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Absorption enhancement of a dual-band metamaterial absorber

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ABSTRACT

In this paper, we propose and fabricate a dual-band metamaterial absorber in 6–24 THz region. Electric field distribution reveal that the first absorption band is obtained from localized surface plasmon (LSP) modes which are excited both on inside and outside edges of each circular-patterned metal-dielectric stack, while the second absorption band is excited by LSP modes on outside edges of each stack. Measured results indicate that the absorption band width can be tuned by increasing the radius of circular-patterned layers or reducing the thickness of dielectric spacing layers. Moreover, the designed dual-band metamaterial absorber is independent on circular-patterned dielectric layer combinations.

1. Introduction

Since the first demonstration by Landy et al.[1], metamaterial absorbers have attracted considerable worldwide attention during the past years. The proposed structure consists of a cut wire and metallic split ring, an absorbance peak about 88% at 11.5 GHz is obtained by coupling separately to magnetic and electric fields within a single unit cell layer [1]. Many novel structure absorbers in the GHz targeted spectrum are designed and manufactured [2–4]. Subsequently, many artificial structures such as sub-wavelength hole arrays, periodical metallic nanoparticles [5,6] are designed for metamaterial absorbers over a wide range of electromagnetic spectrum (microwave, THz, infrared and visible frequencies). Metamaterial absorbers are considered to apply in sensors [7] and photonic applications [8], due to their unique electromagnetic properties. In these absorbers, near-unity absorbance is realized by modulating the arrangement of geometrical parameter and dielectric layer. Most of structure designed strategies for perfect metamaterial absorbers employ the conventional multilayer structure, which consists of a bottom metal reflector layer, a middle dielectric spacer layer, and a top structured metal layer. On the one hand, many metamaterial absorbers with a single dielectric layer are proposed and fabricated, to obtain a single absorption peak [9–12]. On the other hand, multi dielectric layers metamaterial absorber is also proposed and fabricated (all of dielectric layers are the same species), a broad absorption band is obtained [13]. However, dual-band metamaterial absorber with broad and flat high absorption bands can't be realized through these existing structure designs. It is important to research the possibility that a dual-band metamaterial absorber can be obtained through using different dielectric layer combinations. Usually, dual-band or multiple-band metamaterial absorbers are designed and manufactured to obtain two or more absorption peaks through elaborately arranging the metallic resonant patterns or stacking different middle dielectric layers with different geometrical dimensions [14,15]. Recently, for dual- and multi-bands absorption, electrical or plasmonic resonances in the top metal layer of metamaterial absorbers are employed, either through fabricating single unit cell with split symmetry with respect to the polarization of incident light, or through fabricating two or more symmetry sub-structures in a single unit cell [16–18]. The dual-band metamaterial absorber based on multiple dielectric materials or thickness is majorly trapped the magnetic component of the incident light. These structures discussed above are complexly to design or fabricate due to they are composed of multiple layers or complex subwavelength holes structure. In fact, the combination of dielectric spacing layer, and the effect of the localized surface plasmon (LSP) resonance between dielectric and metal layers in a single unit cell, are two vital but often overlooked factors in designing and manufacturing dual-band metamaterial absorbers. In our previous work [19], we found that the coupling of LSP modes between metal-dielectric-metal layers leads to the transmission of metamaterials reduce. So it is possible that increasing the intensity of the coupling of LSP modes to induce one weaken transmission peak or band. The weaken transmission in this paper [19] is in the frequency region from

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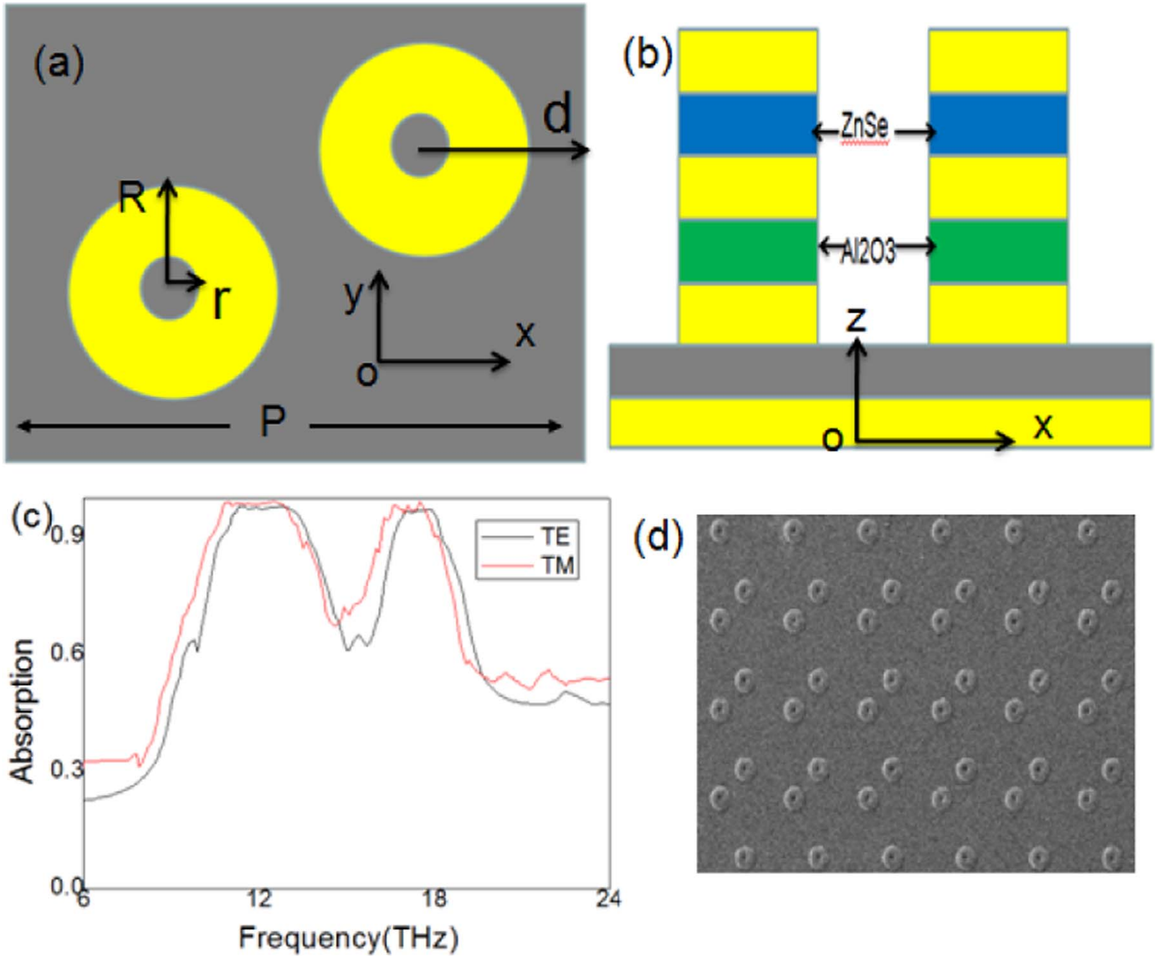

Fig. 1. (a) Top view of a unit cell; (b) Side view of a unit cell on the xoz plane. The yellow part is silver layer, the gray part is SU-8 layer, the green part is Al_2O_3 layer, the blue part is ZnSe layer; (c) Measured absorption spectra (black: TE, red: TM); (d) The SEM of samples. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5 to 25 THz. Therefore, it is necessary to study whether LSP mode can also induce a transmission absorbed in this frequency region.

2. Materials and methods

Fig. 1(a-b) shows the proposed dual-band metamaterial absorber structure. It contains seven functional layers. All the structural parameters are: P=20μm, R=3.0μm, r=1μm, d=8.0μm, $h_d = h_{AL2O3} = h_{ZnSe} = h_{SU8} = 0.3\mu m$, $h_{silver} = 0.28\mu m$. Fig. 1(c) shows the measured absorption, and Fig. 1(d) is the scanning electron microscope (SEM) of samples. The proposed absorber is fabricated as following: first, a silver layer is deposited onto the upper surface of silicon substrate by low pressure chemical vapor deposition under 55e-10 (atm) working pressure by using a ZZL-U400H at a rate of 2.0 Å s^{-1} by electron beam evaporation. A SU8 layer is spin onto the upper surface of silver layer by suing MSC-400Bz-6N spinner at a speed of 2300 rpm for 40 s, and the SU-8 layer will be baked by using a C-MAG HP10 hot plate at 90 °C for 50 s. Then, other two silver layers and two dielectric layers (an Al_2O_3 layer and a ZnSe layer) are deposited alternately. These two silver layers are also deposited onto the upper surface of silicon substrate by low pressure chemical vapor deposition under 55e-10 (atm) working pressure at a rate of 2.0 Å s^{-1} by electron beam evaporation (ZZL-U400H). The Al_2O_3 layer and ZnSe layer are deposited on this silver layer plasma-enhanced chemical vapor deposition (PECVD). Such a dielectric layer arrangement is different with previous literature [16–18]. Finally, the double-circular-patterned metal-dielectric stacks arrays are defined by regular electron-beam lithography (EBL) and the equipment is CABL-9000C. The active area of samples are around $3 \times 3mm^2$. The samples are characterized by a JEOL JSM-5610LV scanning electron microscope. The measured reflection spectra are obtained by a Bruker Optics Equinox 55 Fourier transform infrared spectrometer at normal incidence. Due to the silver ground plane is thick enough that the designed structure does not allow any electromagnetic transmit, which leads to the transmission $T(f)$ very close to zero. It means that the absorption can be calculated as$A(f) = 1 - R(f)$, where$A(f)$is the frequency-dependent absorption, and $R(f)$is the frequency-dependent reflection. Ansofts HFSS 13.0 is applied to investigate the relationship between the resonance frequency and the electric field distributions between dielectric and silver layers. In simulations, silver layer is described by the Drude model with a collision frequency of$\gamma_D = 9 \times 10^{13}s^{-1}$and a plasma frequency of $\omega_p = 1.37 \times 10^{16}s^{-1}$ [20]. The ground plane dielectric layer is SU8 [21]. The complex permittivity of dielectric constants of ZnSe is set to 5.74 and Al_2O_3 is set to 2.28 [8,22]. The simulated incident wave is set to be normal to the proposed structure in the negative direction of the Z-axis. In our simulations, ideal electric-magnetic conductor planes will be adopted on boundaries of the unit cell normal to the x and y axis, respectively [23]. The simulated unit cell is modeled in air. Comparison these results in Fig. 1(c), it should be noted that these absorption bands are independent of incident polarizations because of the symmetric arrangement of double circular-patterned metal-dielectric stacks array.