Optics Communications 370 (2016) 245–249

Contents lists available at ScienceDirect

Optics Communications

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

A wide-angle broadband polarization-dependent absorber with stacked metal-dielectric grating

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ARTICLE INFO

Article history:
Received 13 December 2015
Received in revised form
19 February 2016
Accepted 13 March 2016
Available online 17 March 2016

Keywords:
Absorber
Absorption
Plasmonics
Broadband

ABSTRACT

We report an absorber in the mid-infrared regime by using stacked metal-dielectric grating structure. The simulation results show that the minimal absorption magnitude is larger than 0.8 in the broadband range for angles up to 60° for TM polarization (magnetic field is parallel to grating grooves). At the same time, absorption for TE polarization (electric field is parallel to grating grooves) is negligible. Furthermore, such broadband absorption for TM polarization can be tuned by shrinking or enlarging the grating parameters. This absorber is a good candidate for potential applications such as polarization detectors and polarizers.

1. Introduction

Electromagnetic metamaterials (MMs), which are constructed with artificial periodic structure, can achieve unique electromagnetic properties not found in nature [1]. By tuning the electric and magnetic responses with special unit cell, metamaterial absorbers have been realized and drawn great attention due to their potential applications in solar cells [2], plasmonic sensors [3], thermal emitters [4], and photodetectors [5]. Generally, a MMs absorber consists of metal-dielectric-metal structure with the principle of resonant electromagnetic responses [6–9]. However, the resonant characteristics in MMs absorbers will result in narrow bandwidth which may limit their applications, such as detector and solar cell. To meet the demand of broadband requirement, many schemes has been proposed to expand the absorption spectrum. For example, dual-band and multi-band absorbers have been realized by introducing metal-dielectric stacks laterally or vertically [10–15]. Also, many multiband absorbers have been achieved by excitation of multipolar or through cavity resonances [16–18]. But the absorption bands of these dual-band and multiband absorbers are discrete. To achieve continuous absorption band, ultrabroadband absorbers have been realized using plasmonic Brewster angle effect which restricts them to operate at special angles [19]. Recently, many researchers realized wide-angle broadband absorption with pyramidal or saw-toothed metal-dielectric layers which have graded widths to minimize the reflection [20–23]. However, fabrication of such absorbers with graded widths is a complicated process because the dose intensity should be carefully designed during the focused ion beam (FIB) milling process. Thus, broadband absorbers with fixed grating widths are expected to solve this problem.

In this paper, we report an absorber in the mid-infrared regime by using stacked metal-dielectric grating structure with the same grating widths. In this multilayer grating, a thinner metal layer and thicker dielectric layer in the upper stacks have been used to realize broadband absorption. The simulation results show that the minimal absorption magnitude is larger than 0.8 in the broadband range for angles up to 60° for TM polarization. At the same time, absorption for TE polarization can be ignored. This absorber is a good candidate for potential applications such as polarization detectors and polarizers.

2. Metal-dielectric-metal grating

Spectrum characteristics of metal-dielectric-metal grating are investigated to show the influence of structure size on the absorption. The absorption band that is going to be achieved is in the mid-infrared regime. To meet thin-layer requirement, the thickness of each layer that will be employed in the multilayer grating is much smaller than the incident wavelength. Fig. 1 shows a metal-dielectric-metal grating. Gold is used as metal material to consume energy in the mid-infrared regime in our design because

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http://dx.doi.org/10.1016/j.optcom.2016.03.033
0030-4018/

of the imaginary part of permittivity of metal. Silica is used as lossless-dielectric material to separate two metallic surfaces. The permittivity of gold and silica is taken from Ref. [24]. The media that supports and surroundings the structure is set as vacuum in Fig. 1. A plane wave with wavelength λ for TM polarization at an angle of θ $(90^{\circ} > \theta \geq 0^{\circ})$ is incident upon the multilayer grating. Rigorous coupled-wave analysis (RCWA) is used to model the structure [25]. The absorption can be calculated with $A = 1 - R - T$. To ensure the calculation accuracy, a total of 101 Fourier components are employed in the simulations process.

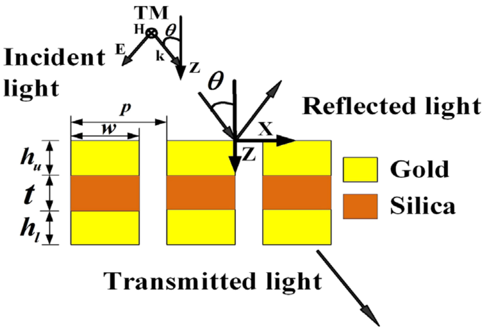

Fig. 1. Geometry of the metal-dielectric-metal grating.

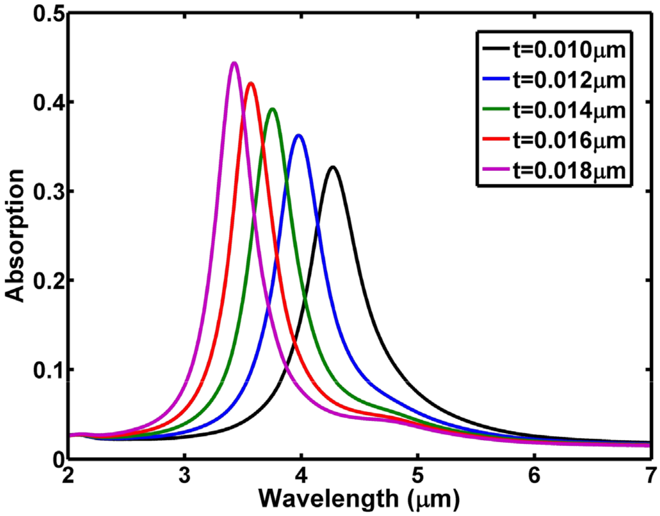

Fig. 2. Absorption as a function of wavelength with different dielectric thickness.

Fig. 2 shows the absorption as a function of wavelength with different dielectric layer thickness. Other parameters are $p = 0.80$ μm, $w = 0.56$ μm, $\theta = 0^{o}$, $h_l = 0.10$ μm, and $h_u = 0.10$ μm. It can be seen that the absorption peak will shift to shorter wavelength with the increasing dielectric thickness. The resonance absorption peaks can be understood with the equivalent circuit approach, and the resonance frequency can be expressed by

$$\omega = \frac{1}{\sqrt{LC}} \tag{1}$$

where L is the effective inductance and C is the effective capacitance [26]. The effective capacitance with the larger dielectric layer thickness will be smaller. This means that the metal-dielectric-metal structure with a larger dielectric-layer thickness has a shorter resonance wavelength according to Eq. (1). Fig. 3(a) shows the transmission spectra with different metal-layer thickness to investigate the influence of metal-layer thickness on the spectra. In the simulation process, other parameters are $p = 0.80$ μm, $w = 0.56$ μm, $\theta = 0^{o}$, $t = 0.10$ μm, and $h_l = 0.10$ μm. As shown in Fig. 3(a), larger transmission will be achieved when the thickness of upper metal layer is smaller than that of the lower metal layer. Thus, one can enhance transmission by choosing smaller thickness of upper metal layer. Fig. 3(b) shows the absorption spectra with different metal-layer thickness. From Fig. 3(b), the absorption magnitudes are slightly changed with upper metal-layer thickness ranged from 0.06 μm to 0.16 μm. Thus, the influence of meal-layer thickness in the range from 0.06 μm to 0.16 μm on absorption can be ignored.

3. Design of a broadband absorber

Considering the tunability of absorption peaks with different dielectric-layer thickness, we employ different dielectric-layer thickness in several metal-dielectric-metal stacks to broaden the absorption spectrum. Because a broadband absorber we want to realize is constructed by a multilayer structure, the electromagnetic wave at the resonant wavelengths in the lower metal-dielectric-metal stacks must transmit through the upper metal-dielectric-metal stacks. Thus the upper stacks are expected to have high transmission for the resonant wavelengths at the lower stacks. We notice that the transmission will be larger when the incident wavelengths are larger than the resonant absorption peaks from Fig. 3. Furthermore, the smaller dielectric-layer thickness in the metal-dielectric-metal stack will result in longer resonant absorption wavelengths from Fig. 2. Thus, to make the electromagnetic wave at resonant absorption wavelengths in the

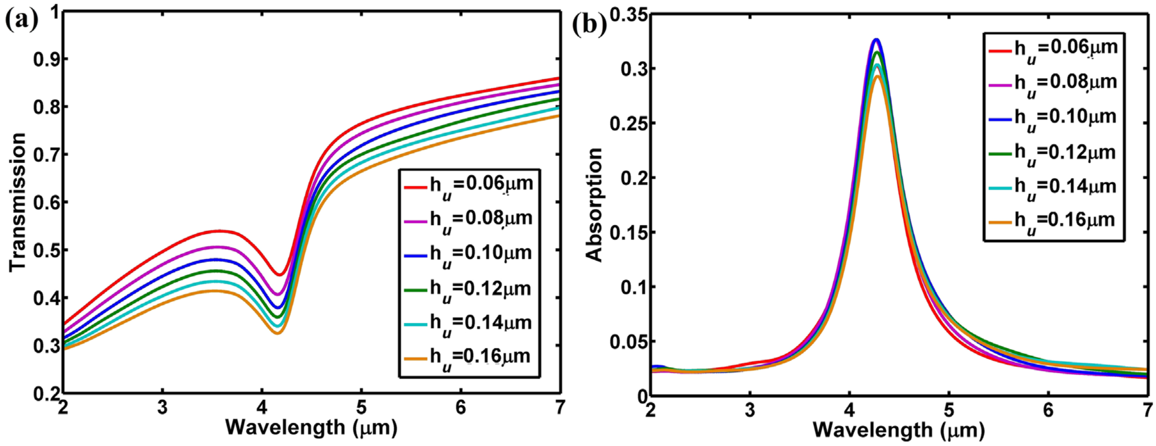

Fig. 3. (a) Transmission spectra and (b) absorption spectra with different upper metal-layer thickness.