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Optical band-stop filter and multi-wavelength channel selector with plasmonic complementary aperture embedded in double-ring resonator

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ABSTRACT

A compact nanoscale wavelength band-stop filter with aperture embedded in double-ring resonator is proposed and numerically investigated by using Finite-Difference Time-Domain (FDTD) method. With a narrow aperture created between embedded double rings, the modes of the split-ring cavity can be modulated by the aperture in different manners when the parameters of the aperture are changed. Furthermore, the absorption peaks of resonator modes can be selectively inhibited by altering the positions of the aperture without changing outer size of the resonator. Based on above characteristics, a 1 × 2 multiple-contact channel selector is designed with a rotating aperture which can select the output waveguide. The proposed filter and selector have potential applications in highly integrated optical circuits.

1. Introduction

Thanks to the ability to highly confine optical field below the diffraction limit and low bend loss, plasmonic resonators have been deemed to a candidate for miniaturized photonic integrated circuits [1,2]. These remarkable superiorities open up a new horizon for researchers to explore their characteristics for further integration. Due to its unique feature, the plasmonic waveguide structure (PWS) has found a variety of applications [3–10]. As one of the most prevalent devices in optical circuits, plasmonic filter based on PWS for wavelength selection has been investigated numerically and experimentally. In the past few years, different types of the plasmonic filters such as nanodisk resonators [11,12], ring resonators [13,14], tooth-shaped waveguide filters [15,16] and rectangular resonators [17,18], have been proposed. Furthermore, some devices based on nanoscale coupled gap resonators [19,20] and the split-ring cavities [21–23] have been used in the fields of the plasmonic filters due to its special transmission characteristics. As reported in Guo, Y [24], the aperture-coupling mechanism was introduced in the designe of plasmonic filters by changing the aperture width and depth. Also in 2013 [23], Iman, Z. proposed the split-ring resonator and found that the resonator mode of this structure is highly sensitive to the position and size of the metallic sidewall. Thus, by introducing the aperture in the split-ring resonator, it provides a unique way to improve the coupling efficiency when the nano-wall width and position are varying.

In this paper, a novel band-stop plasmonic filter based on plasmonic complementary aperture embedded in double-ring is proposed and the transmission properties are investigated numerically and analytically. Comparing with previous works, we adopt a new adjustment mechanism to the cavity to enhance the filtering characteristics. The absorption wavelength is easily modulated when we change the width of the aperture and reflective index of the medium in the cavity. Moreover, by locating the aperture at some specific positions, the resonance modes can be selectively inhibited or excited. Besides, a multi-wavelength channel selector based on this inhibiting structure is also proposed. This structure, which can decrease plasmonic filter dimensions, so may has potential applications in highly integrated optical circuits.

2. Modeling and theoretical analysis

The schematic of the proposed band-stop filter is composed of PWS shown in Fig. 1(a). The parameters of the filter are the width of the bus waveguide (w), the distance between the resonator and the waveguide (h), outer and inner radius of the split-ring (R_o,R_i),

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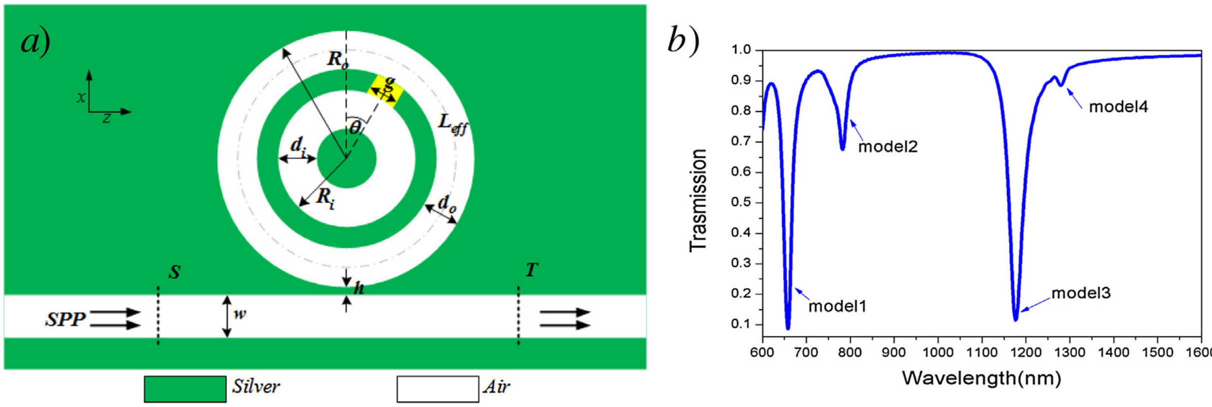

Fig. 1. (a)The schematic diagram of the plasmonic filter. (b)The transmission spectrum of the filter with $w = 50nm$,$h = 15nm$, $R_o = 160nm$, $R_i = 80nm$, $d_o = 50nm$, $d_i = 40nm$, $\theta = 0^o$, $g = 20nm$.

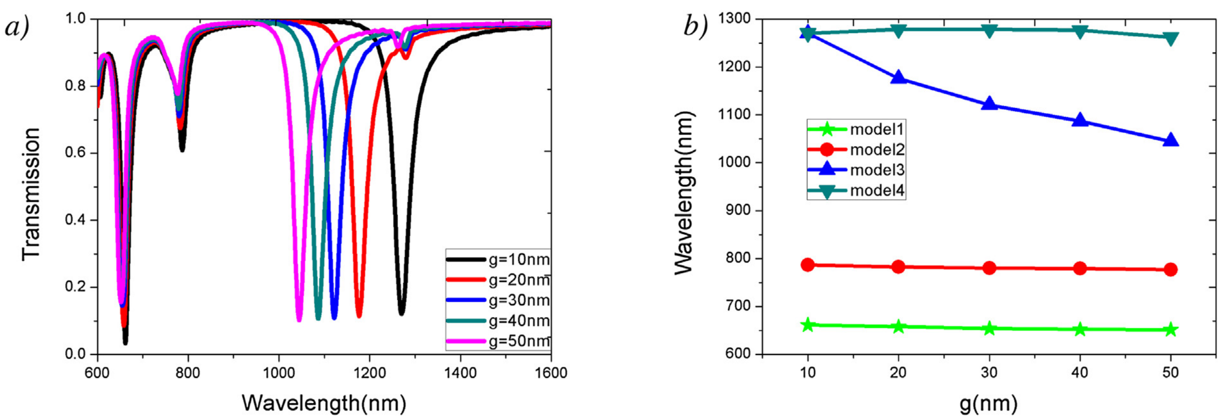

Fig. 2. (a) The transmission spectra with different width of the aperture at $\theta = 0^o$. (b) The resonant wavelength of mode (1–4) as a function of the aperture size.

the width of the outer and inner bus waveguide (d_o,d_i), the width of the aperture (g),and the angle between the direction of the aperture and the original direction (θ). Here the parameters w,h are set to be 50 nm, 15 nm respectively. And the aperture marked in yellow is set to be air or other dielectric.

Only the fundamental model (TM_0) can propagate along the waveguide because the width of the waveguide is much less than the incident wavelength. The dispersion relation of the fundamental TM_0model in the PWS is given by [25].

$$\varepsilon_{in}k_{z2} + \varepsilon_m k_{z1} \ \coth(-\frac{ik_{z1}}{2}\omega) = 0 \tag{1}$$

$k_{z1}$and k_{z2}defined as $k_{z1}^2 = \varepsilon_{in}k_0^2 - \beta^2$, $k_{z2}^2 = \varepsilon_m k_0^2 - \beta^2$where ε_{in}, ε_mS are the dielectric constants of the insulator and the metal, respectively. $k_0 = 2\pi/\lambda$ is the free-space wave vector. The dielectric constants of the metal silver is characterized by the Lorentz-Drude model [25,26]:

$$\varepsilon_m(\omega) = \varepsilon_\infty - \frac{\omega_D^2}{\omega^2 + i\gamma_D\omega} - \sum_1^2 \frac{g_{Lm}\omega_{Lm}^2 \Delta\varepsilon}{\omega^2 - \omega_{Lm}^2 + i2\gamma_{Lm}\omega} \tag{2}$$

Here ε_∞ is the dielectric constant at the infinite frequency, and$\omega$is the angular frequency of the incident wavelength. The parameters provide good description of permittivity data for silver listed in Ref. [27].

When the incident optical wave transmits through input waveguide, the absorption peaks will occur due to the resonance effect. The resonant wavelength is determined by the resonance condition:

$$L_{eff}n_{eff} = N\lambda, \qquad N = 1, 2, 3..., \tag{3}$$

where L_{eff} is the effective length of the split-ring resonator and n_{eff} is the effective refractive index of the incident light. In the FDTD simulation, the grid sizes in the x and z directions are $\Delta x = \Delta z = 5nm$. To calculate transmittance of the cavities $T = P_{out}/P_{in}$ incident power of P_{in} and transmitted power of P_{out} are monitored at positions S and T, respectively (Fig. 1(a)).

3. Simulation results and discussions

For the simulations, we use the FDTD method to obtain the transmission characteristics. When the incident light is side-coupled into the resonator by the PWS, the transmission spectrum of the filter is shown in Fig. 1(b) with $w = 50nm$, $\theta = 0^o$, $h = 15nm$, $g = 20nm$. From it, one can see that there are four transmission dips at the wavelength ranging from 0.6um to 1.6um according to the resonance condition in Eq (3).

3.1. Transmission properties of the resonators: the effects of aperture size

Firstly, we make an analysis of the aperture sizes on the transmission spectra and especially on the resonance wavelengths of the resonator. The transmission spectra with varied sizes of the aperture and the corresponding resonance wavelengths of the mode (1–4) as a function of the aperture sizes are shown in Fig. 2(a) and