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

B. Ni[1,]*, X. Y. Chen[2], B. Chen[2], D. B. Zhang[3], X. D. Wang[4], H. Liu[1], G. H. Hua[1], H. Zhou[1]
[1] Jiangsu Key Laboratory of Meteorological Observation and Information Processing,
Nanjing University of Information Science & Technology, Nanjing, China, 210044
[2] College of Photonic and Electronic Engineering, Fujian Normal University, Fuzhou, China, 350007
[3] Dept. of Physics, Changshu Institute of Technology, No.99, Nansanhuan, Changshu, China 215500
[4] No. 50 Research Institute of China Electronics Technology Group Corporation, Shanghai, China, 200331

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.

* Corresponding author: bni@nuist.edu.cn

II. Numerical model and simulations

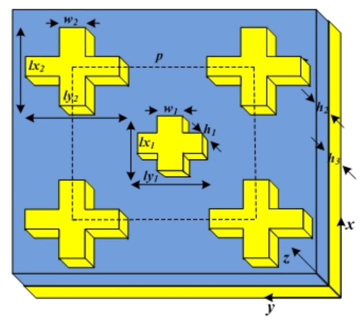

Figure 1. (Color online) Schematic of the dual-band polarization filter cell structure

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 (MgF_2) 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 =80 nm and w =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 MgF_2 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]: $\varepsilon_m = \varepsilon_0\{1-\omega_p^2/\omega(\omega+i\gamma)\}$. Here, ε_0 is the permittivity of the vacuum, the plasma wavelength ω_p =$1.37\times10^{16}\,s^{-1}$, ω is the angle wavelength of the incident wave, and the damping rate γ=4.08×10^{13} 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].

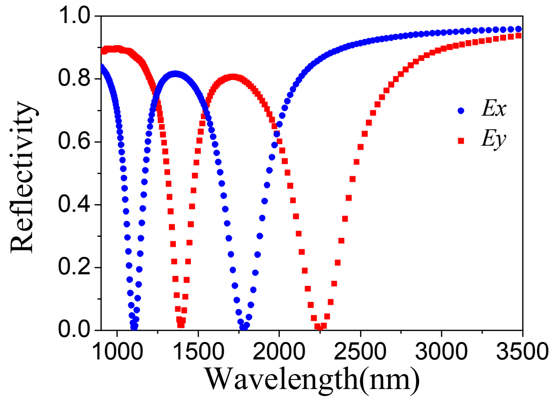

Figure 2. (Color online) Reflection spectra of the filter with l_{x1}=250 nm, l_{x2}=430 nm, l_{y1}=330 nm and l_{y2}=530 nm for *Ex* and *Ey* polarization

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 *Ex* and *Ey* polarization at the same time. The wavelengths of the dips for *Ex* polarization are 1107 nm and 1787 nm and for *Ey* polarization are 1398 nm and 2254 nm, respectively.

It is found that the resonant wavelengths can be tuned freely by adjusting he length of the corresponding rectangular strip. Fig. 3 presents the reflection spectra of the filter for E_x polarization of the rectangular strips with different length l_{x1} and l_{x2}. When l_{x1} and l_{x2} increase from 230 nm and 410 nm to l_{x1} =270 nm and l_{x2} =450 nm respectively with every step of 20 nm while l_{y1} and l_{y2} are fixed at 330 nm and 530 nm, it is found that the two resonant wavelengths for *Ex* polarization exhibit a redshift at the same time.

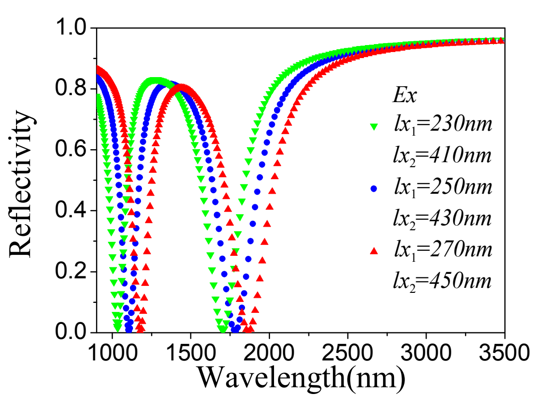

Figure 3. (Color online) Reflection spectra of the filter structure as a function of the length of the gold strips l_{x1} and l_{x2}

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 *Ex* and *Ey* polarization at the same time. Moreover, It is found that the resonant wavelengths can be tuned freely by adjusting he length of the corresponding rectangular strip.

Acknowledgments

This work was supported in part by the National Natural Science Foundation of China grants (61401216), Natural Science Foundation of Jiangsu Province (BK20131001), by the Natural science fund for colleges and universities in Jiangsu Province (13KJB510017), by the Priority Academic Program Development of Jiangsu Higher Education Institutions, and by the Startup Foundation for Introducing Talent of NUIST (S8113075001).

References

[1] W. L. Barnes, A. Dereux, and T. W. Ebbesen. Surface plasmon subwavelength optics [J], Nature. **424** 824-30, 2003

[2] E. Ozbay, Plasmonics: merging photonics and electronics at nanoscale dimensions Science. **311** 189-93, 2006

[3] J. Miao, W. Hu, Y. Jing, W. Luo, L. Liao, A. Pan, S. Wu, J. Cheng, X. Chen, and W. Lu, Surface Plasmon-Enhanced Photodetection in Few-Layer MoS2 Phototransistors with Au Nanostructure Arrays, Small, DOI: 10.1002/smll.201403422, 2015

[4] N. Liu, M. Mesch, T. Weiss, M. Hentschel, and H. Harald Giessen H, Infrared perfect absorber and its application as plasmonic sensor Nano Lett **10** 7 2342-8, 2010

[5] W. Qiu and W. Hu, Laser beam induced current microscopy and photocurrent mapping for junction characterization of infrared photodetectors, Science China-Physics Mechanics & Astronomy, 58, 027001 (2015).

[6] N. Guo, W.D. Hu, X. S. Chen, L. Wang, and W. Lu, Enhanced plasmonic resonant excitation in a grating gated field-effect transistor with supplemental gates, Optics Express, 21, 1606–1614,2013

[7] W. D. Hu, L. Wang, X. S. Chen, N. Guo, J. S. Miao, A. Q. Yu, and W. Lu, “Room-Temperature Plasmonic Resonant Absorption for Grating-gate GaN HEMTs in far infrared terahertz domain”, Optical and Quantum Electronics, 45, 713-720, 2013.

[8] G. H. Li, X. S. Chen, B. Ni, O. P.Li, L. J. Huang, Y. Jiang, W. D. Hu, and W. Lu, Fractal H-shaped plasmonic nanocavity, Nanotechnology, 24, 205702, 2013

[9] N. I. Landy, S. Sajuyigbe, J. J. Mock, D. R. Smith, and W. J. Padilla. Perfect metamaterial absorber Phys. Rev. Lett. **100** 207402, 2008

[10] J. Hendrickson, J. P. Guo, B. Y. Zhang, W. Buchwald, and R. Soref, Wideband perfect light absorber at midwave infrared using multiplexed metal structures Opt. Lett **37** 3 371-3, 2012

[11] X. Li, L. Y. Yang, C. G. Hu, X. G. Luo, M. H. Hong, Tunable bandwidth of band-stop filter by metamaterial cell coupling in optical frequency. Opt. Express **19,** 5283 (2011).

[12] M. N. Abbas, C. C. Wen, C. Y. Chung, M. H. Shih, An omni-directional mid-infrared tunable plasmonic polarization filter, Nanotechnology **23,** 444007, 2012

[13] Z. H. Han, E. Forsberg, and S. L. He, Surface plasmon bragg gratings formed in metal-insulator-metal waveguides IEEE Photon Technol Lett 19 91-3, 2007

[14] EastFDTD v3.0, DONGJUN Science and Technology Co. China