Dual-band terahertz metamaterial absorbers using two types of conventional frequency selective surface elements

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Abstract: A simple means to obtain the performance of dual-band terahertz metamaterial absorber was demonstrated with numerical approaches in this paper. The dual-band absorbance of a single-layer nearly perfect absorber has been realized by employing the two conventional FSS single frequency resonant elements with different geometry shapes in single periodic cell, which can provide two tunable resonant frequencies independently for terahertz application.

Keywords: Terahertz, Metamaterial absorber, Dual band, Frequency selective surface.

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1. Introduction

Since the first demonstration by Landy et al. [1], experimental verifications [2, 3] and theory explanation [4] by several investigators, perfect metamaterial absorbers have been developed from the microwave to the visible band recently. The development of this kind of device is especially attractive for THz band because a strong absorbing material is generally unattainable in nature in this frequency band. The absorb characteristics of electromagnetic wave of absorber with artificial periodic structures depends on the unit cell geometry and periodic arrangement. The dual-band [7-11], tri-band [12], multiband [13] and wideband [14] absorbers have been reported after single band metamaterial absorber was designed and fabricated [1-6].

The literatures have proposed a few methods to realize dual-band, multiband and wide-band operation of metamaterial absorbers. One of the effective methods of multiple band operation is using multiple vertically stacked metallic layers to realize multiband absorbencies, each absorption band corresponding to a specific layer. An alternative method is to use single-layer dielectric structure with one metallic element constructed of a special geometric shape to give rise to two resonate frequencies. However, both of these structures are very complicated, imposing considerable restrictions on both design and fabrication. Another approach for making dualband absorbers is using single-layer structure with two or multiple resonators, the double square loop and double rings were reported in [9, 10], but same shape resonator will result in significant mutual coupling between two elements when the positions of two metallic patches were close to each other.

The absorber elements used in [1, 2] are based on using so called electric split-ring metamaterial resonators in the top metal layer, some of consecutive proposed structures were frequency selective surface (FSS) elements such as cross [5] and square loop [11-13]. In fact, the element structures of resonate absorber used recently in terahertz device have been successfully utilized in FSS as spatial filters of microwaves and millimeter waves in microwave engineering for many years, these classical element shapes include dipole, crossed dipole, three-legged, Jerusalem cross, square loop and concentric ring et..[15].

In this paper, we proposed an approach to obtain performance of dual-band THz metamaterial absorber by combining two traditional FSS units with different shapes in single unit cell. The merits of present methodology is better able to control two resonant frequencies individually and decrease mutual coupling between two conducting patches greatly comparing with use of two same geometric shape metal elements (dual square loops and dual rings).

2. Single-layered dualresonate unite cell

The shapes of resonant element used in traditional FSS design can be divided as type A (metal filled patch) such as dipole patch, crossed dipole and three-legged patch, and type B (metal unfilled patch) such as ring, square loop and hexagon loop as depicted in Figure 1. These two types can be combined easily, any one of type A can be placed into one of type B to form combined structure as in Figure 2.

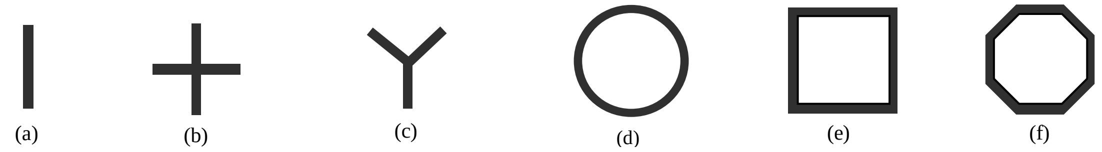


Fig. 1 Basic element structures of the conventional FSS resonator can be divided to type A: (a) dipole, (b) crossed dipole, (c) three-legged dipole, and type B: (d) ring, (e) square loop, and (f) hexagon loop.

The unite cell of dualband absorbers we proposed is consisted of two conducting patches each selected from type A and type B resonate elements. There are many possible combining configurations according to elements depicted in Fig.1. Only 6 possible combing structures are illustrated in Fig. 2 for the page permission.

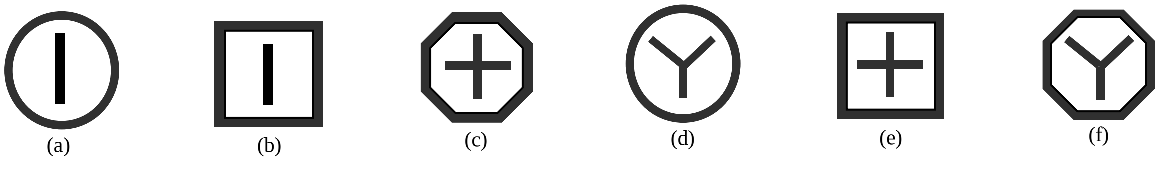


Fig. 2 Several dualband configurations of combined of traditional FSS elements: (a) diople/ring, (b) dipole/square loop, (c) crossed dipole/hexagon loop, (d) three-legged dipole/ring, (e) crossed dipole/square loop and (f) three-legged dipole/hexagon loop.

3. Dualband design and results

The work to investigate our idea was developed in two steps. In the first step, some of basic single-frequency FSS element structure, dipole, crossed dipole, and three-legged dipole that belong to type A, and circular ring and square loop that belong to type B, were designed to obtain resonant frequencies at 1.5 *GHz* and 3.0 *GHz*, separately. In the second step, these single FSS elements were combined on top of the same dielectric layer to achieve a dual-band response.

Absorber structure model is shown in Figure 3, a TE mode plane wave with electric field E parallel to x axis direction and wave vector k perpendicular to the patch surface illuminates the patch at normal incidence. The domain of computation is truncated by defining the periodic boundary conditions on the sides that are perpendicular and parallel to the E-field, respectively.

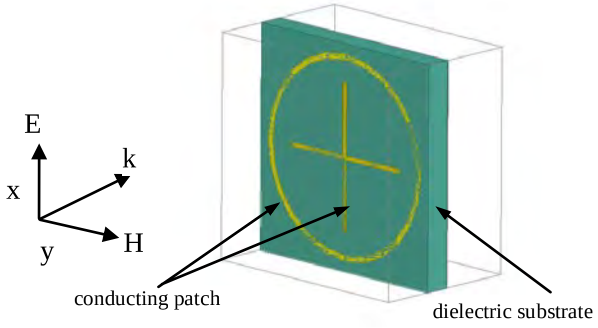


Fig. 3 Schematic illustration of the electromagnetic wave incidence on terahertz absorber

The full-wave method of FEM analysis software HFSS was used to design and analyze absorber. For simplification, metal ground plane was adopt to make sure that the transmission is zero during the whole simulation. The geometric dimensions of the investigated elements are given in Table 1.

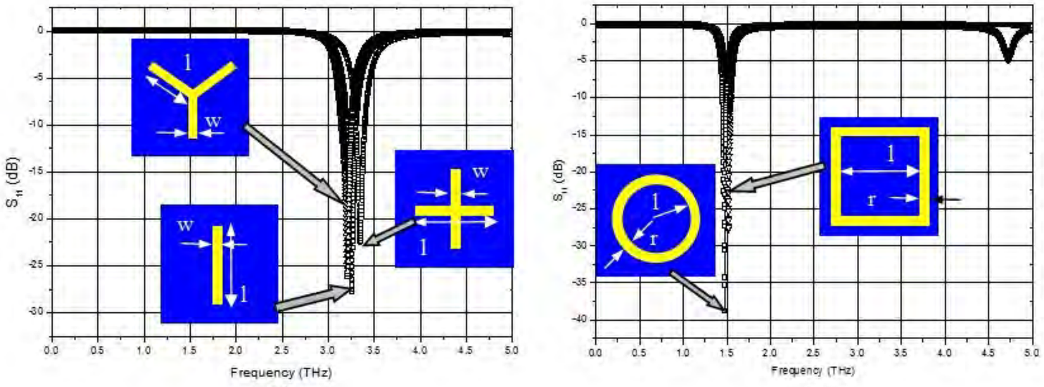
Tab. 1 Geometric dimensions of elements for investigation

Element shape	*w(um)*	*l(um)*	*r(um)*
Dipole	0.8	23.2	
Cross	0.8	24.2	
Three-legged	1.6	13	
Ring		8.7	1.0
Square loop		15.2	1.0

Each metallic patches were fabricated on dielectric substrate board selected as a polyimide (relative permittivity $\varepsilon_r = 3.5$, permeability $\mu_r = 1.0$) with a thickness of 5.0 *um*, and the metal ground with a 0.02 gold thickness.

Figure.4 shows the Reflection coefficient magnitudes of the single FSS elements for TE incidence and normal incidence. We see that the resonate points appear around 3.0 *THz* for type

A and 1.5 *THz* for type B by a reflection of about -22 *dB* and -30 *dB*. It should be pointed out that, practically, the resonant frequency can be controlled to appear at any frequency point by changing the geometric dimension of FSS resonators. The reason for arranging 1.5/3.0 *THz* as the working frequency is for simulation and demonstration conveniently only.

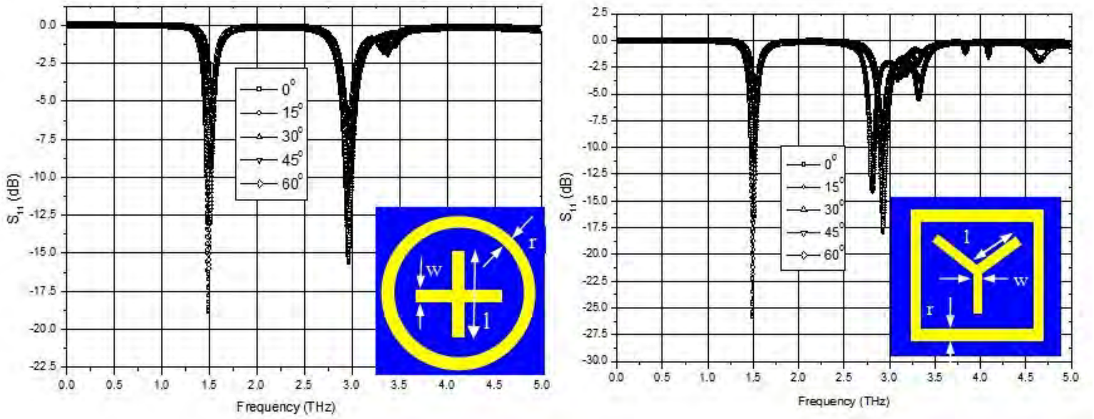


(a) (b)

Fig. 4 The Reflection coefficients of the single FSS unite cell for TE incidence and normal incidence. (a) type A and (b) type B

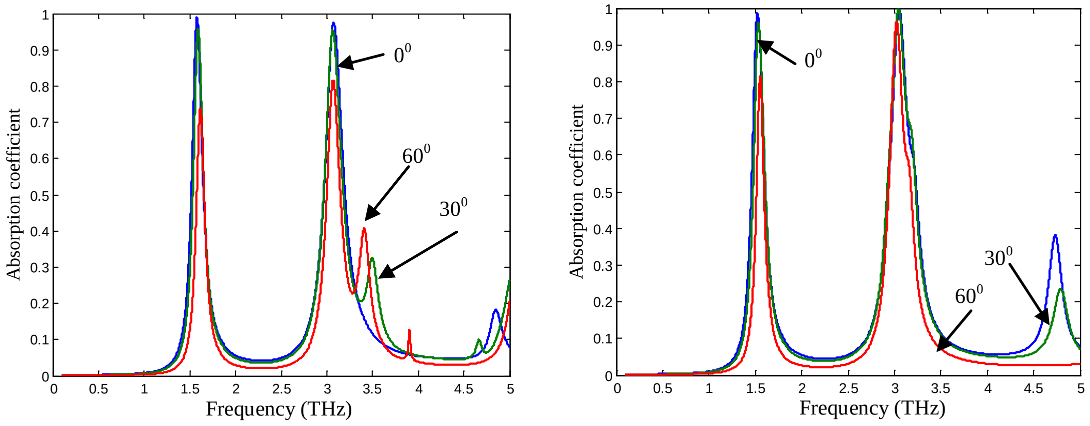
It is demonstrated that the traditional FSS elements consisted of conducting patch can be used to obtain terahertz response.

For dualband design, the cross combining of ring and three-legged combining of square loop structures were selected for comparable investigated mainly because they have different angular sensitivity with regards to their element shapes. The element parameters of the combing of two elements which were investigated above are varied slightly comparable to the case of single element, l=26.2 *um*, w=0.8 *um*, r=1.0 *um* for cross/ring unit cell, and l=12.5 *um*, w=1.6 *um*, r=2.6 *um* for three legged/square loop unit cell. Substrate permittivity is same as the case in single frequency investigations above except that the substrate thickness becomes 4.5 *um*.



(a) (b)

Fig. 5 Reflection coefficients of the dual-band absorbers for TE incidence and frequency response for different incidence angles. (a) cross/ring and (b) three-legged/square loop



（a） (b)

Fig. 6 Simulated absorbance values under different angles of incidence for TE waves, (a) cross/ring and (b) three-legged/square loop

The proposed structures exhibited a terahertz dual-band response in Figure 5. Reflection coefficient and frequency response for TE incidence and for different incidence angles ranging from 0 degrees to 60 degrees were demonstrated. The resonate frequencies appear at two frequencies around the 1.5 *THZ* and 3.0 *THZ* which were completed in the work of single resonator design given above. The absorption coefficient A can be calculated out according to absorption formula $A=1-S_{11}^2$, the reflection coefficients of -19 *dB* at 1.5 *THz* and -16 *dB* at 2.9 *THz* for cross/ring unite cell corresponds to absorption coefficient of 98.7% and 97.3%, respectively; the reflection coefficients of -26 *dB* at 1.5 *THz* and -17.7 *dB* at 2.9 *THz* for three-legged/square loop resulting in peaks of absorption coefficients reached 98.4% and 96.4% as shown in Fig. 6 respectively. The simulations results show good stability of incident angle, Absorbing effect slightly worse at 3.0 *THz* because three-legged element has worse characteristics of angle stability.

4. Conclusions

Design and numerical investigations are presented for the new dual-band nearly perfect absorbers with conventional FSS element structures in this article. The proposed dual-band nearly perfect absorber resulted in the dual-resonant behavior is easy to analyze and to fabricate with low cost materials. Two examples of proposed structures of absorber are studied, and the results exhibit a very high absorption peak at two frequency points over a wide range of incident angles. The work presented provides a simpler dual-resonate method than those of structures reported previously. The idea of proposed method can be applied to other frequency band by selecting the shape and changing the size of the two deferent resonant elements.

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