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Broadband infrared metamaterial absorber based on anodic aluminum oxide template

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ABSTRACT

In this work, a broadband infrared metamaterial absorber is proposed based on trapezoid-shaped anodic aluminum oxide (AAO) template. Unlike traditional metamaterial absorber constructed from metal-dielectric-metal sandwich structure, our proposed absorber is composed of trapezoid-shaped AAO template with metallic nanowires inside. The infrared absorption efficiency is numerically calculated and the mechanism analysis is given in the paper. Owing to the superposition of multiple resonances produced by the nanowires with different heights, the infrared metamatrial absorber can keep high absorption efficiency during broad working wavelength band from 3.4 μm to 6.1 μm. In addition, the resonance wavelength is associated with the height of nanowires, which indicates that the resonance wavelength can be modulated flexibly through changing the heights of nanowires. This kind of design can also be adapted to other wavelength regions.

1. Introduction

Metamaterial, as a new kind of artificial electromagnetic medium, has aroused the attention all over the world. It holds some unique properties which are beyond comparable in electromagnetic waves manipulation than conventional materials, such as polarization conversion [1–3], anomalous reflection [4–11], transmission/reflection focus [12–15], surface plasma polarization inspiration [16], perfect absorption [17–19] and so on. Traditional absorber material mainly relies on the loss of material itself, which usually leads to narrow absorption working spectrum and low efficiency. With the appearance of metamaterial, it becomes possible for us to design artificial material which is able to achieve impedance matching with the vacuum during a broadband spectrum, and this can make electromagnetic wave penetrates into material as much as possible and then be absorbed. And in turn metamaterial absorber can achieve a higher absorption efficiency. In fact, metamaterial absorbers have experienced full development and many attracting achievements have been fulfilled. For example, a broadband metamaterial absorber at mid-infrared using multiplexed cross structure was proposed [20]. By using metal/dielectric/metal structure with double metal ring, polarization insensitive dual-band metamaterial absorber was designed in THz region [21]. Based on traditional sandwich structure, through placing multiple dielectric layers to broaden band, a broadband mid-infrared metamaterial absorbers was proposed [22], ultra-broadband Terahertz absorption by was achieved by the uniaxial anisotropic gold nanowire arrays [23].

In general, each specific metal-dielectric-metal structure corresponds to a specific absorption band. To obtain a wider absorption, we have to either scarify the simpleness of the structure (to design complex surface metallic structure) or the bulky dielectric layer as told in Ref. [22]. However, in our work, different from conventional sandwich structure, we have investigated on AAO template with metallic nanowire filled in. And we fabricate an AAO template Al nanowires sample with single height to validate our analysis. Through further studying the property of nanowires with different heights, we propose a trapezoid-shaped structure with different heights nanowires filled inside. Due to the fact that the resonance frequency is manipulated by the height of metallic nanowire, the broadband absorption is achieved through superstition of the inset metallic nanowire with different height. To explain the mechanism of the infrared metamaterial absorber, the numerical simulated distribution of electric field is simulated. This kind of designation is much more flexible than sandwich structure in bandwidth manipulation and what's more the design method can be extended to any other working band as well.

2. Principle of single band absorber and experimental validation

In this work, the schematic graph of resonator unit cell of proposed broadband infrared metamaterial absorber was exhibited in

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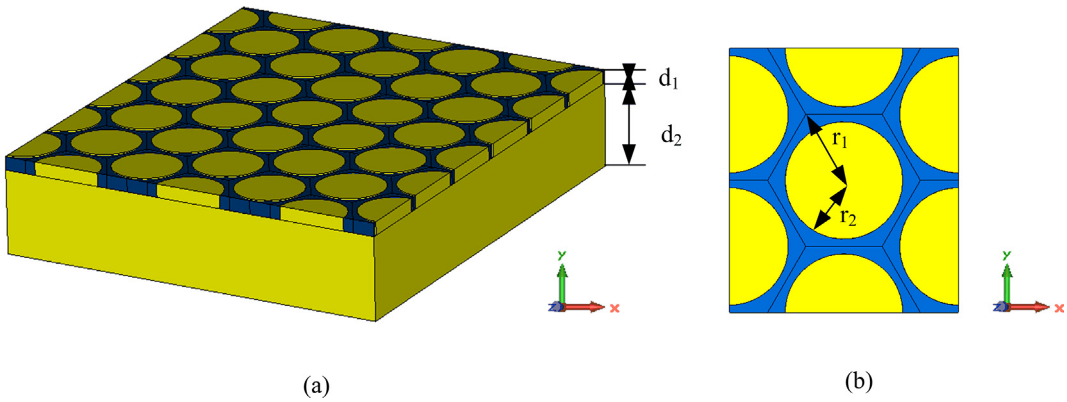

Fig. 1. The schematic graph of resonator structure. (a) Perspective view of metamaterial absorber resonator, (b) front view of metamaterial absorber resonator.

Fig. 1. The metamaterial absorber was composed of two layers. The surface layer was hexagon AAO porous which can be served as dielectric layer, and with Al metal filled in the porous to form nanowire. While the bottom layer was metal Al served as supporting substrate and reflective background. The corresponding parameters was as below: r_1 = 450 nm, r_2 = 400 nm, d_1 = 0.6 μm, d_2 = 2 μm, ε_{AAO} = 2.78 [22], and Drude model [24] was utilized in Al metal.

The unit cell of the proposed nanowire metamaterial absorber can be viewed as two parts: resonating part and loss part. The metallic nanowires inside the AAO porous serve as nano-resonators. Through periodic arranging the nanowires array, the resonance is produced by nanowire resonators. The corresponding resonance wavelength is determined by the height of the nanowire. And it can be calculated as:

$$\lambda = \frac{4 * \sqrt{\varepsilon\mu} * d}{(2k + 1)} \tag{1}$$

While k stands for integer, ε and μ stands for permittivity and permeability respectively. d stands for the height of nanowires.

The AAO template worked as loss part. Due to the strong resonance excited by the nanowire resonators, the power of incident electromagnetic waves can be consumed by the AAO dielectric. Thus, two parts together constitute nearly perfect absorption.

In order to verify above-analysis, a series of single height unit cells were simulated by Commercial Software CST Microwave Studio, and the corresponding S parameters and absorption curves were shown in Fig. 2. As can be seen from the graph, the nanowires with different heights exhibit different absorption peaks at 3.33 μm, 3.77 μm, 4.2 μm, 4.59 μm, 5 μm, 5.42 μm, respectively. The simulated resonance frequency was just accordance with the calculated one, which indicated that our resonance equation was correct.

To further explain the principle of proposed metamaterial absorber, the electric field of the unit cell at resonant frequency is tracked through CST field monitor, and we take a sample of d_1 = 0.6 μm whose resonant wavelength is 4.2 μm for example, and the corresponding electric field distribution is shown in Fig. 3.

It is clear to find that the resonance is strong at corresponding frequency and the resonance mainly concentrates on the interface between two adjacent nanowires. In other words, due to the strong resonance caused by nanowires, the power of incident waves is absorbed by the dielectric. As a consequence, high effective absorption is achieved.

To validate our previous analysis, we made a sample of d_1 = 0.6 μm. The fabrication of the unit cell is rather simple. The porous AAO template with Al substrate was purchased from Shangmu Technology Company. Prior to evaporation, the AAO template was cleaned to remove the impurities. And then the vacuum evaporation method was utilized to deposit the Al metal film to the surface side of AAO template. After evaporation, the metallic nanowires were formed in the AAO porous. Finally, the redundant Al was peeled off through physical method. The detailed fabrication flow schematic was displayed in Fig. 4.

As it can be seen from zoom graph in Fig. 4, the surface was evenly overspread with hexagon AAO porous. The material of white wall of hole is Al_2O_3, while the material of black hole is Al metal. The shapes of AAO porous were not uniform hexagon shape, some of porous bigger while others smaller.

The integrating sphere is used to measure the absorption efficiency. As can be seen from Fig. 5, the resonance takes place at 4.2 μm and so there produces an absorption peak. In the simulation results, the absorption can reach nearly 99.8%, while we just

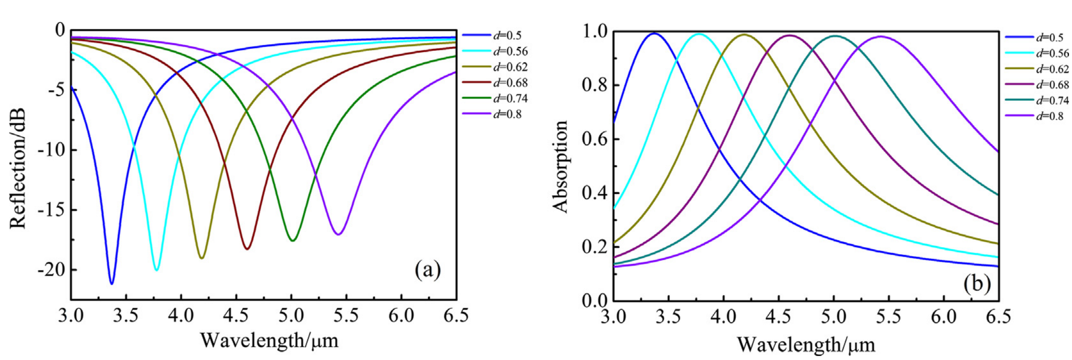

Fig. 2. S parameters and absorption curves of nanowires with different heights. (a) The reflection S parameters curves. (b) The absorption curves.