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Research paper

All-Optical NOT Gate Based on Nanoring Silver-Air Plasmonic Waveguide

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Abstract

In this work, all-optical plasmonic NOT logic gate was proposed by using metal-insulator-metal (MIM) plasmonic waveguides design. This logic gate is numerically analyzed by COMSOL Multiphysics 5.3a. Recently, plasmonics have attracted more attention due to its huge applications in all optical signal processing. Due to it's highly localization to metallic surfaces, surface plasmon (SP) may have many applications in sub wavelength to guide the optical signal in waveguides to overcome the diffraction limit which considered a big problem in conventional optics. The proposed design of MIM structure is consist of a dielectric waveguides plus metallic claddings, which guide the incident light strongly in the insulator region. Strong localization and relatively simple fabrication make the MIM waveguides the potential key design of Nano-scale all optical devices. Our design consists of symmetric ring structures with straight waveguides which based on MIM structure. All-optical logic gate (NOT gate) behavior is achieved from utilizing the interface between straight waveguides and ring structure waveguides. By switching the activation of the control port, the propagation of the outgoing field in the output waveguide will be changed. As the simulation results show, the proposed structure could operate as an all-optical NOT logic gate. This gate would be a potential component in many applications of all-optical signals processing.

Keywords: *Surface Plasmon (SP); Metal-Insulator-Metal (MIM); Plasmonic NOT Gate; All Optical Signal Processing.*

1. Introduction

Recently the need for huge bandwidth has precipitately risen to overcome the limitations of conventional electronic devices. The main goals of all-optical signal processing are to achieve high data rate and overcoming the diffraction limit problem in conventional optics. For the time being, prototypes of plasmonic logic gates with high data rates are step out from the research laboratories. The researchers are interested in this technology to make it applicable as soon as possible. To build all optical systems, it is necessary to make all the parts of the systems such as multiplexers, data synchronization unit, frequency recovery, address checker, and signal amplification and regeneration, etc. should be all in optical domain. To make all optical signals processing present, all – optical gates are the basic requirement. Gates are the main elements to perform all-optical processing functions. Surface plasmon is existed between dielectric and metal of surface EMW. Most important characteristic of surface plasmon polariton (SPP) is the ability of coupling the electromagnetic waves to make the propagation of free electrons oscillations at dielectric – metal interfaces [1]. Many promising applications of (SPPs) are there in highly integrated optical circuits because they overcome the conventional diffraction limit that is affect the traditional photonic devices, and they can manipulate the propagating light on sub-wavelength scales [2]. SPP has been proposed several sub-wavelength all optical devices, such as switches [3], all optical logic gates, modulators [5], sensors [6, 7], and nanowires [8]. MIM structure consists of a dielectric material waveguide between two metallic material claddings, which powerfully confine the light in the insulator part [9]. In our work, we designed a MIM model which includes nanoring structures with straight waveguides. We proposed two straight waveguides with two nanoring structures to demonstrate a NOT logic gate based on MIM waveguide structure.

2. 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 widths of MIM plasmonic waveguides are extremely smaller than the incident wavelengths, low orders transverse magnetic (TM) modes can propagate only. The equation of dispersion of (TM) mode in the waveguide is given by [10]:

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

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. Free space wave vector (κ_0) is defined as: $\kappa_0 = \frac{2\pi}{\lambda}$. β is the constant of propagation which represented by the effective index of the waveguide $\eta_{eff} = \frac{\beta}{\kappa_0}$.

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In our proposed system, the dielectric is assumed to be air thus $\varepsilon_d = 1$ and the metal to be silver. Drude model [11] is used to calculate the dielectric constant (ε_m) of silver as:

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

At 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. The transmission of the proposed system is defined as $T = \frac{P_{tr}}{P_{in}}$ [12], where P_{in} is the incident power, while P_{tr} represents the power of transmission. Two straight waveguides have been used in this structure with two ring structures to achieve the behavior of NOT logic gate based on the MIM waveguide structure. The proposed structure of the NOT logic gate is shown in Fig. 1. The central incident wavelength , is 850 nm, the ring structure radii of are R1 = 100 nm and r = 50 nm, the width of the straight waveguide w is 50 nm, and the coupling distances d between the ring structures and straight waveguides is 20 nm. In our proposed NOT logic gate, we used three ports input, output and signal ports, the signal port must always be in ON state. By changing the state of the input port, the state of the output port will be varied. When the state of the input port is disabled (OFF state), the state of the output port is enabled (ON state). The distribution of the magnetic field in case of input port in off state is shown in Fig. 2a. The efficiency of the transmission in this case is shown in Fig. 2b. When the state of the input port A is enabled (ON state), the state of the output port is disabled (OFF state), the distribution of the magnetic field in this case is shown in Fig. 3a and the transmission efficiency is shown in Fig. 3b.

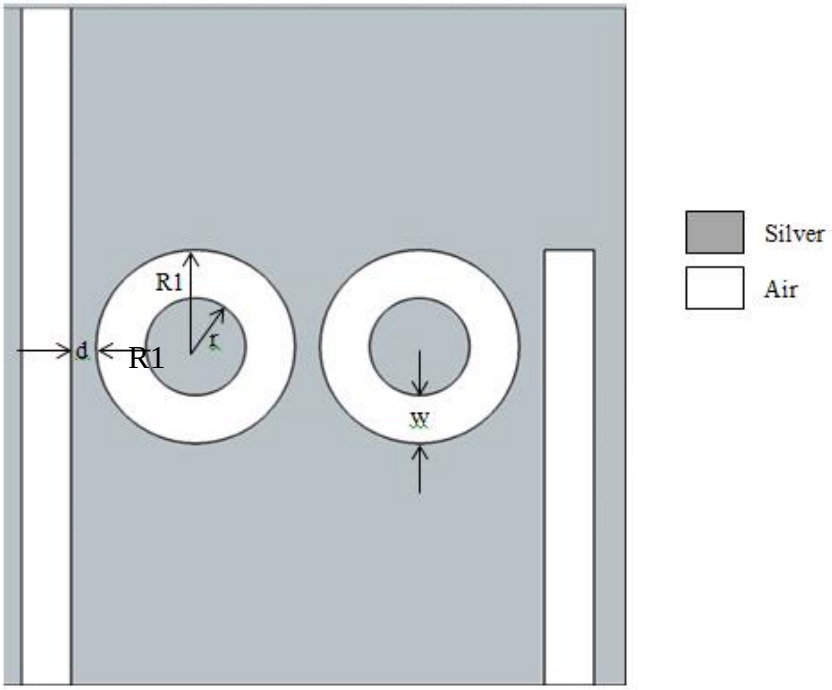


Fig. 1: The Proposed Structure All Optical Plasmonic NOT Gate.

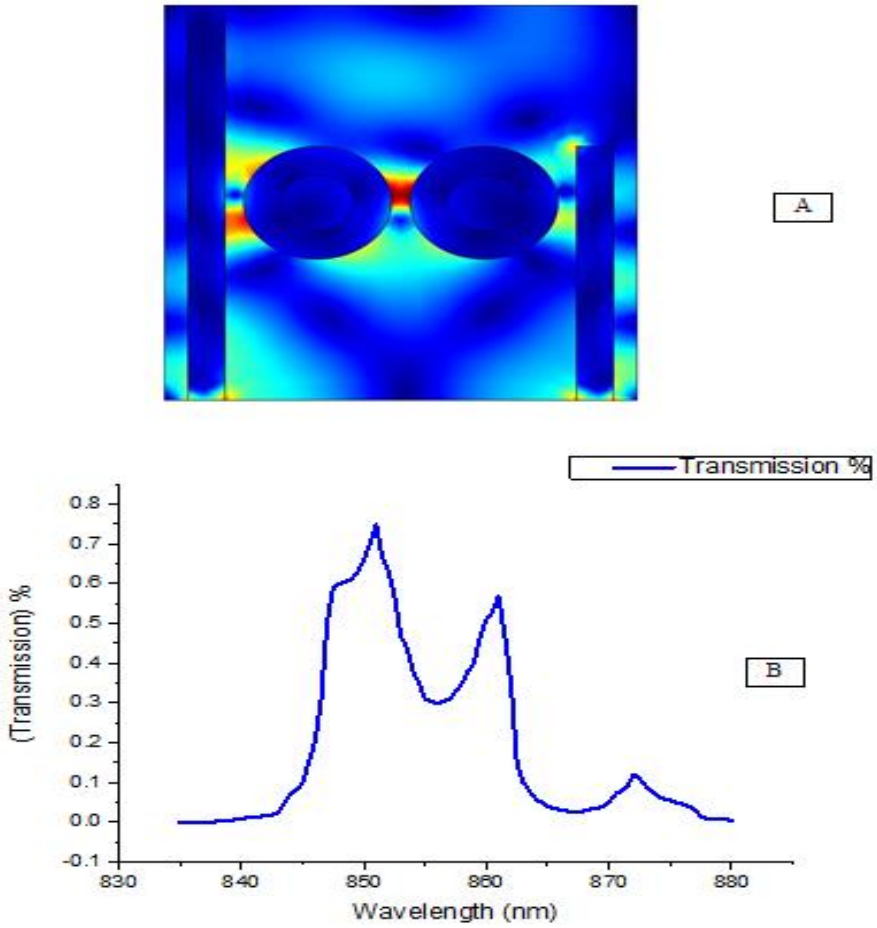


Fig. 2: When the Input Port Is Disabled, A) The Magnetic Field Distribution and B) The Transmission Spectrum.

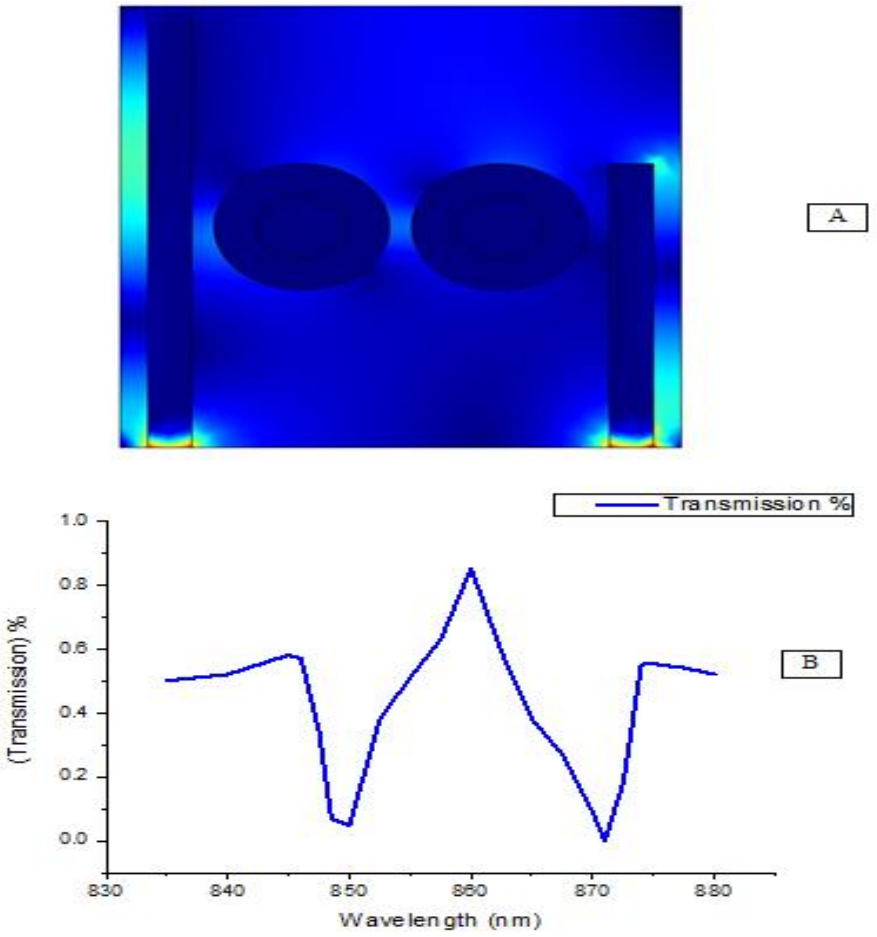


Fig. 3: When the Input Port Is Enabled, A) The Magnetic Field Distribution and B) The Transmission Spectrum.

The truth table and transmission efficiency which obtained from the proposed structure is shown in Table 1.

Table 1: Truth Table and Transmission Efficiency of the Proposed NOT Gate

Input	Output	Transmission Efficiency
0	1	66.13 %
1	0	4.87 %

3. Conclusion

In conclusion, a NOT logic gate were proposed and numerically investigated based on MIM plasmonic nanostructure. The coupling property between straight waveguides and ring structures were utilized to design all-optical plasmonic NOT gate. By changing the state of the control port, we can make outgoing field propagating in the output waveguide or not. The numerical results show that the proposed structure of the gate could operate as plasmonic NOT gate. The proposed design of plasmonic NOT gate would be a main part in many applications that used to perform all optical signals processing.

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