



An ultra-narrowband absorber with a dielectric-dielectric-metal structure based on guide-mode resonance

Yan-Lin Liao^a, Yan Zhao^{b,*}

^a Key Laboratory of Intelligent Computing & Signal Processing, Ministry of Education, Anhui University, Hefei, PR China

^b Department of Applied Physics, Anhui Medical University, Hefei 230032, PR China

ARTICLE INFO

Article history:

Received 20 May 2016

Received in revised form

8 July 2016

Accepted 8 August 2016

Keywords:

Absorption

Resonance

Absorber

ABSTRACT

We report an ultra-narrowband absorber with a dielectric-dielectric-metal (DDM) tri-layer structure which is composed of a dielectric grating as the top layer, a dielectric spacer and a metal substrate. The simulation results show that, we can get an ultra-narrowband absorber with the absorption bandwidth less than 0.05 nm and the absorption rate more than 0.99 within an ultra-narrow angle for TE polarization (electric field is parallel to grating grooves). The results also show that the ultra-narrowband absorption for TE polarization is originated from guide-mode resonance and low power loss in the metal substrate. This ultra-narrowband absorber is a good candidate for application in coherent emission of light by thermal source.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Absorption manipulation by designing artificial nanostructures is a very important issue because absorbers with near-perfect absorption have lots of applications such as sensors [1], solar cells [2], thermal emitters [3] and photodetectors [4]. Typical absorber is composed of a metal-dielectric-metal (MDM) structure [5–9]. In such a tri-layer structure, the electric dipole resonance is excited in the top layer which is a structured metallic structure, and the magnetic resonance is excited in both the top metallic layer and bottom metallic layer. This electric and magnetic resonance can be tuned by adjusting geometrical parameters. In addition, the intense resonance, which is an origin of strong absorption, results in a narrow absorption bandwidth which is a very critical factor in some applications. For example, an absorber with narrower absorption bandwidth exhibits better temporal coherence when a narrowband absorber is applied as a thermal emitter [10]. Thus, an ultra-narrowband perfect absorber with very narrow absorption bandwidth is desirable.

To date, several ultra-narrowband absorbers have been reported. For example, in 1997, Sharon et al. reported strong absorption with theoretical bandwidth of 0.08 nm with a metal-based grating-waveguide structure [11]. In 2014, Meng et al. realized an ultra-narrow absorption bandwidth of 0.4 nm with shallow grating grooves [12]. In 2015, Zhao et al. reported an ultra-narrow absorption bandwidth of 2 nm based on two cascaded

metal-insulator-metal stacks [13]. In 2015, our group proposed a scheme to manipulate the absorption bandwidth by using the hybridization of gap plasmon mode and Fabry–Perot resonance mode, and an ultra-narrow absorption bandwidth can be realized with an appropriate thickness of dielectric layer [14]. Very recently, He et al. achieved an ultra-narrowband absorber based on a solid (bar) and an inverse (slot) compound metallic nanostructure, and its absorption bandwidth is less than 8 nm at optical frequencies [15].

The aforementioned ultra-narrowband absorbers have advantages and disadvantages compared with each other. For example, the absorbers in Refs. [11,13] have advantages in fabrication cost because of the dielectric microstructure or multilayer film without structured layer, but their absorption rates at the absorption peaks are only about 0.9 in theory. Although the others have larger absorption, fabrication of such absorbers is costly because realization of their metallic microstructures requires advanced lithography or focused ion beam milling techniques. Furthermore, the narrowest absorption bandwidth in these absorbers is 0.08 nm in theory [11]. Considering the characteristics of the ultra-narrowband absorbers mentioned above, a perfect absorber with both a more feasible fabrication scheme and a narrower bandwidth is still desirable.

In this paper, we reported an ultra-narrowband absorber with a DDM structure. The simulation results show that, the absorption bandwidth is less than 0.05 nm and the absorption rate is more than 0.99 within an ultra-narrow angle for TE polarization. The simulation results also show that the absorption peak can be shifted by changing the structure parameters. This ultra-narrowband absorber can be used as an ultra-narrowband high-

* Corresponding author.

E-mail address: zhaoyan@ahmu.edu.cn (Y. Zhao).

directional thermal emitter.

2. Structure

Fig. 1 shows the DDM structure. The top-layer microstructure is a grating which can be described by slit width w , period p , and height h . The middle layer is a dielectric film with thickness t . The metal substrate is used to efficiently block light from penetrating. A plane electromagnetic wave with wavelength λ at an angle of θ ($90^\circ > \theta \geq 0^\circ$) is incident upon this DDM structure. The reflection R and transmission T of the DDM structure are evaluated with the rigorous coupled-wave analysis (RCWA) [16], and the absorption can be obtained with $A = 1 - R - T$. The reflection R is the sum of reflected Fourier components, and the transmission T is the sum of transmitted Fourier components. The accuracy of the results relies on the number of Fourier components in the simulations process. We employ a total of 111 Fourier components which are sufficient to ensure the convergence and calculation accuracy. We choose gold as the material of metal substrate to consume electromagnetic wave energy because of the imaginary part of metal permittivity, and its permittivity is taken from Ref. [17]. We choose silica as the lossless-dielectric material of the top and middle layer, and its optical properties can be achieved from Cauchy formula:

$$n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} \quad (1)$$

where $A = 1.491$, $B = 0.00686$, $C = -0.0007648$, and λ has units of micrometers in this paper.

3. Results and discussion

Fig. 2 shows the absorption spectrum of the DDM structure with the optimized structure parameters of $p = 0.800 \mu\text{m}$, $w = 0.400 \mu\text{m}$, $\theta = 0^\circ$, $h = 0.047 \mu\text{m}$, and $t = 2.010 \mu\text{m}$. As shown in Fig. 2, there is an absorption peak at $\lambda = 1.17752 \mu\text{m}$ with the absorption rate larger than 0.99 and the absorption full width at half maximum (FWHM) less than 0.05 nm for TE polarization. From Fig. 2, we can get an ultra-narrowband absorber with the narrowest absorption bandwidth by using a DDM structure. Compared with the bandwidths of typical absorbers based on MDM structures [5–9], the bandwidth of our absorber is smaller than those several orders of magnitude. Furthermore, the materials of the top layer and middle layer in our absorber are identical. This dielectric material configuration in our absorber is more favorable for standard masked-based fabrication process, compared with the ultra-narrowband absorbers with MDM structures reported in Refs. [14,15].

To investigate the ultra-narrowband absorption mechanism,

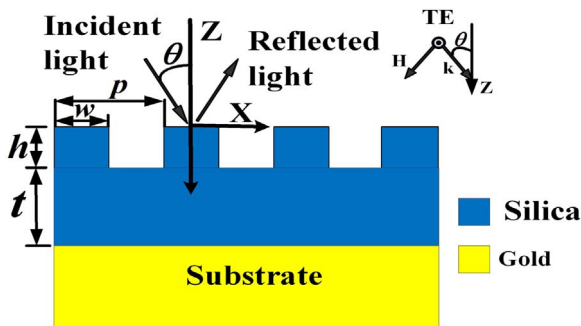


Fig. 1. Geometry of the DDM structure.

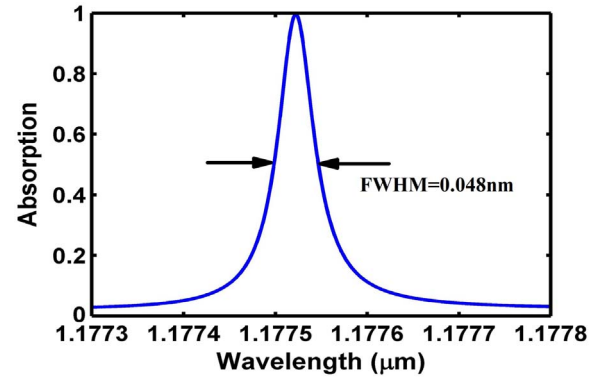


Fig. 2. Absorption as a function of wavelength.

the magnitudes of electric field $|E_y|$ at incident wavelength $\lambda = 1.17752 \mu\text{m}$ are plotted within two unit cells for TE polarization in Fig. 3(a). From Fig. 3(a), we can see fundamental mode excitation with guide-mode resonance. Furthermore, Fig. 3(a) shows that the electric field intensity is almost zero in the metal zone. Such field distribution in Fig. 3(a) means that low power loss takes place within a round trip in the resonance because the power loss is in proportion to the square of the electric field intensity inside the metal material [18]. To present a qualitative understanding of the absorption characteristics, we plot the time-averaged power loss density of our proposed structure in Fig. 3(b). The time-averaged power loss density for a nonmagnetic dispersive medium in Fig. 3(b) can be described by

$$\frac{dP}{dV} = \frac{1}{2} \epsilon_0 \omega \text{Im} \epsilon(\omega) |E|^2 \quad (2)$$

where ω is the angular frequency, ϵ_0 is the permittivity of vacuum and $\text{Im} \epsilon(\omega)$ is the imaginary part of relative permittivity. From Fig. 3(b), we can see that the power loss occurs in the metal substrate. We also notice that the maximal value in Fig. 3(b) is lower than that reported in Ref. [19] several orders of magnitude. Considering the huge difference in the time-averaged power loss density between our DDM structure and that one in Ref. [19], we can neglect the volume difference, so that the power loss in our absorber will be much smaller. We can treat the proposed structure as a Fabry–Perot cavity. The low power loss in this cavity indicates a high quality factor which eventually yields a narrow absorption bandwidth in our absorber. From the above discussion, we can conclude that the ultra-narrowband absorption for TE polarization is originated from guide-mode resonance and low power loss in the metal substrate.

To investigate how the absorption is affected by the incident angles, the absorption spectra with different incident angles are simulated in Fig. 4(a). As the incident angle increases in Fig. 4(a), the absorption peak with fundamental mode will red-shift, and the absorption rate of fundamental mode decrease when θ deviates from 0° . In addition, more than one peak with strong absorption can be observed because of high-order guide-mode resonance. To show the relationship between the absorption rate and the incident angle at the absorption peak, the angle-resolved absorption at the incident wavelength of $1.17752 \mu\text{m}$ is shown in Fig. 4(b). We define the angular width of FWHM with $\Delta\theta$ to describe the angle-resolved absorption characteristics. From Fig. 4(b), we can see that the largest absorption can be attained at $\theta = 0^\circ$, and $\Delta\theta$ at $\theta = 0^\circ$ is less than 0.070 mrad. This means that our absorber is highly directional. According to Kirchhoff's law that the absorption equals emissivity, this absorber can be applied as a directional thermal emitter. Furthermore, the small $\Delta\theta$ in our absorber indicates the corresponding spatial coherence length is

Download English Version:

<https://daneshyari.com/en/article/7927709>

Download Persian Version:

<https://daneshyari.com/article/7927709>

[Daneshyari.com](https://daneshyari.com)