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Ultrathin flexible dual band terahertz absorber

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ABSTRACT

We propose an ultrathin and flexible dual band absorber operated at terahertz frequencies based on metamaterial. The metamaterial structure consists of periodical split ring resonators with two asymmetric gaps and *a* metallic ground plane, separated by *a* thin-flexible dielectric spacer. Particularly, the dielectric spacer is *a* free-standing polyimide film with thickness of 25 μm, resulting in highly flexible for our absorber and making it promising for non-planar applications such as micro-bolometers and stealth aircraft. Experimental results show that the absorber has two resonant absorption frequencies (0.41 THz and 0.75 THz) with absorption rates 92.2% and 97.4%, respectively. The resonances at the absorption frequencies come from normal dipole resonance and high-order dipole resonance which is inaccessible in the symmetrical structure. Multiple reflection interference theory is used to analyze the mechanism of the absorber and the results are in good agreement with simulated and experimental results. Furthermore, the absorption properties are studied under various spacer thicknesses. This kind of metamaterial absorber is insensitive to polarization, has high absorption rates (over 90%) with wide incident angles range from 0° to 45° and the absorption rates are also above 90% when wrapping it to a curved surface.

1. Introduction

The electromagnetic (EM) metamaterials are a class of artificial structures with astonishing properties, such as negative refraction. Due to their unusual characteristics which cannot be found in nature materials, many research studies have been carried out in many applications, such as super lens [1], filters [2–4], waveguide [5], cloaking [6], absorbers [7–11], and so on. Since N. I. Landy firstly presented metamaterial absorber (MMA) with nearly unity absorptivity in 2008 [7], the perfect absorbers have attached great interests in recent years due to the potential applications to thermal emitter [12], bolometer [13] sensing [14], etc. Recently, perfect MMAs operated at various frequency spectra ranging from microwave through terahertz (THz) to optical band, which had been demonstrated by using different metamaterial resonators [15–18] and multilayer approaches [19,20]. In this paper, we propose *a* dual band and ultra-flexible THz absorber by using split ring resonators (SRRs) with two asymmetric gaps. Importantly, the majority of previous THz absorbers are patterned on rigid substrates, such as silicon, which are limited for applications on curved surfaces [21–23]. However our designed structure is on *a* highly flexible polyimide (PI) film with thickness of 25 μm without a rigid substrate, and can easily be wrapped into cylinder with a radius of *a* few millimeters. As it is flexible, low cost and conformable adhesion, the absorber can be used in non-planar or conformal geometry applications such as covering the fuselage of stealth aircraft or being applied in micro-bolometers to absorb radiant power at certain frequencies [24,25]. The metamaterial based on SRR with broken symmetry had been widely studied to achieve electromagnetic induced transparency (EIT) effect or Fano resonance [26–29], but few research applied this structure to absorber applications. In our work, we experimentally find the absorber shows two distinctive absorption peaks at frequencies of 0.41 THz and 0.75 THz with absorption rates 92.2% and 97.4%, respectively. Comparing the properties of symmetric structure to that of asymmetric structure, a high-order dipole resonance exists in the later one. The resonance mode in asymmetric structure arises from the coupling between horizontal and vertical arms. We employ multi-reflection interference theory model [30,31] to investigate the mechanism of this absorber and verify the validity of theoretical calculation by comparing with numerical simulated and experimental results. The influence of the spacer thickness is discussed to further understand magnitude and phase conditions of the theory. Also, the absorber is studied under different polarization angles and various incident angles in order to prove the designed structure is omnidirectional and polarization-insensitive for both TE and TM polarization. In addition, the absorption properties with curved surface are researched, which exhibit high absorption rates (over 90%). Our flexible absorber enables many promising applications in THz field such as antennas, filtering and stealth technologies.

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2. Design and experiment

The unit cell of the designed polarization-independent MMA consists of 2×2 array of SRRs, in which the single SRR "2" is in 90° rotation with SRR "1". SRRs "1" and "3" have the same directions and SRRs "2" and "4" have the same directions, as shown in Fig. 1(a). The complete MMA is the periodic extension of the unit cell in both "x" and "y" directions, as given in Fig. 1(c). All four SRRs in the unit cell have the same dimensions with the single SRR illustrated in Fig. 1(b), and the final optimized geometrical parameters are as follows: $a = 153\ \mu m$, $l = 131\ \mu m$, $w = 8\ \mu m$, and $g = 10\ \mu m$. The fabricated sample contains three layers: the top layer is an array of aluminum (Al) patterns which were 0.2 μm-thick and were fabricated by conventional optical lithography, the lower layer is *a* 0.2 μm-thick Al film without any structure. This Al plate is magnetron sputtered to totally eliminate the transmission of the structure across the entire frequency range. So the absorption is calculated by $A(w) = 1 - R(w) - T(w) = 1 - |S_{11}|^2 - |S_{21}|^2 = 1 - |S_{11}|^2$. Between the two metallic layers, *a* 25 μm-thick polyimide film is used as dielectric spacer to separate them. Due to the low thickness of the polyimide, the absorber has good mechanical flexibility (see Fig. 1 (d)), which is suitable for widely used in THz field.

The numerical simulation of the designed MMA was carried out by using commercial software, CST Microwave Studio. The wave propagation direction is perpendicular to the plane of the SRRs array and electric field polarized perpendicular to the gaps at normal incidence. Both Al layers were modeled as lossy metal with electrical conductivity of $\sigma = 3.56 \times 10^7$ s/m (behave almost like perfect conductor compared to visible region [32]), and the polyimide spacer is taken as a lossy material with dielectric constant of $\varepsilon = 3.4$ and dielectric loss tangent of $\tan(\delta) = 0.09$. The simulated absorption is shown in Fig. 2 (red line), revealing two absorption peaks at the frequencies 0.41 THz and 0.75 THz with absorption rates 99.7% and 99.6%, respectively. In the experiment, the total size of our sample is 15 mm × 15 mm. Furthermore the

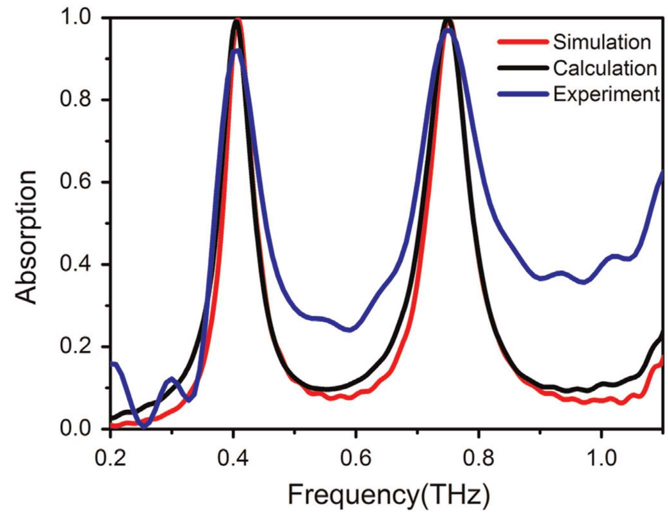

Fig. 2. The comparison of absorption spectrum among simulation (red line), experiment (blue line) and theoretical calculation (dark line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

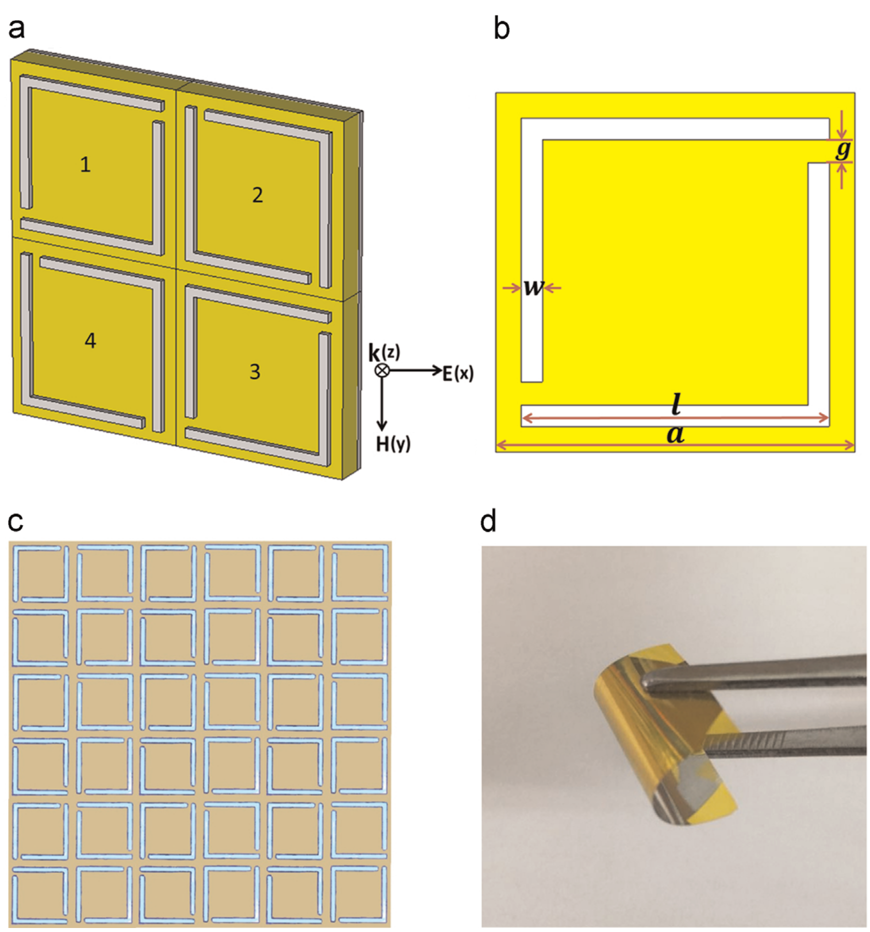

Fig. 1. The schematic of dual band absorber. (a) The perspective view of unit cell. (b) The front view of the single SRR. (c) The fabricated structure and (d) the photograph of thin-flexible dielectric spacer with a layer of Al film.