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CONCURRENT DUAL BAND FILTERS USING PLASMONIC MIM WAVEGUIDE RING RESONATOR

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ABSTRACT

This paper describes the design and analysis of metal-insulator-metal (MIM) waveguide based band-pass and band-stop filters by using ring resonators. MIM waveguide based ring resonators has been analysed in terms of their electrical parameters by using commercially available electromagnetic full-wave simulation software. A MIM waveguide based ring resonators has been designed and simulated to obtain its transmission and reflection coefficients. Ring resonator based dual band filters are more compact with reduced space and power requirements in photonic integrated circuits (PICs). By using this concept several other components can be design such as multiplexers/diplexers, directional couplers/branch line couplers and antenna.

Keywords: SPPs, MIM waveguide, ring resonator, nanophotonics

INTRODUCTION

A bounded and propagating electromagnetic surface wave coupled with surface collective oscillations of free electrons in a metal is known as Surface Plasmon Polaritons (SPPs) [1, 2]. SPPs are the information and energy carriers in nanophotonics in order to overcome the diffraction limit of light in conventional optics. In recent years SPPs have plenty of potential applications like manipulating and guiding the light truly on deep subwavelength scales [1-3]. Based up on SPPs, various MIM waveguide structures has been designed theoretically [4-6] and verified experimentally [7, 8]. Recently, researchers have been designed and investigated filters like single tooth and multiple tooth shaped filters by using Plasmonic MIM waveguides [9, 10]. The transmission characteristics of these filters have several bands in their transmission spectra and the wavelengths of the light are allowed to pass through the structure while one or several wavelengths are stopped. In consequence, several filters are available and they are very important in nanophotonics to transmit the light, which can allow light only at a given wavelengths and other wavelengths are not allowed. As a result, it is required to find out a SPPs filter with a simple design that can have concurrent dual band operation in between O & L bands.

Planar plasmonic waveguide resonators are classified into two categories. They are MIM and IMI waveguide based resonators [11, 12]. Resonators behave as filters, which can accept or reject specific wavelengths from an input signal in single or dual band. The transmission line resonators have low Q-values as compared to waveguide based resonators; but they possess simple design, smaller in size and large applicability to different nanophotonic circuits [13, 14]. The MIM waveguide based resonators in cylindrical and rectangular shapes can be used at THz frequencies in the design of filters and other tuning elements.

The MIM waveguide based resonators can be excited in various resonant modes. The basic characteristics of such resonators are their resonant frequencies, Q-factors and field distributions. These properties must be known for the lowest order resonant mode and a few higher order modes to allow proper selection of a mode that can be used for a particular application. The mode should be excited by a suitable coupling mechanism.

MIM Waveguide resonators

Plasmonic MIM uniform width resonator (MIMUWR) can be described by following definition i.e., the transmission line have identical characteristic impedance using an electrical length of π radians and these kind of transmission line resonators are simply called as MIMUWR and are shown in Figure-1. Because of their simple design and easy analysis, transmission line resonators are generally used in the conventional filters [15, 16]. But practical MIMUWRs have a number of disadvantages like limited design parameters because of their simple design.

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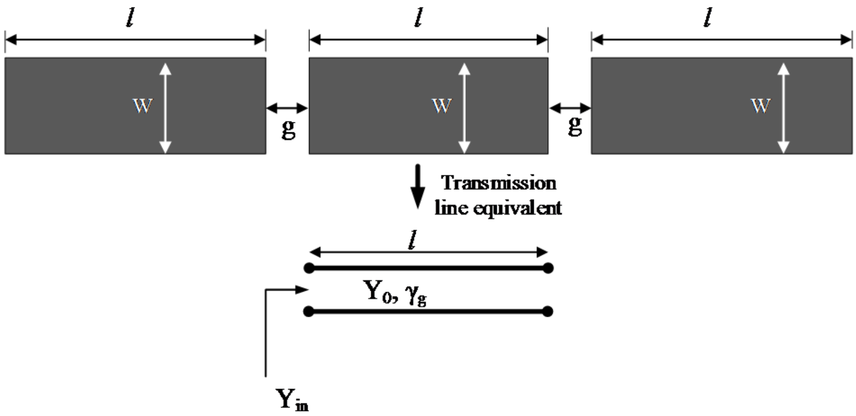

Fig.1 (a) Basic structures and transmission line equivalent of uniform width resonator with l = 318 nm , W = 54 nm and g = 20 nm (b) equivalent circuit

A transmission line with an open end circuit with length of $\lambda_g/2$ or multiples of $\lambda_g/2$ at a frequency $\omega = \omega_0$ can behave as a parallel type resonator. The basic characteristics of transmission line resonators have been described in several text books such as Pozar [17].

The input admittance (Y_{in}) of the open circuit with the length l is

$$Y_{in} = Y_0 \tanh(\gamma_g l) = Y_0 \frac{\tanh \alpha_g l + j \tan \beta_g l}{1 + j \tan \beta_g l \tanh \alpha_g l} \quad (1)$$

Where Y_0 is output admittance, γ_g, α_g and β_g are described earlier in [17].

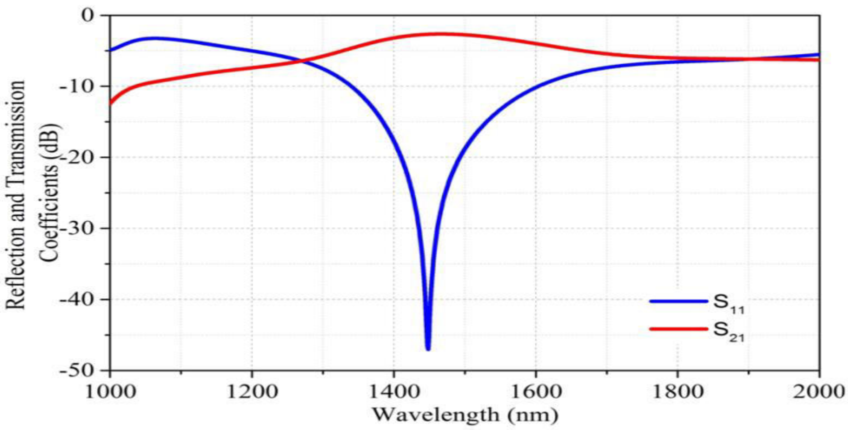

Fig. 2 Transmission and Reflection Coefficients for UWR with L = 318 nm , W = 54 nm and g = 20 nm

Figure-2 shows the transmission and reflection coefficients of the MIMUWR and the corresponding wavelength of the reflection coefficient is 1435 nm at -48 dB.

Geometry and simulation results

Figure-3 shows the MIM waveguide ring resonator which usually consists of two feed lines, two semi-infinite metallic layers, and a nanodisk resonator in the middle of the two feed lines [18, 19]. The dielectric material used in design is silica with dielectric constant (ε_i) 2.50. The metal has been assumed as optical silver and the basic characteristics of the material have been already described in [20, 21]. The structure would only support waves that have an integral multiple of the guided wavelength equal to the mean circumference [22].

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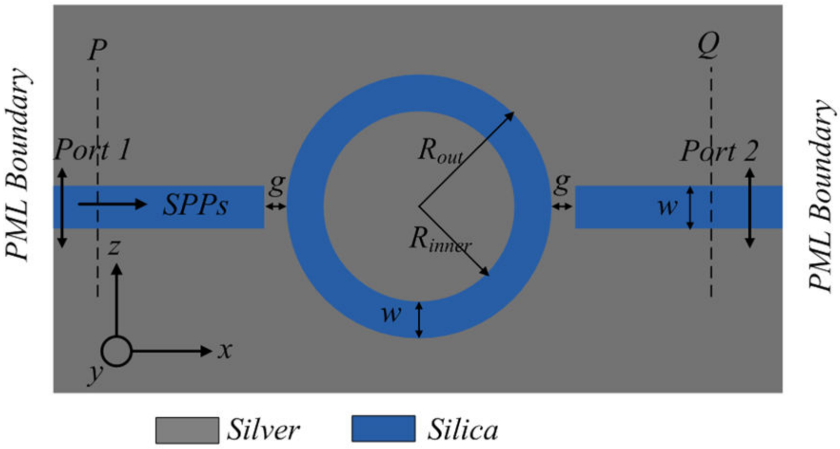

Fig. 3. Schematic structure of a plasmonic filter structure with a circular ring resonator with w = 70 nm, R_{out} = 380 nm, R_{in} = 310 nm, g = 10nm and λ_g = 1066nm

The ring resonator structure consists of two coupled waveguides as shown in Figure-3, in which the outer radius is denoted by R_{out} and inner radius by R_{inner}. The actual radius of the ring is considered to be the mean value of R_{out} and R_{inner}, i.e. $R_m = (R_{out}+R_{inner})/2$. Here, *w* represents the width of the coupled waveguides and the ring and *g* shows the coupling length between the two.

The following equation describes the resonance condition for the ring resonator [22]

$$\frac{J_n'(kR_m)}{J_n'(kR_{inner})}-\frac{N_n'(kR_m)}{N_n'(kR_{inner})}=0, \tag{2}$$

Where *k* is wave vector. J_n' and N_n' are the derivatives to the Bessel functions of the first kind and second kind of order n, respectively.

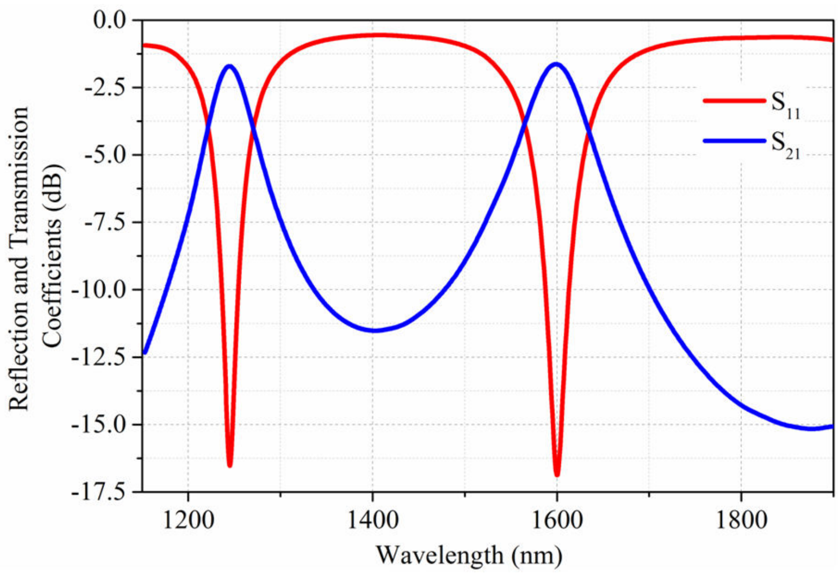

Fig. 4 . Transmission and Reflection Coefficients for circular ring resonator with w = 70 nm, R_{out} = 380 nm, R_{in} = 310 nm and g = 10nm.

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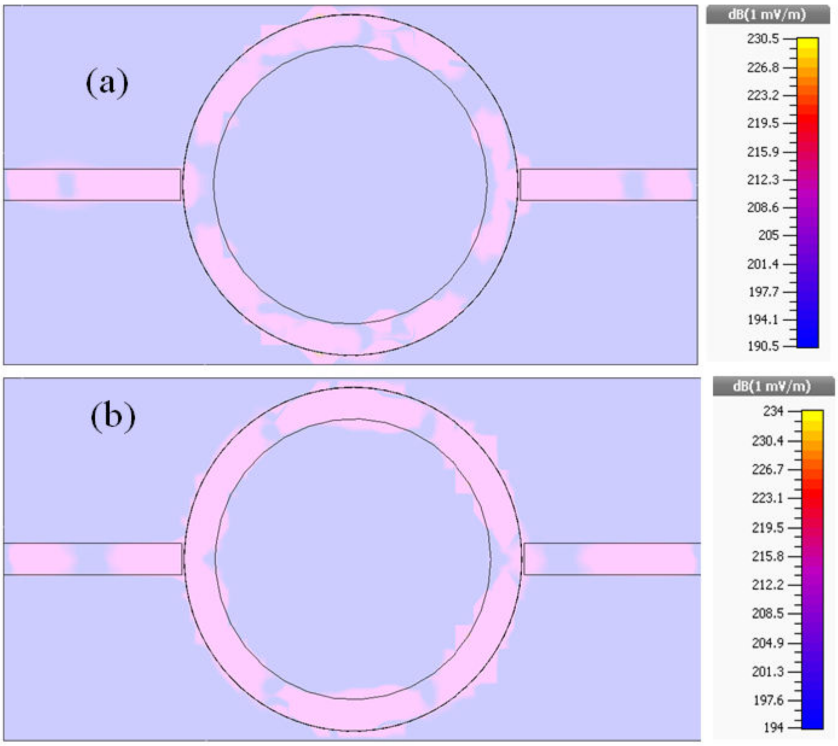

Fig. 5 . Field distribution at wavelengths (a) 1245-nm; (b)1600-nm.

Figure-4 shows the transmission and reflection coefficients of the ring resonator with physical dimensions w = 70 nm, R_{out} = 380 nm, R_{in} = 310 nm and g = 10 nm. First pass band is occur at fundamental frequency $f_{fundamental}$ = 240.797 THz (1245 nm) at the same time as second pass band is occur at spurious frequency $f_{spurious}$ = 187.37 THz (1600 nm), because of internal loss in the nanocavity and waveguide loss in the metal slits. Figure-5 (a) and (b) shows the magnetic field distributions at the fundamental wavelength of 1245 nm and at the spurious wavelength of 1600 nm respectively.

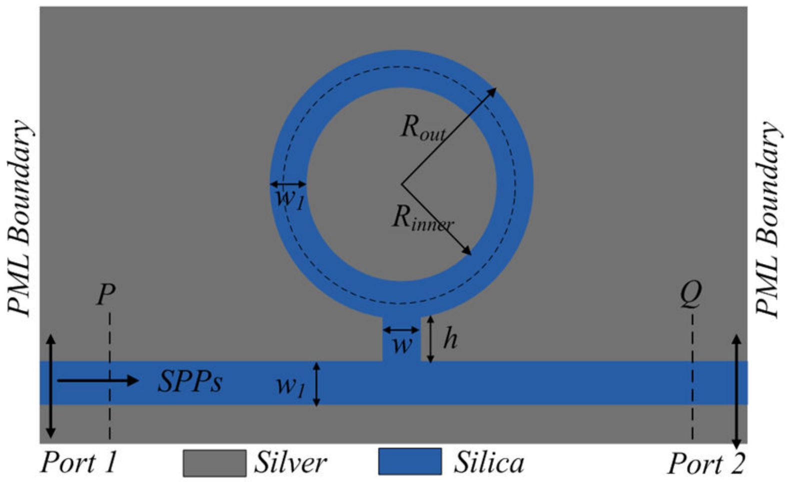

Fig. 6 . Schematic structure of a plasmonic filter structure with a circular ring resonator with w_1 = w = 70 nm, R_{out} = 380 nm, R_{in} = 310 nm and h = 125 nm

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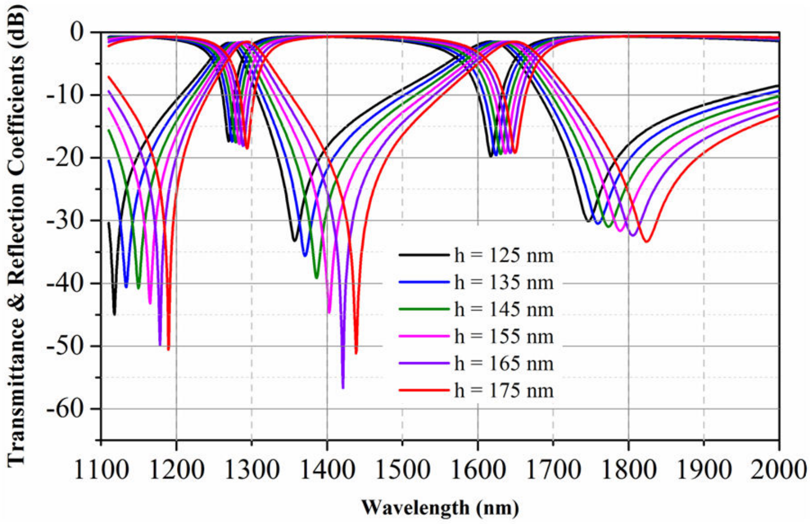

Fig. 7 . Variation of transmission and reflection coefficients for circular ring resonator as a function of h with $w_1 = w = 70$ **nm**, $R_{out} = 380$ **nm**, $R_{in} = 310$ **nm** and $\lambda g = 1318$ nm

The MIM slot waveguide based plasmonic ring resonator with a radius r and connected to a slot waveguide through a small aperture of width (w) and height (h) in the ring side wall shown in Figure-6. The waveguides support the fundamental transverse magnetic (TM) mode with propagation length due to the absorption loss in the metal layer.

The transmission and reflection coefficients of the ring resonator at fundamental wavelength 1270 nm that is equivalent to $3\lambda g/2$ as shown in Figure-7. The magnitude of magnetic fields at wavelengths 1270 nm and 1620 nm as shown in Figure-8 (a) and (b).

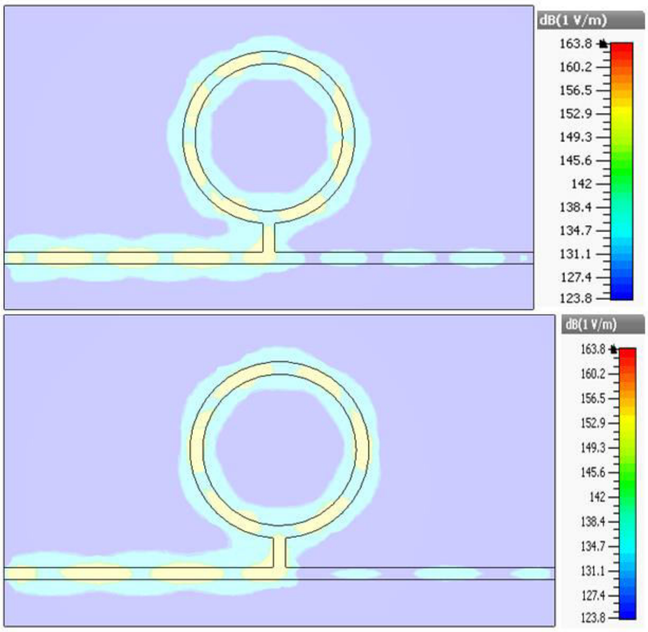

Fig. 8 . Field distribution at wavelengths (a) 1270 nm; (b) 1620 nm

CONCLUSIONS

The transmission and reflection coefficients of MIM slot waveguide along with the resonant behaviour of ring resonator have been numerically investigated. Dual band characteristics of ring resonator have been found and useful in the design of dual band integrated circuits. The concept will reduce the space and power requirements in the system and determine the more compact system.

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Simulation results of a dual band band-pass and band-stop filters using MIM waveguide based ring resonators shows the existence of two simultaneous pass and stop bands in the structure. By using this concept, the structure can be extended to design several other components such as couplers, diplexers and power splitters/combiners.

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