Multiband THz Metamaterial Absorber Based on Snowflake-type Resonators

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Abstract— Recently, the devices operating in the terahertz (THz) frequency band have aroused tremendous interests because of their gigantic potential applications in the areas such as security, public health, and biomedicine. In this work, ultrathin multiband THz metamaterial absorbers are proposed, and the design, simulation, and theoretical analysis of the absorbers are presented. First, a dualband absorber consisting of snowflake-type resonator array is designed, which is printed on a grounded polyimide dielectric spacer. Numerical simulations shows that the proposed structure has two perfect absorption peaks at 0.952 and 1.818 THz with absorption rates reaching 99.7% and 99.9%, respectively. By carefully designing the geometrical parameters and layout of the snowflake-type resonators, a quadband absorber with four perfect absorption peaks is implemented. The numerical simulation result shows that four different absorption peaks appear at 0.752, 0.950, 1.454, and 1.696 THz with the absorption rates of 98.8%, 97.8%, 92.1%, and 90%, respectively.

1. INTRODUCTION

Metamaterials, which are constitutive of artificial electromagnetic materials, have attracted considerable interests due to their ability to exhibit novel properties that may not be found in nature, including negative refractive index, cloaking and sound filtering [1–4].

The THz range is known as the terahertz gap because of its noticeable underutilization. However, with substantial advance of processing craft extending from the microwave band to the THz band, the research of THz metamaterials has achieved huge progress. In recent years, the idea of THz metamaterial absorbers has attracted wide interests among scientists [5–7]. In 2008, the first THz metamaterial absorber was designed and proposed with an experimental absorptivity of 70% at 1.3 terahertz by Hu Tao, etc. [8]. Afterwards, a triple-band THz metamaterial absorber was fabricated by Xiaopeng Shen, et al., which had three distinctive absorption peaks at 0.5, 1.03, and 1.71 THz with absorption rates of 96.4%, 96.3%, and 96.7%, respectively [9].

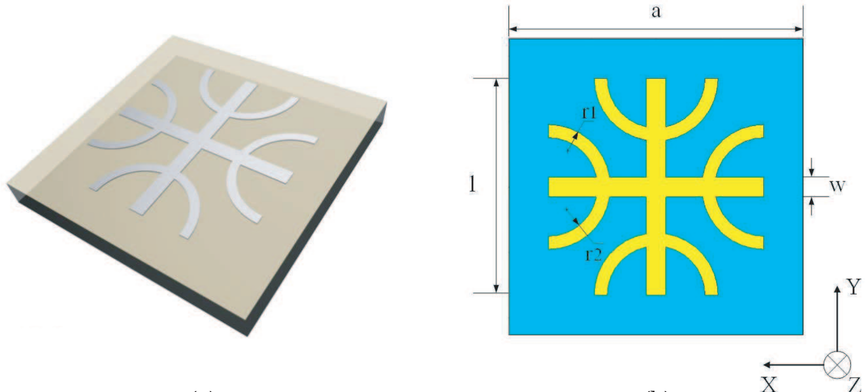
In this paper, we adopt a direct but efficient approach as is illustrated in [10] to achieve two kinds of multiband THz metamaterial absorbers based on snowflake-type resonators: a dualband THz absorber and a quadband THz absorber, both of which have perfect absorption rates in the designed frequency bands over wide angles of incident waves. These two kinds of designs are presented afterwards. In design A, two distinct absorption peaks appear at 0.952 and 1.818 THz with the absorption rates of 99.7% and 99.9%, respectively; in design B, four distinct absorption peaks appear at 0.752, 0.950, 1.454, and 1.696 THz with the absorption rates of 98.8%, 97.8%, 92.1%, and 90%, respectively. The current distributions on the surfaces of snowflake-type resonators in the peaks of absorption are also presented to gain a better insight into the physics behind the multiple absorption mechanism.

2. DESIGNS OF MULTIBAND ABSORBERS

2.1. Design of Dualband Absorber

The structure of the dualband absorber is shown in Fig. 1(a), which consists of three layers including a snowflake-type resonator array, a polymide dielectric spacer and a metallic back layer. The upper aluminum snowflake-type resonator layer is responsible for the electric resonance when the THz electromagnetic wave illuminate on the surface. The back layer is also an aluminum sheet, hence the magnetic field is supposed to drive circulating currents between the upper layer and the back layer. The entire absorber is the periodic extension of the unit cell (Fig. 1(b)) in both X and Y directions.

By optimizing the geometry of the snowflake-type resonator and the thickness of the dielectric substrate, we can adjust the effective permittivity and permeability of the structure to realize the impedance matching between the structure and the free space, which means the minimum value of the reflection. The transmission is equal to zero due to the metal back layer. With the definition of the absorption $A = 1 - T - R = 1 - |S_{21}|^2 - |S_{11}|^2 = 1 - |S_{11}|^2$, we can easily draw a conclusion



(a) (b)

Figure 1: The structure of the dualband THz metamaterial absorber: (a) the perspective view of the unit cell, (b) the front view of the unit cell.

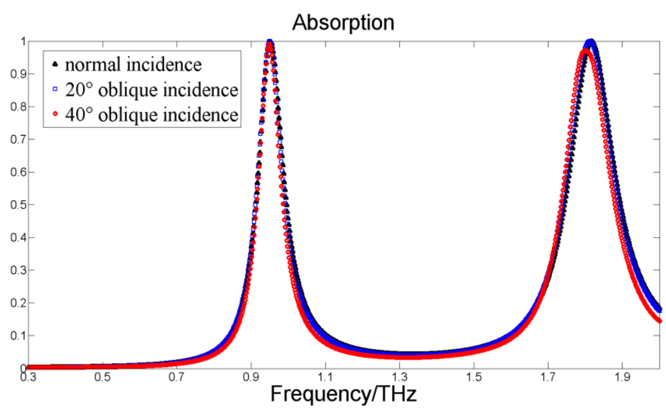
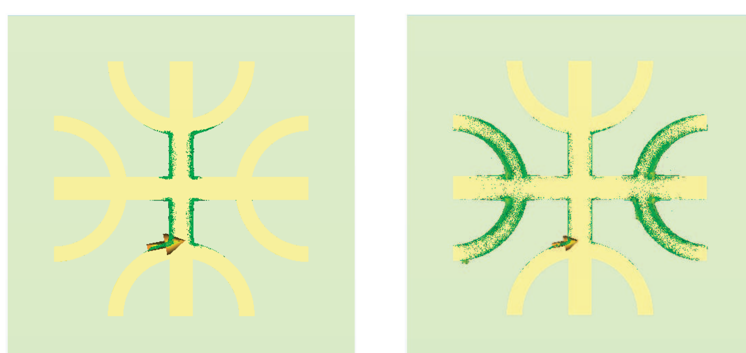


Figure 2: The simulated absorption spectra of the dualband absorber at various incident angles of THz waves.



(a) (b)

Figure 3: The current distributions on the surfaces of snowflake-type resonators: (a) at 0.952 THz, (b) at 1.818 THz..

that the maximum of the absorption rate could be achieved when the reflection rate meets the minimum value.

The final optimization geometry of the unit cell is given by: $a = 90\,\mu\text{m}$, $l = 66\,\mu\text{m}$, $w = 6\,\mu\text{m}$, $r_1 = 19\,\mu\text{m}$, and $r_2 = 15\,\mu\text{m}$. The thickness of the polyimide dielectric spacer is only $10\,\mu\text{m}$, whose relative permittivity is 3 and tangent loss is 0.03. The commercial software, CST Microwave Studio 2011, is used here for numerical simulations, which indicates that the proposed structure has two perfect absorption peaks at 0.952 THz and 1.818 THz with absorption rates reaching 99.7% and 99.9%, respectively, for the normal incidence THz wave, as is shown in Fig. 2. It is also shown that the absorption rate can still maintained above 95% even when the incidence angle is increased to 40°.

In order to further investigate the absorption mechanism of the dualband absorber, the current distributions on the surfaces of snowflake-type resonators at 0.952 THz and 1.818 THz are presented in Fig. 3. It shows that at 0.952 THz, most of currents are distributed in the central cross structure while at 1.818 THz most of currents are distributed in the sideward semicircle structures, which implies that the central cross structure is responsible for the lower frequence absorption peak while the higher frequence absorption peak originates from the sideward semicircles.

3. DESIGN OF QUADBAND ABSORBER

Basing on the dualband absorber structure, we extend the unit cell in Fig. 1(a) to 2 × 2 of the snowflake elements, which is illustrated in Fig. 4(a). As presented in Fig. 4(b), the quadband absorber unit cell is composed of two sets of snowflake resonators with different geometrical parameters, which means we can achieve a quadband absorber by combining two different kinds of dualband absorber.

By carefully designing the geometrical parameters and layout of the snowflake-type resonators, four perfect absorption peaks are finally implemented as plotted in Fig. 5. The ultimate optimization geometry of the unit cell is given by: $a = 180\,\mu\text{m}$, $l_1 = 80\,\mu\text{m}$, $w_1 = 8\,\mu\text{m}$, $l_2 = 64\,\mu\text{m}$, $w_2 = 15\,\mu\text{m}$, $r_{11} = 24\,\mu\text{m}$, $r_{12} = 18\,\mu\text{m}$, $r_{21} = 23\,\mu\text{m}$, $r_{22} = 17\,\mu\text{m}$. From the simulation result we acquire four excellent absorption peaks which appear at 0.752, 0.950, 1.454, and 1.696 THz with the absorption rates of 98.8%, 97.8%, 92.1%, and 90%, respectively, in the case of normal incidence. The wide angle performance is also investigated for the case of the quadband absorber which shows

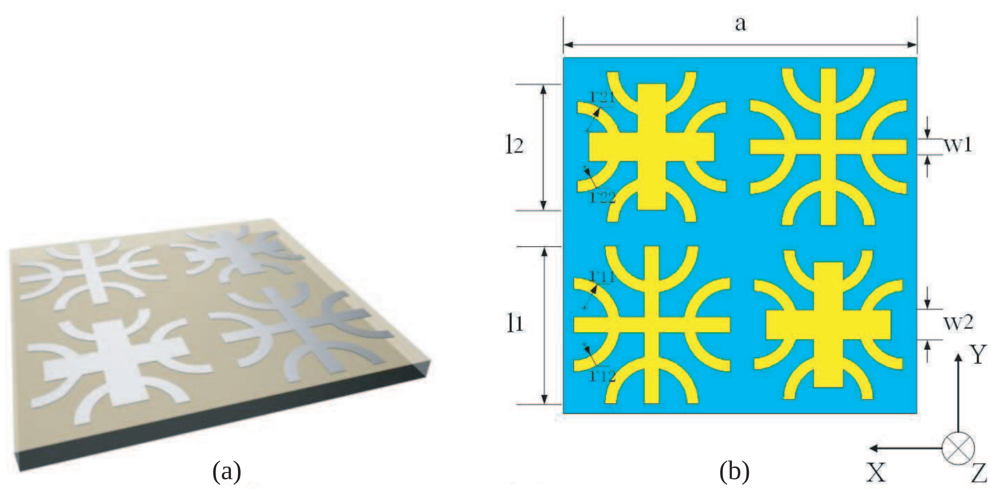


Figure 4: The structure of the quadband THz metamaterial absorber: (a) the perspective view of the unit cell, (b) the front view of the unit cell.

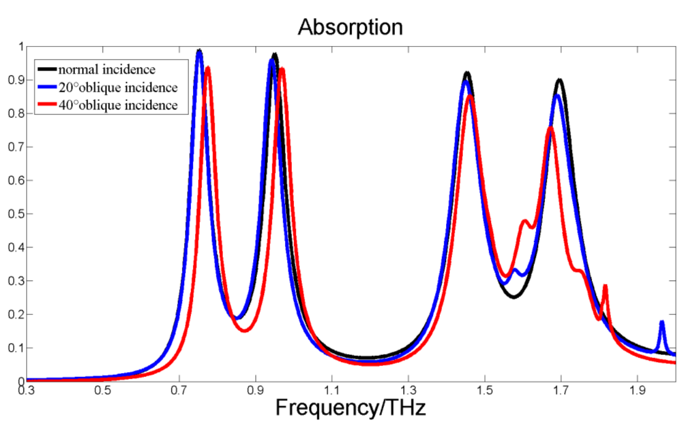


Figure 5: The simulated absorption spectra of the dualband absorber at various incident angles of THz waves.

that the structure still remain good absorptive performance even when the oblique incidence angle increase to 40° and the center frequencies of absorption peaks almost keep accord with the case of normal incidence.

Similar to the case of dualband absorber, only the particular part of the snowflake elements is resonant under each different absorption frequency. The current distributions on the surface of the structure at four resonant frequencies are omitted here.

4. CONCLUSION

In our paper, a series of ultrathin multiband THz metamaterial absorbers are proposed, in which the design, simulation and theoretical analysis of the absorbers are presented. The snowflake-type resonator is adopted to realize a dulaband absorber and based on which a quadband absorber is subsequently achieved. Simulation results of both dualband and quadband absorbers are provided to verify our designs. And we've also drawn a conclusion that particular parts of the snowflake structures are responsible for each different absorption peaks by investigating the surface current distributions.

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