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Dual Band Band-Pass Filters using Plasmonic Split-mode Ring Resonator

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Abstract*: This article presents a two types of plasmonic split mode ring resonator band-pass filter (BPF) using metal-insulator-metal (MIM) waveguide. The two filters operate at two optical wavelengths in between O (1260-nm to1360-nm) and L (1565-nm to 1625-nm) bands. The designed split-modes ring resonators are designed using local resonance and notch perturbation split-modes respectively. A full wave simulation software tool has been used in the designing of the split-mode resonator band-pass filter. These filters are used in the designing of dual-band high density photonic integrated circuits (PICs).

I. INTRODUCTION

Surface plasmonic polaritons (SPPs) are the basic evanescent waves that travel along the metal-dielectric interface [1], which are laterally limited to the diffraction limit subwavelength metallic designs. Recently, several researchers on nano-plasmonic metal-insulator-metal (MIM) waveguides [2] are confirmed to be more effective technique for guiding the light with nanoscale mode. Being well recognized ring resonators are generally studied and reported [3] using plasmonic MIM waveguides. Various resonators are already studied and researched by theory and experiments, including square ring [4], circular ring [5], triangular ring resonator [6] and disc ring resonator [7].Still, most of these split-mode resonators are symmetrical in shape. Keeping this fact in mind, we had proposed a dual band band-pass filter using plasmonic ring resonator.

This article demonstrates the two different kinds of plasmonic split-mode ring resonators for the first time and investigates a nano-scale plasmonic band pass filters at O and L optical bands. The full-wave simulations is performed in order to find the transmission performances of the proposed devices using CST Microwave studio suite. The dual mode nature has been observed in the two types of split-mode ring resonators. The characteristics of circular ring resonators has been realized with two-feed lines when the refractive index of the insulator and the width of the feed-lines is fixed. The reflection and transmission coefficients of the plasmonic split-mode resonators has been obtained at THz frequencies which contains potential applications in photonic integrated circuits (PICs) [8].

The proposed devices has been designed using CST Microwave studio suite. The local resonance split-mode ring resonator and notch perturbation split mode ring resonator has been analyzed and the results shows the dual band characteristics in the transmission spectrum of the optical frequencies. The transmission spectrum of the dual band band-pass filter split-mode resonators has been observed when refractive index of the insulator and width of the feed-line is fixed. We carry out the full-wave simulation with dimensions, a perfect matched layer (PML) boundary conditions, time step ($\Delta t = \Delta x/2c$, c is the velocity of light in vacuum), mesh sizes are 5-nm × 5-nm. To simplify the calculation, the metal and insulator are assumed to be silver and silica, respectively. The parameters for the silver and silica can be fixed as $\varepsilon\infty = 3.7$, $\omega p = 1.38 \times 1016$ rad/s, $\Upsilon = 2.73 \times 1013$ rad/s and $\varepsilon i = 2.50$ (silica) that are obtained by fitting experimental results [9].

The resonant frequencies of the micro strip ring resonator has been calculated by Wolff and Knoppik [10] by assuming a magnetic wall model. Resonance splitting observation by disturbing the symmetry of the ring has been reported by Wolff. No work has done to calculate the characteristics of the modes that split and magnitude of splitting .The two degenerate modes of symmetric resonator solutions are given as follows.

$$E_z = \{CJ_m\ (kr) + DN_m\ (kr)\}\cos(m\theta)$$
$$H_r = \frac{m}{jw\mu_0}\{CJ_m\ (kr) + DN_m\ (kr)\}\sin(m\theta) \quad (1)$$
$$H_\theta = \frac{k}{jw\mu_0}\{CJ'_m\ (kr) + DN'_m\ (kr)\}\cos(m\theta)$$

And

$$E_z = \{CJ_m\ (kr) + DN_m\ (kr)\}\sin(m\theta)$$
$$H_r = \frac{-m}{jw\mu_0}\{CJ_m\ (kr) + DN_m\ (kr)\}\cos(m\theta)$$
(2)
$$H_\theta = \frac{k}{jw\mu_0}\{CJ'_m\ (kr) + DN'_m\ (kr)\}\sin(m\theta)$$

Where C and D are constants, J_m (kr) is the first kind of order m Bessel function, N_m (kr) is the second kind of the order m, and k is the wavenumber. By changing the circular ring resonator symmetry, degenerate modes of the split-mode ring resonator has been observed. The symmetry of circular ring resonator is distributed if the notch present at the circumference of the resonator. The notch is located at the azimuthal angles of $\theta = 0^0$, 90^0, 180^0, or 270^0 the one solution becomes zero, and only one solution exists. If $\theta = 45^0$, 135^0, 225^0, 315^0 then for odd m value both solution exists and the resonance split is distributed for even m value one solution becomes 0 as mentioned above, hence resonance doesn't split.

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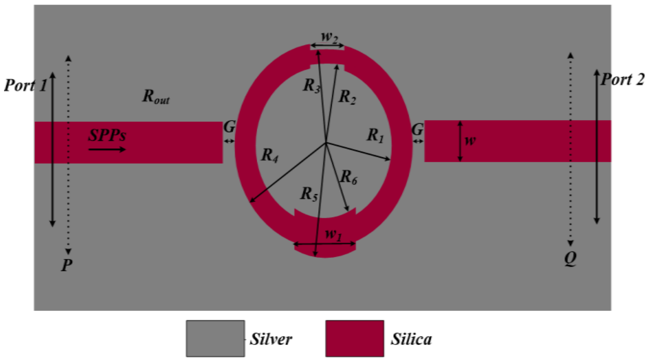

Fig.1 Geometry of the local resonance split-mode ring resonator with R_1 = 285 nm, R_2 = 310 nm, R_3 = 424 nm, R_4 = 449 nm, R_5 = 474 nm, R_6 = 260 nm, w_1 = 190 nm, w_2 = 190 nm, w = 160 nm and G = 5 nm

The design of a local resonance split-mode ring resonator has two parallel coupled feed lines has shown in Fig. 1. The dimensions of the local resonance split-mode ring resonator are R_1 = 287 nm, R_2 = 312 nm, R_3 = 396 nm, R_4 = 421 nm, w_1 = 60 nm, w = 120 nm and G = 5 nm. The full wave simulation is carried out using CST microwave studio. Fig. 2 represents the variation in reflection and transmission coefficient for the proposed local resonance split-mode ring resonator. The desired bands operate at optical bands O (1281-nm) and L (1602-nm) respectively. Fig 3 shows the field distribution at wavelengths 1281 (nm) and 1602 (nm).

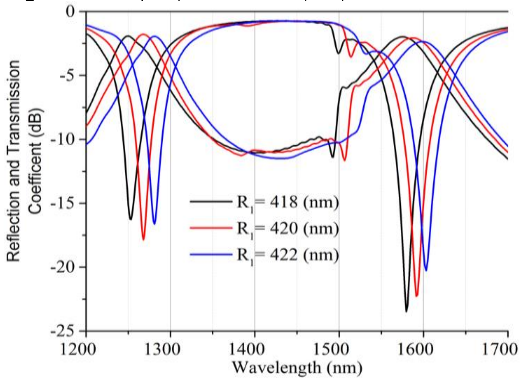

Fig.2 Variation of reflection and transmission coefficient with wavelength as a function of Radius (R_1)

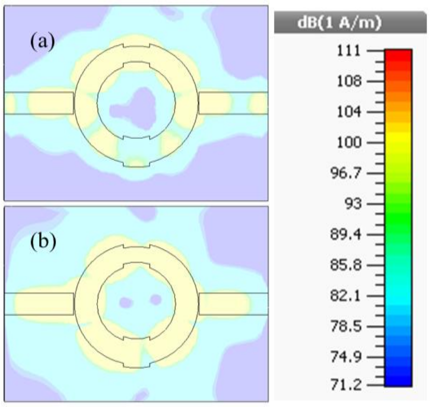

Fig.3 Field distribution at wavelength (a)1281-nm and (b)1602-nm

The design of a notch perturbation split-mode ring resonator has two parallel coupled feed lines has shown in Fig. 4 the dimensions of the notch perturbation split-mode ring resonator with R_1 = 287 nm, R_2 = 312 nm, R_3 = 396 nm, R_4 = 421 nm, w_1 = 60 nm, w = 120 nm and G = 5 nm. The full wave simulation is carried out using CST microwave studio. Fig. 5 represents the variation in reflection and transmission coefficient for the proposed local resonance split-mode ring resonator. The desired bands operate at optical bands O (1280-nm) and L (1566-nm) respectively. Fig 6 shows the field distribution at wavelengths 1280 (nm) and 1566 (nm).

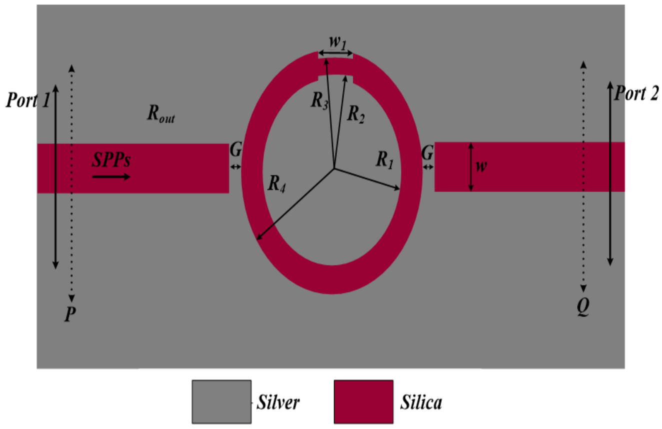

Fig.4 Geometry of the notch perturbation split-mode ring resonator with, R_1 = 287 nm, R_2 = 312 nm, R_3 = 396 nm, R_4 = 421 nm, w_1 = 60 nm, w = 120 nm and G = 5 nm.

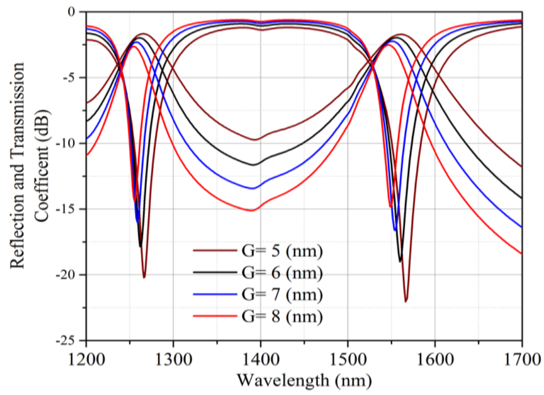

Fig.5 Variation of reflection and transmission coefficient with wavelength as a function of Gap (G)

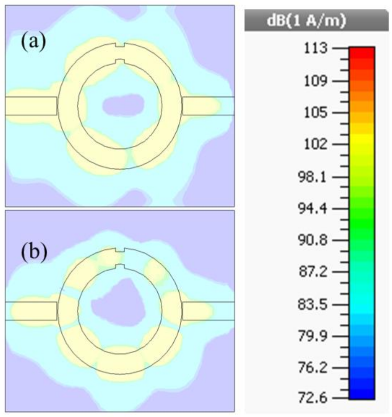

Fig.6 Field distribution at wavelength (a)1280-nm and (b)1566-nm

II. CONCLUSION

In this paper we have numerically investigated the basic characteristics of plasmonic split mode ring resonator band-pass filters (BPF) using metal-insulator-metal (MIM) waveguide. The two filters operate at two optical wavelengths in between O (1260-nm to1360-nm) and L (1565-nm to 1625-nm) bands.

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The designed split-modes ring resonators are designed using local resonance and notch perturbation split-modes respectively. In this paper the basic characteristics like reflection and transmission characteristics, field distribution had be analyzed. A full wave simulation software tool has been used in the designing and analysis of split-mode resonator band-pass filter. These filters are further used in the designing of dual-band high density photonic integrated circuits (PICs).

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