Plasmonic De-multiplexer with High Contrast ratio using Metal-Insulator-Metal Waveguide

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Received 09.03.2019 received in revised form 15.07.2019, accepted 20.07.2019

Abstract: In this paper, we have investigated and stimulated a two channel demultiplexer based on plasmonics metal-insulator-metal (MIM) waveguide. The metal used is silver (Ag) and insulating material is air respectively. The proposed structure is numerically analyzed by using the two dimensional (2-D) finite difference time domains (FDTD) method. Here the crosstalk and the quality factor are measured. The minimum value of crosstalk measured is -14.36dB and the maximum value of quality factor is 56.81.

Keywords: Plasmonics, Metal-Insulator-Metal (MIM) Waveguide, Demultiplexers

1. INTRODUCTION

Plasmonics is a newly emerged and fast growing branch of optics [1]. It is considered as one of the major replacement of photonics of 21st century. Now a day's plasmonics is spreading in a vast manner. Plasmonics consist the capacity of both photonics as well as electronics. Thus plasmonics act as a bridge between electronics and photonics to build extremely small and extremely fast devices. It operates on THz frequency range. The term plasmonics is derived from plasmons. Plasmons are density waves of electrons, emerged when light hits the surface of metal under certain conditions. These density waves are generated at optical frequency and are very small and rapid. Plasmonics is a major part of nanophotonics which defines how the electromagnetic waves are confined over a smaller dimension. Surface Plasmon polaritons (SPPs) and localized surface plasmons are the two main ingredients of plasmonics. SPPs are optical frequency or terahertz electromagnetic waves. Devices made up of SPPs are used in telecommunication sector [2]. Surface Plasmon polaritons are the electromagnetic waves which propagate at the interface between a dielectric and a conductor in a perpendicular direction [3]. Due to coupling of electromagnetic waves these waves generate. SPPs exist only for TM mode because at optical frequencies the dielectric function of metal has negative real part [4].

A few tens of microns propagation in visible or near infrared region of SPPs can be improved by wave guiding schemes. There are two types of SPP wave guiding schemes, termed as: Insulator metal insulator wave guiding scheme (IMI) [5] and Metal insulator metal wave guiding scheme (MIM) [6]. Among these waveguides, MIM waveguide offers low transmission loss and strong confinement of light [6]. Thus MIM waveguide is widely used [7] as compared to IMI waveguide [8]. Recently MIM waveguide based demultiplexers are used due to their simplicity, miniature size, low crosstalk and high quality factor. Now a day's various plasmonic devices have been studied such as filters[9-10], logic gates[11], splitter[12], couplers[13-14], multiplexers/demultiplexers [15-18], switches [19] etc.

2. INTRODUCTION TO DRUDE MODEL

The optical properties of the metals can be explained by a plasma model. According to this model free electrons start oscillation when electromagnetic field is applied and their motion is damped via collision with collision frequency γ. Thus, the relative permittivity function of metals can be explained by Drude model [20] as follows:

$$\varepsilon(\omega) = 1 - \frac{\omega_p^2}{\omega^2 + i\gamma\omega} \qquad (1)$$

where, ω_p is plasma frequency of free electron gas and ω is the angular frequency of light wave. It is experimentally verified that silver is best the metal for plasmonic waveguides due to its lower guiding losses [21]. Here silver parameters are $\omega_p = 1.38 \times 10^{16}$ rad/s and $\gamma = 0.27 \times 10^{14}$ rad/s [22]. In recent year optical demultiplexer has attracted many researchers due to its application in communication system.

The performance of demultiplexer is measured by using crosstalk and quality factor.
The crosstalk can be given as-

$$\text{Crosstalk} = 10\log_{10}\frac{P_1}{P_2}\ \text{dB} \qquad (2)$$

here, P_1 is the power of interested channel and P_2 is the output power of other channel. Crosstalk is calculated in terms of decibel denoted with dB. The quality factor [23] is defined as the ratio between resonance wavelength (λ) and their half power beam width (HPBW) ($\Delta\lambda_{FWHW}$). It can be expressed as

$$Q = \frac{\lambda}{\Delta\lambda_{FWHM}} \qquad (3)$$

λ is resonant wavelength and $\Delta\lambda_{FWHM}$ is half power beam width. Quality factor is a unit less quantity and it defines the depiction of signal.

3. PROPOSED STRUCTURES

The schematic of first proposed geometry is shown in fig.1. The structure is composed of metal-insulator-metal (MIM) waveguide and linear stubs. The width of MIM waveguide is chosen small in value in order to execute fundamental mode. When an input field is launched on the input waveguide, SP mode propagates along the interface between insulating layer and metal. The structure acts as two channel de-multiplexer and it will de-multiplex two desired wavelength band depending on the length of the stub. Fig 2(a) and fig 2(b) shows the magnetic field distribution at different input conditions of λ=1400nm and λ=1550nm respectively. Transmittance spectrum of first structure is shown in fig. 3.

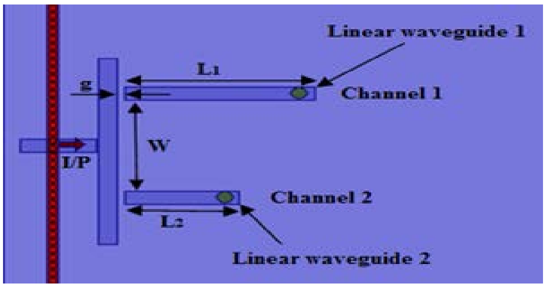
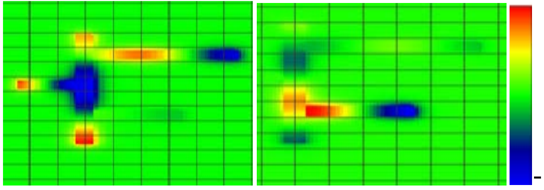


Figure 1: Schematic view of linear 2 channel demultiplexer with following parameters: L_1=500nm, L_2=300nm, W=400nm, g=10nm



(a) (b)

Figure 2 Magnetic field distribution of proposed structure at operating wavelength of (a) 1400nm (b) 1550nm

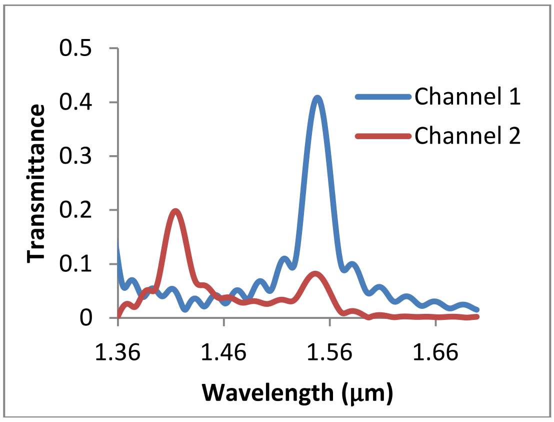


Figure 3: Transmittance curve

According to length of resonator, different signals can be de-multiplexed. The resonant wavelength or resonance condition can be determined using [24]:

$$2k\,Re\left(n_{eff}\right)L + \varphi_r = 2m\pi, \quad m = 1,2,3 \qquad (4)$$

where k = 2 π/λ is the propagation constant defined for free space, ϕ_r is the phase shift offered by a reflection from the edge of metal-insulator interface, L is the effective length of the resonator (L = h1) and n_{eff} is the effective index of the refractive index that can be calculated from the dispersion relation [24-25].

The wavelength of channel 1 and channel 2 can be tuned by changing the length of resonator. As the length of linear stub 1 is larger than length of linear stub 2 thus the transmittance curve of channel 1 is obtained at higher wavelength as compared to channel 2. The measured quantities are

C= -7.07dB and Q=51.43 for channel 1

C=-6.22dB and Q=48.94 for channel 2

In the second structure linear waveguide stubs are replaced by rectangular stubs. The structure consists of MIM waveguide and two rectangular resonators. The schematic is shown in fig. 4 and magnetic profile is shown in fig. 5(a) and 5(b). The obtained transmittance spectrum is shown in fig. 6. The resonance condition of the resonator is derived from the same equation 4. Due to square resonator, the reflection is offered at each vertex of square and hence resonance condition is blue shifted but the total length (or perimeter) of square resonator is large to maintain the nearly same resonance condition. The value of resonator separation is adjusted (D=500nm) to optimum value that reduces the crosstalk of 1st channel in 2nd channel.

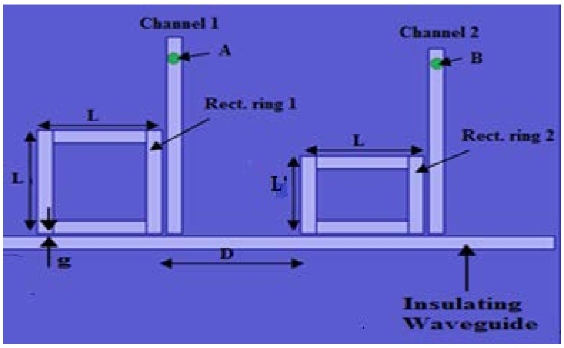
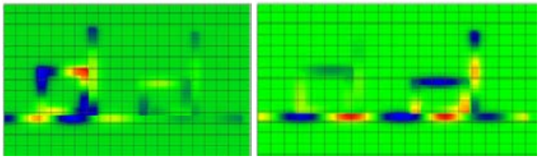


Figure 4: Rectangular resonator based demultiplexer with following parameters: L=400nm, L′=300nm, D=500nm, g=10nm



(a) (b)

Figure 5: Magnetic field distribution at operating wavelength of (a) 1440nm (b) 1560nm

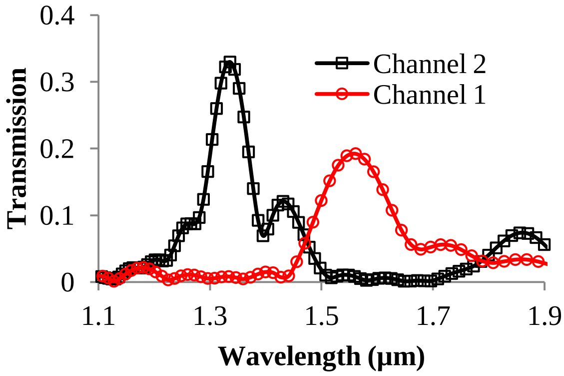


Figure 6 : Transmittance curve

The values of measured characteristics are
C=-10.36dB and Q=45.44 for channel 1
C=-14.3 dB and Q=56.81 for channel 2

The value of resonant wavelength can be tuned by changing parameters of resonators. Therefore desired wavelength can be de-multiplexed by changing geometrical parameters. At last, lower value of crosstalk is obtained in second structure. The second geometry offers large value of quality factor as compared to first structure. The distance between both the resonators is optimized for lower value of crosstalk.

4. CONCLUSION

This paper presents a demultiplexer which works on principle of plasmonics and it is analyzed by using the two dimensional (2-D) finite difference time domain (FDTD) method. The performance of device is measured with crosstalk and quality factor. The minimum crosstalk observed is -14.3dB and maximum value of quality factor measured is 56.81.

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