Optics Communications 387 (2017) 55–60

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Split-cross antenna based narrowband mid-infrared absorber for sensing applications

Ao Yang[a], Kecheng Yang[a], Lun Zhou[a], Junyu Li[a], Xiaochao Tan[a], Huan Liu[a], Haisheng Song[a,b], Jiang Tang[a,b], Feng Liu[c], Fei Yi[a,*]

[a] School of Optical and Electrical Information, Huazhong University of Science and Technology, Wuhan 430074, China
[b] Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, China
[c] Department of Physics, Shanghai Normal University, Shanghai 200234, China

ARTICLE INFO

Keywords:
Nanoantenna
Absorbers
Mid-infrared
Sensors
Plasmonics
Narrowband

ABSTRACT

We have investigated numerically a narrowband near unity mid-infrared absorber based on a periodic array of gold split cross antenna backed by a dielectric spacer and a gold backmirror. We systematically studied the spectral dependence on the antenna parameters and explored the optimized parameters for nanofabrication. The optimized structure has a linewidth of 39 nm at 3.17 μm and the peak absorption is 96.5%. This can be explained in terms of surface lattice resonance of the periodic structure. The investigated structure can be devised as a mid-infrared refractive index sensor. Due to the strong near field enhancement and spectral dependence on the surface dielectric conditions, the narrow linewidth arises from the coupled plasmonic-photonic modes in the structure and has potential applications in plasmonic biosensing.

1. Introduction

The subwavelength control of light-matter interaction available in optical antennas [1,2], or resonant metallic nanostructures [3], has been an active area of research in nanophotonics. When excited resonantly, the metallic nanostructures enable the conversion between freely propagating electromagnetic waves and intensive optical near field through localized surface plasmon resonance [4,5]. The strong light concentration capability of optical antenna has been used to enhance the light-matter interaction in photovoltaic, photodetection, biosensing and gas sensing [6–11]. On the other hand, the oscillating electron plasma in the resonantly excited metallic structures inevitably causes dissipation of electromagnetic energy due to free carrier absorption. The high optical absorption of optical antenna has led to the demonstration of absorbers for radiation from THz to visible wavelength range [12,13]. The electromagnetic energy dissipated in the nanostructured metallic resonators eventually turns into heat and the thermoplasmonic effect of optical antennas [14] has been applied to thermal infrared detection [15,16] and photothermal cancer therapy [17].

One commonly used structure for plasmonic absorber is a metal-insulator-metal(MIM) trilayer cavity [18] which consists of an optical antenna resonator, a dielectric spacer and a metallic ground plane. Such configuration allows separate tuning of the electric and magnetic resonances to match the impedance of the trilayer cavity to free space and thus minimize the reflectance at a certain wavelength [19]. When the ground plane is thick enough to block the transmission of light, near unity absorption of optical radiation can be achieved due to minimized reflectance. For applications such as spectral filtering and refractive index sensing, absorber with narrow linewidth is highly desirable [20,21]. So far, many MIM type narrowband absorbers with various antenna structures have been reported. However, most of them are in the visible and near infrared region [22], leaving the strategically important mid-wavelength infrared range (3–5 μm) underexplored. In the mid-infrared range, narrowband absorbers can be applied to novel applications such as pixel-level spectral filtering and polarization control for mid-infrared photodetectors and infrared gas sensing based on narrowband detector [23–25]. Therefore, we report in this paper a narrowband mid-infrared near unity absorber based on a split cross antenna backed by a dielectric spacer and a metal plate. The split cross antenna is formed by placing together four nanorods in an “X” fashion. Such a configuration is as simple to fabricate as nanorods but has more degrees of freedom in spectral tailoring. An optimized linewidth of 35 nm is achieved at around 3 μm with near unity absorption, which is useful for making narrowband mid IR photodetector free of external spectral filter. Moreover, the strongly enhanced optical near field at the surface of the nanorods can be used for sensing minute refractive index change in the surrounding. In our case, optical near field can be

* Corresponding author.
E-mail address: feiyi@hust.edu.cn (F. Yi).

http://dx.doi.org/10.1016/j.optcom.2016.11.029
Received 6 September 2016; Received in revised form 25 October 2016; Accepted 14 November 2016
Available online 19 November 2016

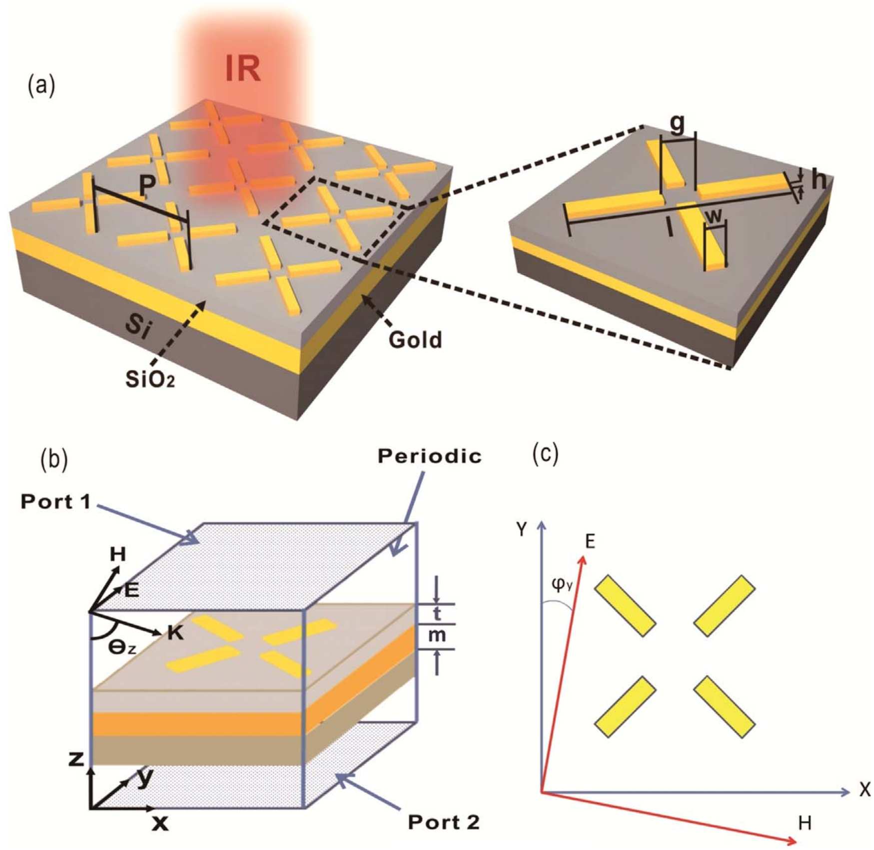

Fig. 1. (a) A schematic drawing of the mid-infrared near unity absorber based on split cross antenna MIM tri-layer structure with relevant design parameters. (b) The configuration of a unit cell of the antenna array and the definition of the incident angle θ_z. (c) Definition of the polarization angle φ_y.

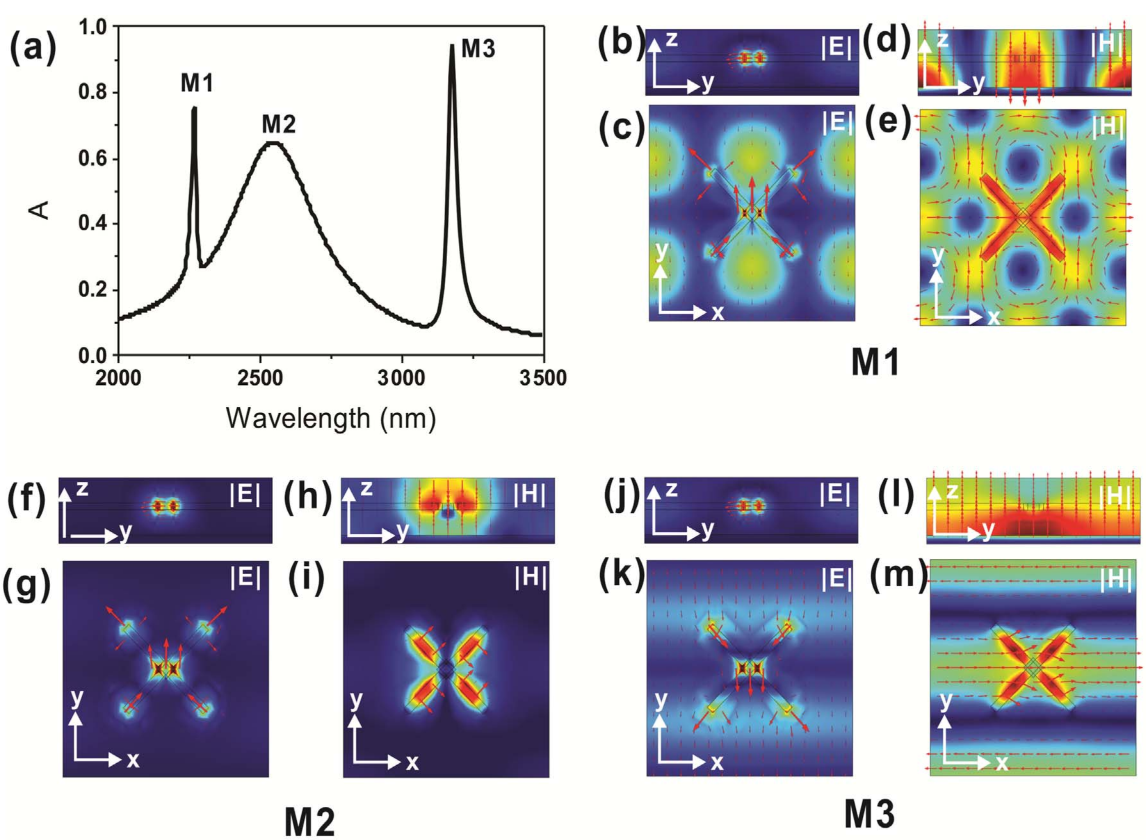

Fig. 2. (a) Spectral absorption of the MIM structure with three resonances (labeled as M1, M2 and M3) in the wavelength range from 2000 nm to 3500 nm. (b-m) The electric field |E| and magnetic field |H| distributions at M1, M2 and M3, respectively. Arrows show the E and H vectors.