The design of terahertz absorber with four peaks by combined four T-shape with ring metal

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A four peaks absorber which includes two metal layers and one dielectric layer is proposed in this paper. The metal layer of absorber is a square array that consists of four T-shape metal cell and ring metal cell that can produce four resonance absorptions. By studying the surface current and electric field z-component, the four peaks is originated from the two distinct resonance modes of the T-shape induced by the incident electromagnetic wave. Due to the symmetrical structure, the proposed absorber is not sensitive to polarization direction of incident waves and can maintain high absorption rate in a wide range angles. There is a potential application value for absorber in electromagnetic stealth, radiation detection and biological detection.

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Keywords: Absorber, Terahertz, Resonance, T-shape

1. Introduction

Since the conception of perfect absorber was proposed by Landy et. al [1] in 2008, The resonance structure of absorber has changed a lot in recent years, all kind of structure, for example, electromagnetic induction coupling (ELC) [2-5] and frequency selective surface (FSS) [6-8] has been applied to absorber. In the area of terahertz [9-19], the metamaterial absorber is widely applied in material detection and spectral imaging. So far there are a lot of literature reports about absorber, the main ideas is to put many resonance structure together. However, this combination have great flaw, such as size is larger and process is difficult. Different from other research, this paper propose a novel double peaks absorber by using plum flower curves, the formation of the double peaks is different from the above methods, the double peaks derived from the resonance model of plum flower curves. In this paper, each cell of absorber have same geometry, same size, same orientation and at the same plane. Compared with the square resonators [21-22], the plum flower curves absorber has a smaller size. The research found that proposed absorber is not sensitive to polarization direction of incident waves and can maintain high absorption rate in a wide range angles.

2. Structure design and characteristics analysis

The proposed absorber is a three layer structure: metal-medium-metal. The two metal layers are gold which conductivity is $\sigma = 4.09\times10^{7} S/m$, the medium layer is polyimide which the real dielectric constant and loss tangent is $\varepsilon_r = 3.5$ and $\tan\delta = 0.057$,respectively. The absorber cell structure as shown in Fig. 1, where a =40um, d=20um, r=12um, R=15um, and W=5um.The bottom of cell is metal film, the surface metal of cell is composed of a square and four semicircles. The thickness of the two metal layers and medium layer is $0.2\mu m$, $0.2\mu m$ and $1.2\mu m$, respectively, the cycle size of x and y direction are $20\mu m$.

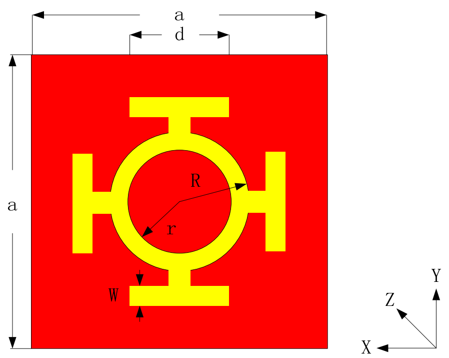

Fig. 1. The structure diagram of the absorber

In this paper, the performance of absorber is simulated by using CST Microwave Studio 2015 which based on the time domain finite integral method. To facilitate the analysis, the direction of *x* and *y* is taken as periodic boundary condition, the direction of *z* is regard as open boundary condition. When the THz wave vertical incidence surface, the absorption A of absorber can be obtained by using $A = 1 - |S_{11}|^2 - |S_{21}|^2$, where S_{11} and S_{21} is expressed respectively as the reflection coefficient and transmission coefficient. Due to the THz waves walking in metal only about 70 nm distance, so the transmission coefficient $S_{21} = 0$ and absorption $A = 1 - |S_{11}|^2$.

In order to get max absorption rate, the reflectivity must be reduced. According to the theory of impedance matching, if the structure parameters of absorber are changed, the equivalent impedance of absorber is changed also. When the equivalent impedance is equal to the free space impedance, the reflectivity is minimum and the absorption is maximum.

The results of the absorption spectrum and S-parameters are simulated by using CST Microwave Studio 2015. It can be seen from Fig. 2 that there are four peaks located at 0.2THz, 1.15THz, 1.43THz and 1.89THz which the absorption rate is 99.87, 98.46, 99.77, and 99.22 %, respectively. The four peaks is mainly caused by the LC resonance, and understanding of such four peaks absorption is clarified by examining the surface current, electric field and magnetic field distributions.

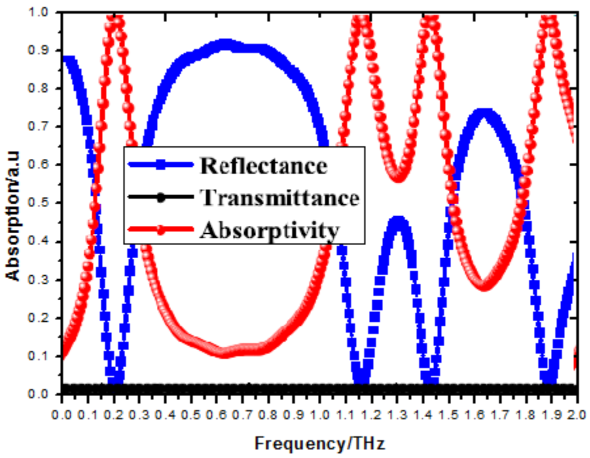

Fig. 2. The reflectance, transmittance and absorptivity of proposed absorber

The absorption spectrum is analyzed as a function of polarization angle for TM wave. The polarization angle is described as the angle which between the coordinate of axis and the polarized direction. Fig. 3 shows the absorption spectra at different polarization angles. It can be seen from Fig. 3 that the first two absorption peaks just hand on the polarization angle, but the latter two absorption peaks relied on the polarization angle of the incident light strongly.

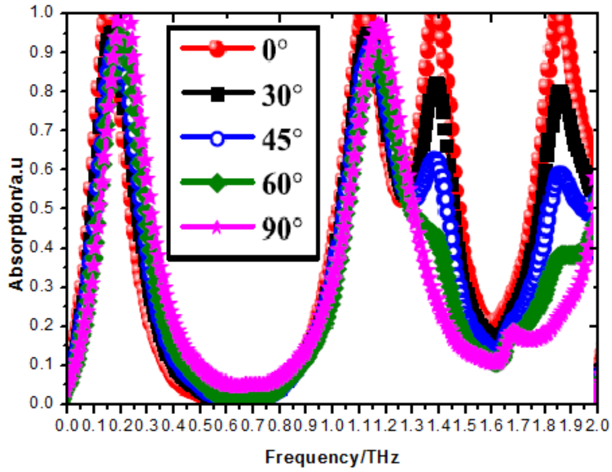

Fig. 3. The contrast figure between square and proposed absorber

3. Absorption principle and experimental simulation

In order to study the absorption principle of proposed absorber, the surface current and *Z* component of electric field are calculated and analyzed in this paper. A field monitor is set in 4.32 THz, the surface current and *z* component are shown in Fig. 4. The Fig. 4(a and b) shows that the reverse parallel current are formed on surface metal and substrate metal, the reverse current can produce strong electromagnetic response, so as to form a resonance in *z* direction. The distributions of electromagnetic field are shown in Fig. 4(c and d). It can be seen from Fig. 4(c and d) that the charges are gathered in surface metal and substrate metal layer along the *y* direction, and the upper and lower metal layer have the opposite charge at the same time. This shows that there are electric dipole resonance caused by electric field in the y direction, The strong electromagnetic resonance make the electromagnetic energy is consumed by absorber.

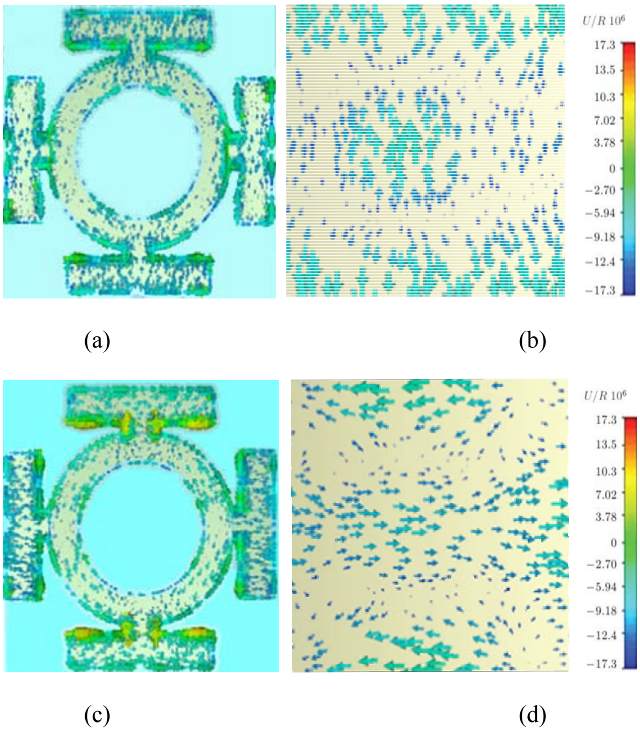

Fig. 4. The surface current and z component of absorber

In the effective medium theory [23], a absorber is regarded as an equivalent medium. By adjust the structure of resonant cell and the distance between upper layer and lower layer, when the relative input impedance $Z/Z_0 = \sqrt{(1+S_{11})^2 - S_{21}^2 / (1-S_{11})^2 - S_{21}^2} = 1$, where Z_0 is the characteristic impedance of free space, the absorber can realize perfect absorption under a specific frequency. Fig. 5 shows the relative input impedance of interface between surface and air.

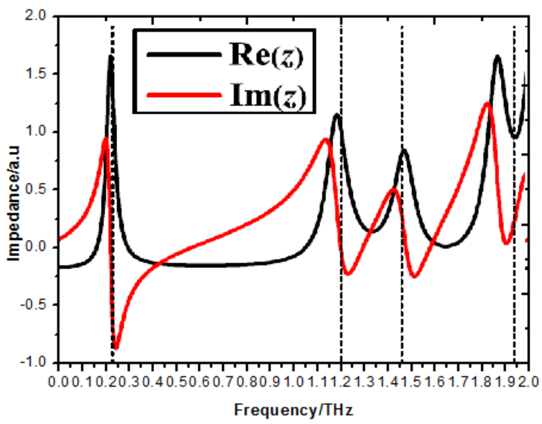

Fig. 5. The relative impedance of absorber

Because of the symmetrical structure, the proposed absorber is not sensitive to the polarization direction of incident wave. Under the condition of different polarization angles φ, the absorption frequency and efficiency of two absorption peaks are almost remains constant. Fig. 6 shows the change of the absorption peak with different polarization angles under the condition of vertical incidence. It can be seen from Fig. 6 that the polarization Angle changes from 0 to 90 and the absorption peak is almost no change.

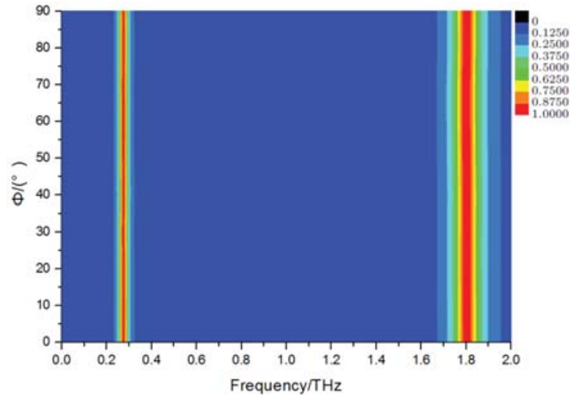

Fig. 6. The change of the absorption peak with different polarization angles under the condition of vertical incidence

In practical application, the incident electromagnetic wave on surface absorber is usually have angle, Fig. 7 shows the change of the absorption with different incident angles under the condition of vertical incidence. It can be seen from Fig. 7 that the absorption is not changed with different incident angles. With the increase of incident angle, we can observe two increased absorption peak at 0.2THz, 1.15THz, 1.43THz and 1.89THz.

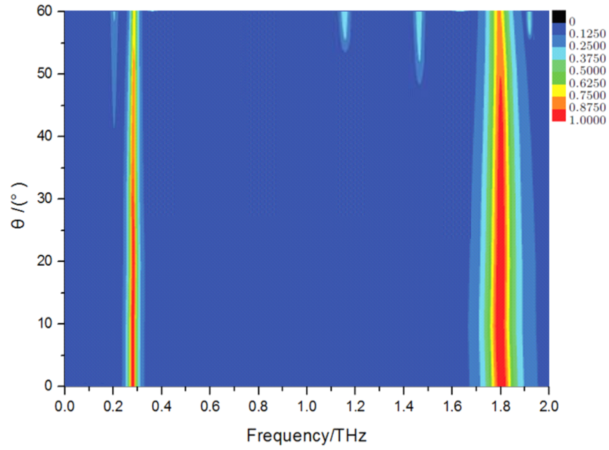

Fig. 7. The change of the absorption with different incident angles under the condition of vertical incidence

4. Conclusion

This paper proposed a new terahertz absorber with four peaks by combined four T-shape metal cell with ring metal. The absorber not only is not sensitive to incident wave polarization, but also can maintain a high absorption rate in large angle. Because of the symmetrical structure, the proposed absorber have advantage of small size and four absorption. The absorber has solved the problem of traditional absorber cannot work at higher frequency. Compared with traditional structure, the terahertz absorber which proposed in this paper has many advantages.

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