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The effects of silver slabs in nanodisk resonator of plasmonic tunable band-pass filter

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ABSTRACT

A novel and simple method to meliorate nanodisk resonator using silver slabs is proposed. In this regard, we numerically and theoretically compared the meliorated resonator with the nanodisk resonator without silver slabs at the plasmonic tunable band-pass filter. It was found that configuration of the proposed resonator leads to reduction of the plasmonic filter dimensions. Also, we calculated the amount of this reduction based on the disk-shaped nanocavity resonant theory and the meliorated resonator simulation results. Therefore, the resonance wavelengths depend on the relative permittivity and nanocavity radius which were consistent with the outcomes achieved by the simulations of FDTD (Finite-Difference Time-Domain). The FDTD simulations shown transmission spectra were tunable by changing of structure parameters. Through this method, it was revealed that simple plasmonic devices can be designed with smaller dimension for highly integrated optical devices.

1. Introduction

SPPs (Surface Plasmon Polaritons) are electromagnetic waves which are confined to outermost layer of metal owing to electron oscillations which are free and are located in the metal and also field of electromagnetic in dielectric that are distributing through the interface of metal-dielectric with exponentially decline in the direction perpendicular to the interface. In the future, they will have lots of usages in the optical devices and circuits, because of light manipulating and classic diffraction limit conquering on sub-wavelength [1–3]. Recently, the structures which are based on SPPs are numerically simulated and empirically represented, for example, Mach – Zehnder interferometers [4], modulators [5], all-optical switches [6,7], splitters [8], y-shaped combiners [9], bends [10], sensors [11], Bragg reflectors [12,13], waveguides [14], mirrors [15] and filters [16]. Filter is the element of optical circuits which to date, more structures of them are planned and designed on the basis of MIM (Metal-Insulator-Metal) waveguides owing to light high rate confinement to the interface and SPPs admirable spread length, such as tooth-shaped waveguide filters [17], filters using rectangular geometry resonators [18], ring resonators [19,21] and disk resonators [20]. All of these filters achieved different resonant wavelengths with changing of structure parameters based on filter resonator, which provides the possibility of designing filters with more flexibility.

During the recent years, filter with nanodisk resonator by Drude model have been designed and investigated [20]. In the present study, we have proposed a novel and simple method to meliorate nanodisk resonator using silver slabs and also we have simulated the tunable plasmonic waveguide band-pass filter which is based on the mentioned resonator by the method of FDTD (Finite-Difference Time-Domain) using a PML-ABC (Perfectly Matched Layer Absorbing Boundary Condition) [22]. We have analyzed the proposed resonator by the nanocavity resonant theory and compared it with the nanodisk resonator without silver slabs. In our study, we found that with locating silver slabs in special positions of a nanodisk resonator with radius of r_o, we can get nanodisk resonator transmission modes with radius of $\left(3/2\right) r_o$ which, in this paper, we call it R_{res}. In other words, $R_{res} \approx 1.5 \times r_o$, r_o is the proposed resonator outer radius. Meanwhile, the above equation is obtained based on the disk-shaped nanocavity resonant theory and the simulation results. Therefore by the proposed method, filter dimensions could be decreased.

2. Structure and theory model

Fig. 1 shows the plasmonic filters which contains two MIM waveguides and (a) a nanodisk resonator without silver slabs, (b) a nanodisk resonator with silver slabs. Air is considered as the insulators inside the slits ($\varepsilon_d = 1$). Silver is selected for the metal,

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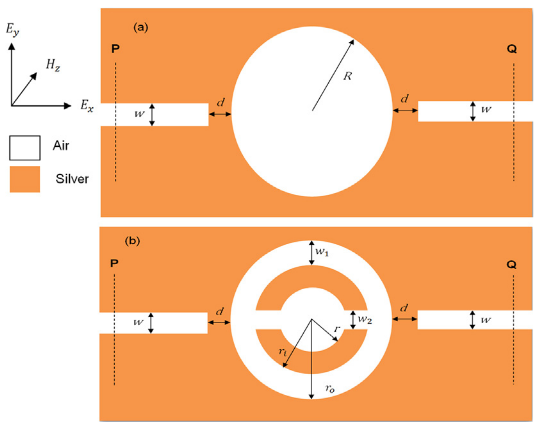

Fig. 1. Shematic structure of plasmonic filter with (a) nanodisk resonator without slabs, (b) nanodisk resonator with silver slabs.

and it's complex relative permittivity is described in Drude model [17].

$$\varepsilon_{\rm m}(\omega) = \varepsilon_\infty - \frac{\omega_{\rm p}^2}{\omega(\omega + i\gamma)} \quad (1)$$

In this formula, ε_∞ stands for dielectric constant for the situation that the frequency is infinite, $\omega_{\rm p}$ is frequency of bulk plasma and γ shows the frequency of electron collision. ω shows the angular frequency related to incident light. About the silver, the concerned parameters can be considered as, $\varepsilon_\infty = 3.7$, $\omega_{\rm p} = 9.1\,{\rm eV}$, also $\gamma = 0.018\,{\rm eV}$ [20]. The input/output waveguides width is w. The d stands for the coupling distance which is between two waveguides and resonator. R is the nanodisk resonator radius without silver slabs [20]. The r_i and r_o are inner and outer radius of the nanodisk resonator with silver slabs, the width between the meliorated resonator outer and inner radius is w_1, the widths of waveguides between silver slabs are w_2 and the nanocavity radius in the middle of it is r.

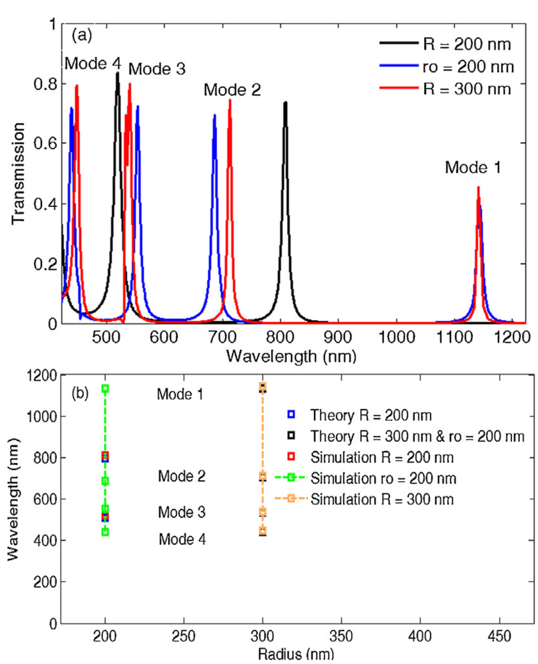

Fig. 2. (a) The filter transmission spectrum using nanodisk resonator without slabs for R = 200, 300 nm and nanodisk resonator with slabs for r_o = 200 nm, (b) comparing the results of nanodisk resonant mode theory and filter simulation for R = 200, 300 nm and r_o = 200 nm.

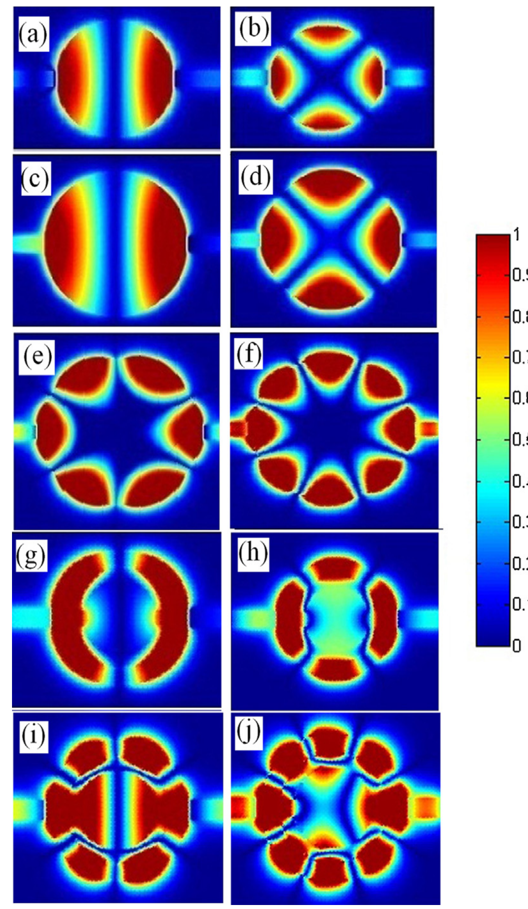

Fig. 3. The normalized field distributions of $|H_z|$ for the nanodisk resonator with radius of (a)–(b) R = 200 nm and (c)–(f) R = 300 nm, (g)–(j) the meliorated resonator with radius of r_o = 200nm at the band-pass filter.

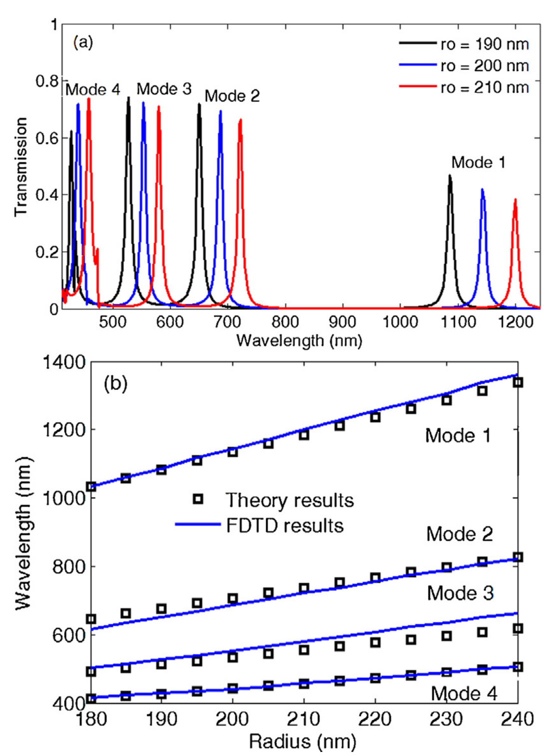

Fig. 4. (a) Transmission spectrum for different radiuses of the proposed resonator, (b) relationship between changing of the radius of the proposed resonator with wavelengths.