Transmission	Transmission Threshold	Output Port State
OFF	0	ON	0	0.725	0.5	ON
ON	180	ON	45	0.35	0.5	OFF

IV. Conclusion

In conclusion, the plasmonic NOT logic gate was proposed, realized and investigated based on IMI plasmonic nanostructure. The constructive and destructive interference between the straight waveguides and nano-rings structures were employed to design all-optical plasmonic NOT gate. By changing the structure dimensions, the phase angle of the incident signal, the state of the output port is also changed accordingly. The simulated results show that the proposed structure of the gate could operate as a plasmonic NOT gate. The proposed design of the plasmonic NOT gate would be the main part of many applications that used to perform all-optical signals processing.

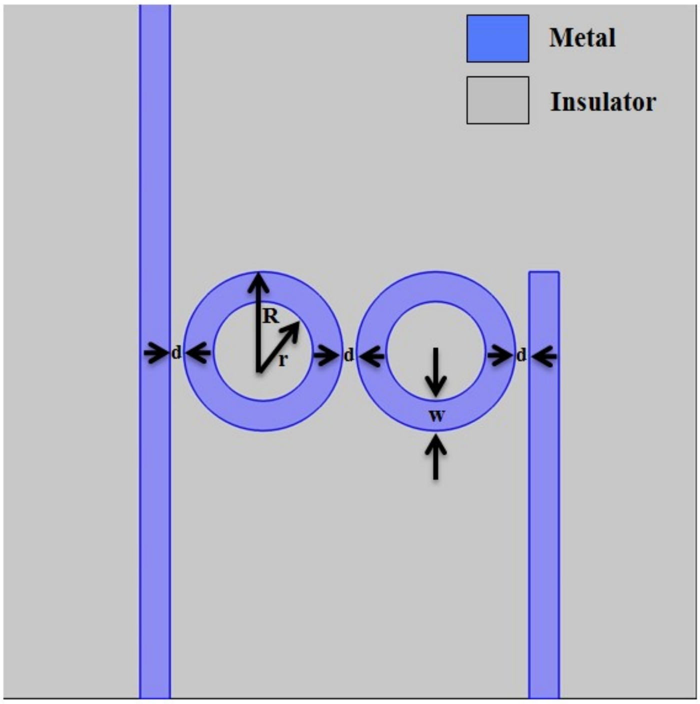


Fig. 1: The Proposed Structure of All-Optical Plasmonic NOT Gate.

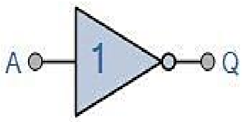
Symbol	Truth Table	
 Inverter or NOT Gate	A	Q
	0	1
	1	0
Boolean Expression Q = not A or $\overline{A}$	Read as inverse of A gives Q	

Fig. 2: The Conventional Symbol of NOT Logic Gate and Its Truth Table.

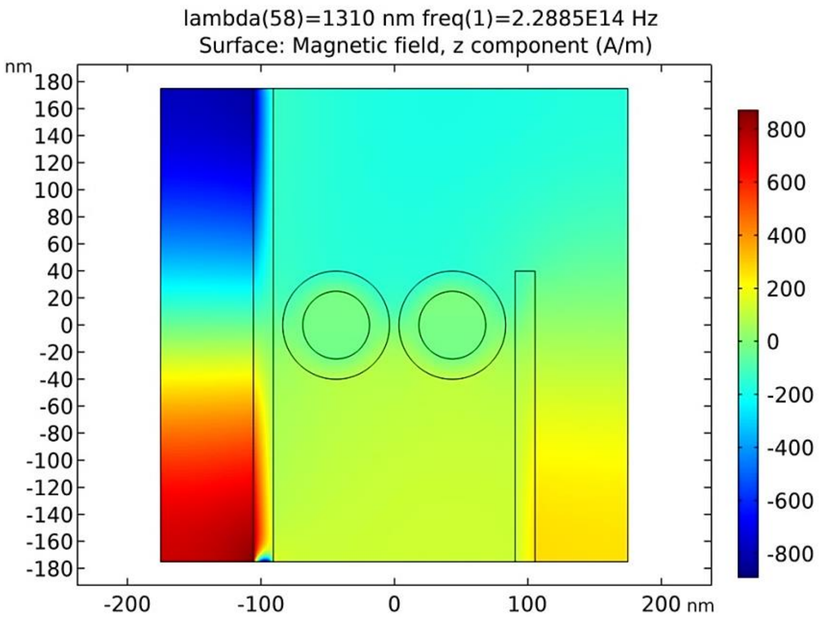


Fig. 3: The Magnetic Field Profile in Case of (ON) Output State.

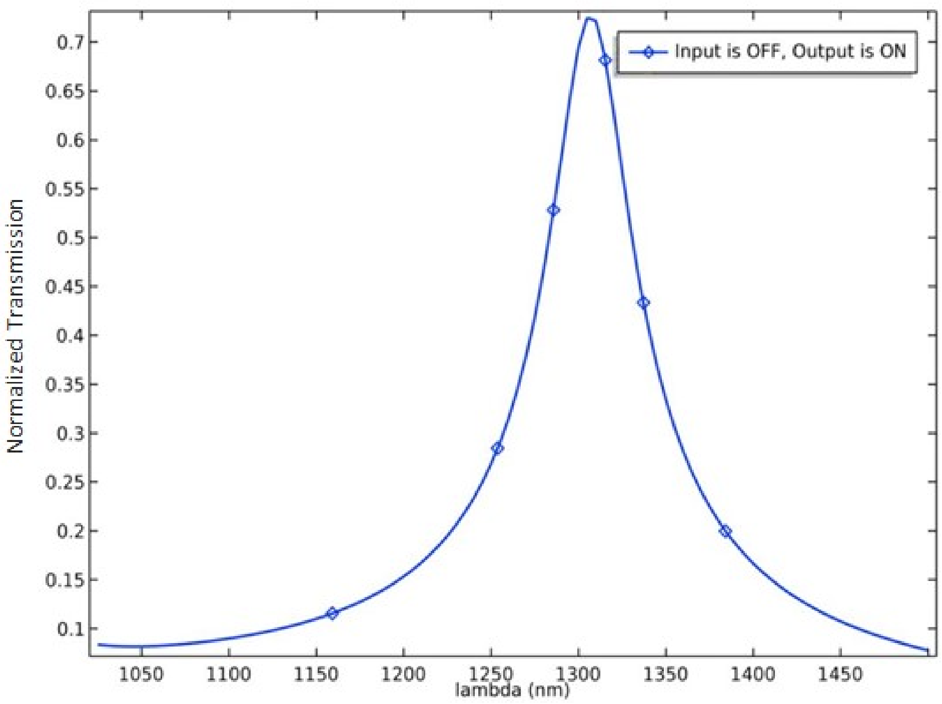


Fig. 4: Optical Transmission as a Function of Wavelength in Case of (ON) Output State.

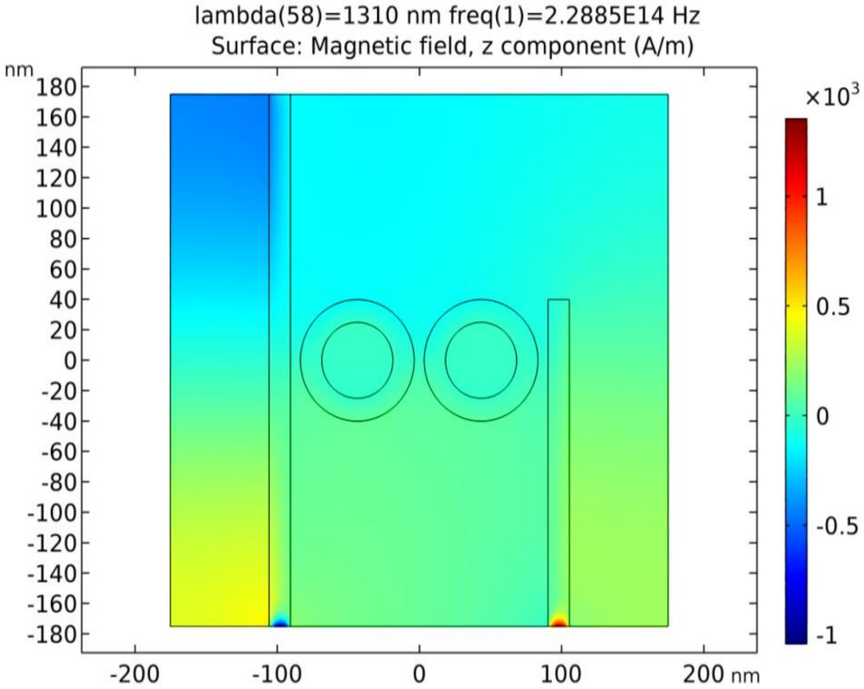


Fig. 5: The Magnetic Field Profile in Case of (OFF) Output State.

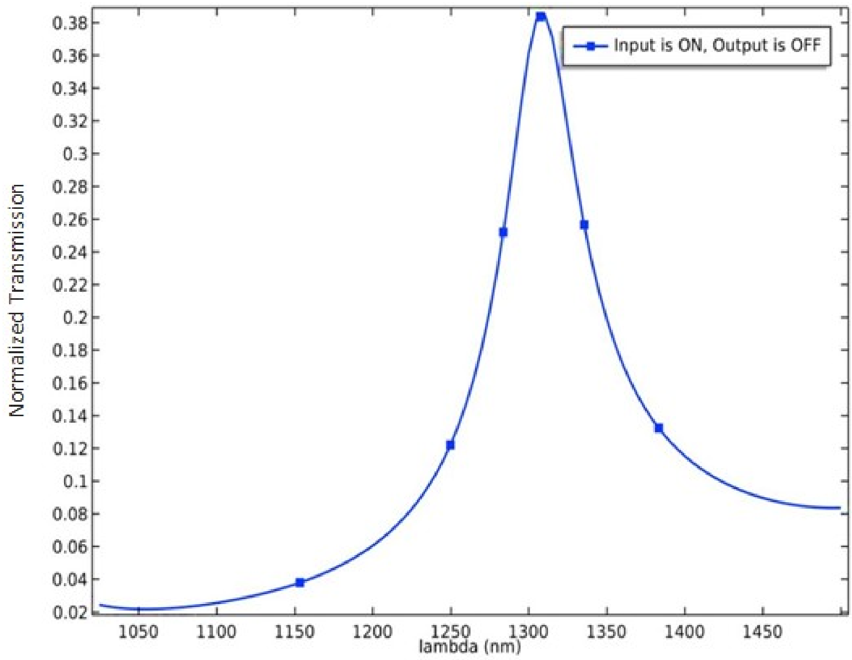


Fig. 6: Optical Transmission as a Function of Wavelength in Case of (OFF) Output State.

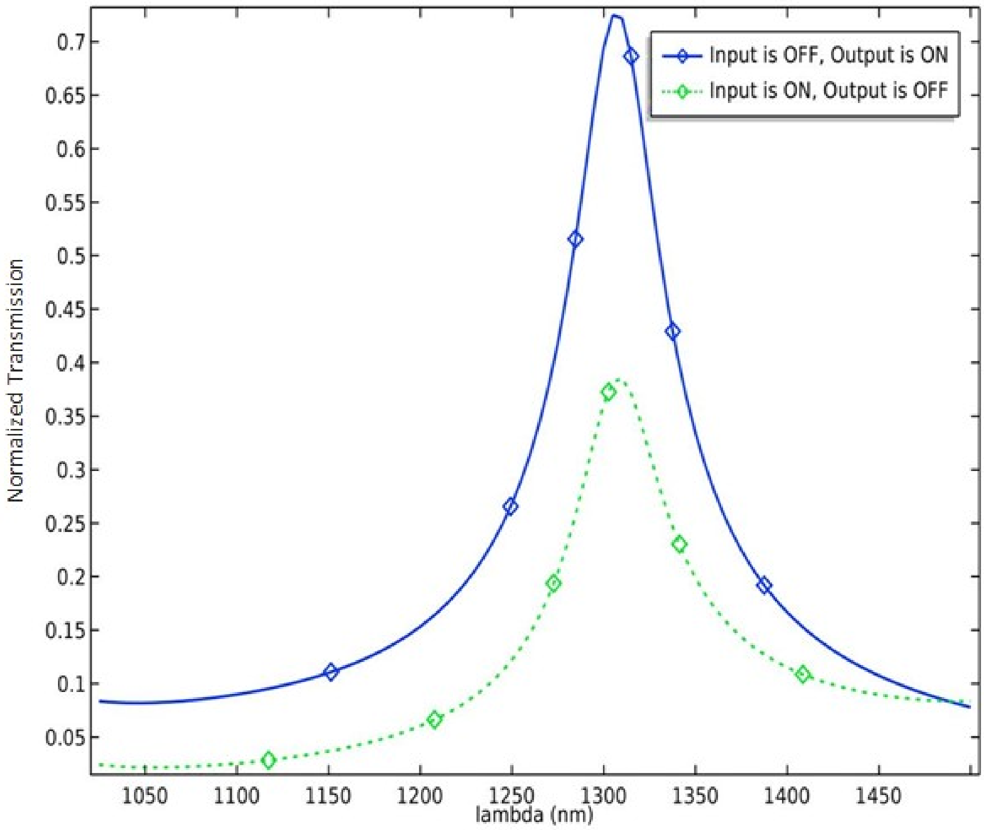


Fig. 6: Optical Transmission as a Function of Wavelength at the Different Condition States.

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