Infrared tunable dual-band polarization filter based on compound asymmetrical cross-shaped resonator

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Abstract

We propose an infrared tunable dual-band polarization filter in this paper. Based on the perfect absorption characteristic of the metal-dielectric-metal sandwich structure, the reflection spectrum performs as a filter. The calculated results show that different dual-band wavelengths are filtered while the incident light has different polarization which is parallel or vertical to the x axis. Moreover, it is found that the resonant wavelengths can be tuned independently and freely by adjusting the length of the corresponding rectangular strip. In addition, it is found that all of the intensities at the filter wavelengths are closed to zero, which implies the filter exhibits good filtering performance.

I. INTRODUCTION

Nanoplasmonic devices have attracted considerable interest because of the surface plasmons (SPs) [1,2] which is utilized in the devices to enhance the optical field intensity and overcome the classical diffraction limit. Recently, many devices based on SPs have been proposed and applied widely, such as plasmonic sensors [3,4], transistors [5,6,7], nanocavity [8] and absorbers [9,10]. Among the devices, plasmonic absorber is one of the most important and successful applications because of its ultra-strong ability of absorbing electromagnetic waves and freely tuning the absorption wavelength. During the investigative process of obtaining a better-performing absorber, researchers have found that an absorber can be applied toward developing a filter which yields a reflection spectrum that performs as a filter.

In 2001, a band-stop filter with a broader stop band for space transmission was realized by making use of plasmon hybridization [11]. Moreover, in 2012, a tunable plasmonic polarization filter based on a metal elliptical disc resonator was reported [12]. The resonant wavelength depends on the light polarization. The frequency of the polarized light can be tuned by changing the axis ratio of the elliptical disc. However, it is obvious that the reported polarization filter only exhibits a single-band filter property. Furthermore, the elliptical shape imparts strict demands on the fabrication process and the modulation range is limited.

In this paper, an infrared tunable dual-band polarization filter based on compound asymmetrical cross-shaped resonator has been investigated. The calculated results show that different dual-band wavelengths are filtered while the incident light has different polarization and the filtered wavelength (resonant wavelength) for different polarization can be modulated by adjusting the length of the corresponding strip.

II. Numerical model and simulations

Fig. 1 shows the basic scheme of the dual-band polarization filter cell structure. The structure consists of three layers. The top layer is a compound asymmetrical cross-shaped resonator formed by two asymmetrical cross-shaped resonators with different size and period. The asymmetrical cross-shaped resonator is formed by two perpendicular rectangular strips (parallel and vertical to the x axis, respectively). The middle and bottom layers are a dielectric spacer (MgF2) and metal film, respectively.

The parameters of the filter structure are as follows. The thickness of all the rectangular strips is $h_1=40$ nm. The width of the rectangular strips of the bigger asymmetrical cross-shaped resonator and the smaller one is $w_1=80$ nm and $w_2=50$ nm, respectively. $l_{x1}$, $l_{x2}$, $l_{y1}$ and $l_{y2}$ are the lengths of the four rectangular strips respectively and be set with different values in this paper. The thicknesses of the MgF2 layer and gold film are $h_2=50$ nm and $h_3=180$ nm, respectively. The periods of the filter cell structure in both the x- and y- directions are $p=600$ nm. The dielectric function of the metal (gold) is given by the Drude model [13]:

$$\varepsilon_m = \varepsilon_0 \omega_p^2 / (\omega_p^2 - \omega^2 - i \gamma \omega)$$

where $\varepsilon_0$ is the permittivity of the vacuum, the plasma wavelength $\omega_p = 1.37 \times 10^{16} \text{s}^{-1}$, $\omega$ is the angle wavelength of the incident wave,
and the damping rate $\gamma = 4.08 \times 10^{13} \text{s}^{-1}$. In order to investigate the characteristics of the filter, the reflection spectra are simulated with the 3D FDTD method based on EastFDTD software [14].

![Figure 2](image-url)  
Figure 2. (Color online) Reflection spectra of the filter with $l_1 = 250$ nm, $l_2 = 430$ nm, $l_1 = 330$ nm and $l_2 = 530$ nm for $E_x$ and $E_y$ polarization

Fig. 2 presents the reflection spectra with different light polarization. The blue line is the reflection spectrum corresponding to $E_x$ polarization (light polarization with the electric filed vector parallel to the x-axis), and the red line corresponds to $E_y$ polarization (light polarization with the electric filed vector vertical to the x-axis). It is easily found that different dual-band wavelengths are filtered for $E_x$ and $E_y$ polarization at the same time. The wavelengths of the dips for $E_x$ polarization are 1107 nm and 1787 nm and for $E_y$ polarization are 1398 nm and 2254 nm, respectively.

It is found that the resonant wavelengths can be tuned freely by adjusting the length of the corresponding rectangular strip. Fig. 3 presents the reflection spectra of the filter for $E_x$ polarization at the same time. Moreover, it is found that the resonant wavelengths can be tuned freely by adjusting the length of the corresponding rectangular strip.

![Figure 3](image-url)  
Figure 3. (Color online) Reflection spectra of the filter structure as a function of the length of the gold strips $l_1$ and $l_2$

III. CONCLUSION

In this paper, an infrared tunable dual-band polarization filter based on compound asymmetrical cross-shaped resonator has been proposed and investigated. The calculated results show that different dual-band wavelengths are filtered for $E_x$ and $E_y$ polarization at the same time. Moreover, it is found that the resonant wavelengths can be tuned freely by adjusting the length of the corresponding rectangular strip.

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