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A wide-angle and polarization insensitive infrared broad band metamaterial absorber

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ABSTRACT

In this paper, we present the design and experimental demonstration of a broad single-band metamaterial absorber composed of a simple two-dimensional periodic silver-SiO_2-silver sandwich array. The experimental results show that a near-perfect absorption band with a bandwidth of approximately 0.4 μm in the THz region is obtained, which is in reasonable agreement with the simulated results. The calculated electric field intensity distributions indicate that the broad absorption band is achieved by plasmonic hybridization of two plasmon resonances: one originates from outward coupling between adjacent unit cells and the other arises from inward coupling between the two sub-structures. The effects of the structural parameters and the SiO_2 layer thickness on the broad absorption band are investigated experimentally. The effect of the angle of incidence on the broad absorption band is also investigated experimentally and the absorption band remains high at large angles of incidence (60°), which thus provides more efficient absorption of obliquely incident beams.

1. Introduction

Artificial electromagnetic (EM) metamaterials have been widely researched and manufactured in recent years for a broad wavelength spectrum from the visible range to the microwave range [1–4]. EM metamaterials can potentially be applied to many types of electromagnetic equipment, including photovoltaic cells [5], photodetectors [6], sensors [7], and thermal emitters [8]. One potential device application of EM metamaterials is absorbers, which are designed to have a high absorption coefficient. Metamaterial absorbers have been researched from the microwave range to the visible range [9–12], and some multiple-band metamaterial absorbers have also been proposed [13,14]. These metamaterial absorbers are mostly based on the excitation of electrical split-ring resonance in their top metallic layers. Alternatively, multiple-band metamaterial absorbers can be developed based on the stacking of multiple metallic and dielectric layers [15]. Usually, the electromagnetic properties of artificial metamaterials are described on the basis of effective parameters. It is possible to maximize the absorption of the radiation of interest while minimizing unwanted reflections through engineering of these effective parameters to obtain impedance matching at the air-metamaterial absorber interface. However, these proposed absorbers can usually only be operated over a narrow frequency range, which leads to difficulty in obtaining a flat and wide absorption band. This is because of the complexity of both the structural design and the electromagnetic dispersion behavior of metamaterial absorbers. This will limit the application of metamaterial absorbers in many electromagnetic devices, such as spectroscopic and image detection devices [16]. Therefore, metamaterial absorbers with wide and flat absorption bands continue to be in demand.

In this paper, a novel composited patterned EM metamaterial absorber with a flat and wide absorption band is designed, simulated, and manufacture. The experimental results demonstrate that a near-perfect absorption band (no less than 86.8% absorption) can be achieved in a contiguous range of frequencies with a bandwidth of approximately 0.4 μm. The proposed metamaterial absorber uses plasmon hybridization of the intra-unit interactions and the neighbor-unit interactions to achieve its broad absorption band, which is different from previous reported devices that operated by combining variously sized sub-structures into a unit cell to obtain the required absorption band response [17–20]. Also, the

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broadband metamaterial absorber can be optimized by adjusting its dimensional parameters, which makes the absorber more attractive for device design and applications.

2. Unit cell design and measured absorption spectrum

As shown in Fig. 1(a) and (b), the designed single-band EM metamaterial absorber consists of three functional layers: a top patterned silver layer with a square pane and a cylindrical patch, a dielectric layer, and a silver plane layer that acts as the bottom reflector. In the designed structure, silver is used for the top and bottom layers, while the dielectric layer is composed of silicon dioxide (SiO_2). The top silver patterned layer consists of a square pane and a cylindrical patch, which show two distinct absorption peaks because of their two distinct resonance modes. In the designed unit cell, the lattice constant is given by "*p*", the silver layer thickness is represented by "*h*", the dielectric layer thickness is given by "*H*", and the pane width and the patch radius are given by "*w*" and "*r*", respectively. The dimensional parameters of the designed structure are given in Table 1. The silver layer is 0.1 μm thick, and the dielectric layer thickness can be adjusted in the experiments. Ansoft's HFSS 13.0 software is used to simulate the proposed metamaterial absorber. All of silver layers follow the Drude model:

$$\varepsilon(\omega) = 1 - \frac{\omega_p^2}{\omega^2 - i\omega\gamma_D} \tag{1}$$

Where, $\gamma_D = 9 \times 10^{13}\ s^{-1}$ is the collision frequency and $\omega_p = 1.37 \times 10^{16}\ s^{-1}$ is the plasma frequency [21]. In simulations, the permittivity of the SiO_2 layer is set to be 2.1025 [22]. Two ideal electric and conductor planes are applied on the boundary normal to the *x* axis and *y* axis [23]. A floquet port is adopted at the top boundary of the unit cell to simulate a normally incident electromagnetic wave, and periodic boundary conditions are used to the four sidewalls. The whole simulated model is tested in air with light incident from air along the *z* axis. To validate the design metamaterial absorber, samples are fabricated by employing electron-beam lithography: first, a layer of silver (0.1 μm) is deposited onto the upper surface of a silicon wafer through using low pressure chemical vapor deposition at a rate of 1.9 Å s^{-1}. Next, a 0.25 μm thick SiO_2 layer is deposited onto the upper surface of the silver layer through using plasma-enhanced chemical vapor deposition. Then, another silver layer is deposited onto the upper surface of the SiO_2 layer also at a rate of 1.9 Å s^{-1}. Finally, an array of designed structure is milled on the top silver layer by using a focused ion beam system. A $3.5 \times 3.5\ mm^2$ area samples are achieved, as shown in Fig. 1(d).

Table 1
All dimensional parameters of the designed structure.

Parameter	*P*	*L*	*w*	*r*	*h*	*H*
Value (μm)	6	4	0.7	0.5	0.1	0.25

For the designed single-band absorber, the calculated absorbance spectrum can be obtained using $A = 1 - R - T$, where *R* and *T* are the calculated reflection and transmission spectra, respectively. Because the bottom silver metallic layer is a continuous and suitably thick metallic layer, it causes the transmittance to drop to zero. Therefore, the calculated absorbance can be simplified as $A = 1 - R$. Because the designed absorber is made using a combination of two single structures, we first must optimize these single

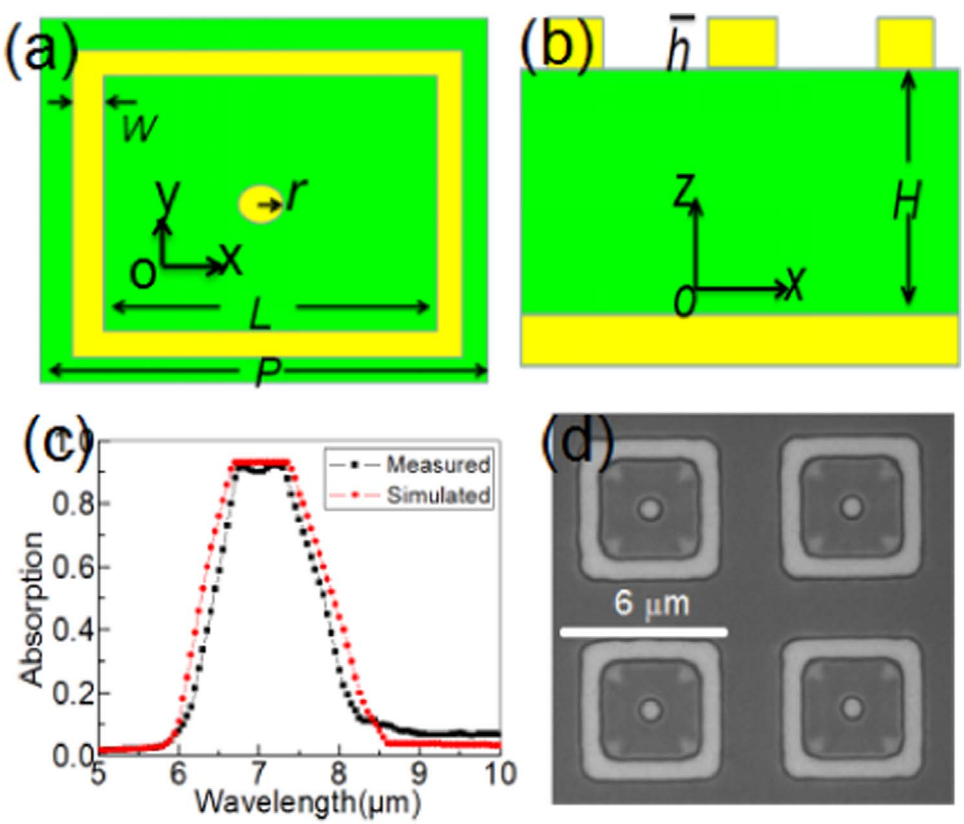

Fig. 1. (a) Top view of the unit cell on the xoy plane. (b) Side view of the unit cell on the xoz plane. The yellow part is silver layer, the green part is SiO_2 layer, (c) Measured and simulated absorption spectra. (d) Photograph of samples. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).