Fan-shaped Patch Element Wideband Terahertz Metamaterial Perfect Absorber

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Abstract— The wide-band absorbance of the absorber made from the well-known metallic dipole patch has been realized by modifying geometrical shape of conventional rectangular bars in single periodic cell. The increase of relative bandwidth of this new absorptive structure with fan-shaped patch can reach and exceed 100% with respect to the centre frequency comparing with conventional dipole patch geometry. The new structure of absorber exciting a new broadband resonant modes results in the bandwidth expanding. The work presented here provides an efficient method to decrease the number of elements and layers of multi-layer metamaterial absorber compared to conventional element structures used previously.

1. INTRODUCTION

Recently, most studies of terahertz metamaterial absorber mainly focus on broadband realization in order to collect as more incident electromagnetic wave as possible. Many approaches such as single layer multiresonant elements composed of different single resonant frequency and multilayer self assembled elements based on electric dipole, LC or standing wave absorption resonance have been used to achieve broadband absorption [1–8].

One of the effective methods of wide-band operation is using multiple vertically stacked metallic and dielectric layers to realize multiband absorbencies, each absorption band corresponding to a specific layer. An alternative method is using single-layer dielectric structure with two or more resonators with self-similar patterns, the double square loop and double rings were reported in [9].

The structures of metamaterial perfect absorber proposed initially are based on using so called electric split-ring metamaterial resonators [10, 12] in the top metal layer and developed consequently by using dipole crossed dipole three-legged, square loop and concentric ring etc.. These element structures are all able to display electric resonance, however at narrow frequencies band range, usually called narrow-band structure. Crossed patch and three-legged patch based on dipole resonance consisted of simple straight metallic bars are well-known structures used in traditional frequency selective surface (FSS) as spatial filters of microwaves and millimeter waves in microwave engineering for many years and they have been successfully utilized in the design terahertz metamaterial perfect absorber as a basic element structure due to their many advantages, such as simple shape, polarized symmetric easy to fabricate and polarized stability. However, theses traditional structures have a major drawback in wideband applications which is narrow bandwidth.

In this paper, a new wideband element structure was proposed which provides a possible method to develop simple single-layer absorber to obtain the performance of wide-band terahertz nearly perfect absorber. The work to investigate our idea was developed in two steps. In the first step, two of basic single-frequency element structure, crossed dipole and three-legged dipole were designed to obtain resonant frequencies at 3.0 THz. In the second step, these two elements were modified to achieve a wide-band response.

2. WIDEBAND FAN-SHAPED STRUCTURES FOR SINGLE-LAYERED ABSORBER

Configurations of the proposed element structure of wideband absorber, which are investigated here, are presented in Fig. 1(a). The geometric shape are fan-like and named here fan-shaped patch absorber, where the four leaf intersect at a right angle to form cross fan-shaped absorber, the three leaf intersect at a 120 degree angle to form three leaf fan-shaped patch absorber. The proposed element have a single metallic layer, and are printed on a dielectric of thickness d. The geometry of leaf is characterized by length L and width W and the unite cell periods are all taken $2L + 1.0$, where all the geometric parameters are in μm unit.

Absorber structure model is shown in Fig. 1(a), 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.

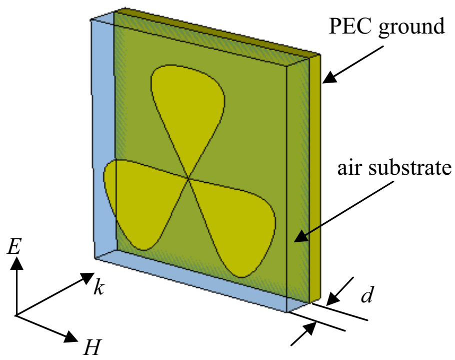

Figure 1: Schematic illustration of the electromagnetic wave incidence on proposed terahertz absorber.

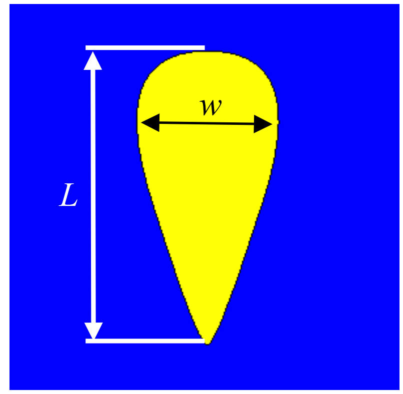

Figure 2: The geometry of investigated wideband absorber element.

The full-wave method of FDTD analysis software CST was used to design and analyze absorber The metal ground plane with a 0.02 (µm) thickness was adopted to make sure that the transmission is zero during the whole simulation. For simplification, each metallic patch was designed on air substrate (relative permittivity $\varepsilon_r = 1.0$, permeability $\mu_r = 1.0$) to avoid the discussion of dielectric loss in design so that explanation of absorbing mechanism can be provided more clearly by resonance absorb theory. The geometric dimensions of the investigated elements are given in Table 1.

Table 1: Geometric dimensions of elements for investigation.

Element shape	***W*** **(µm)**	***L*** **(µm)**	***d*** **(µm)**
Traditional cross dipole	2.0	23.0	3.0
Traditional three-legged patch	2.0	26.0	3.0
Proposed cross fan-shaped	40.0	40.0	1.5
Proposed three leaf fan-shaped	30.0	43.0	1.5

3. RESULTS AND VERIFICATIONS

The calculated reflection coefficient and absorption coefficient for TE normal incidence were demonstrated. Fig. 3 and Fig. 4. The proposed structures exhibited a terahertz wideband response in Fig. 3(a) and Fig. 4(a). For comparison, the proposed structures and conventional structures are designed at the same resonant frequency We see that the resonate point appears around 3.0 THz

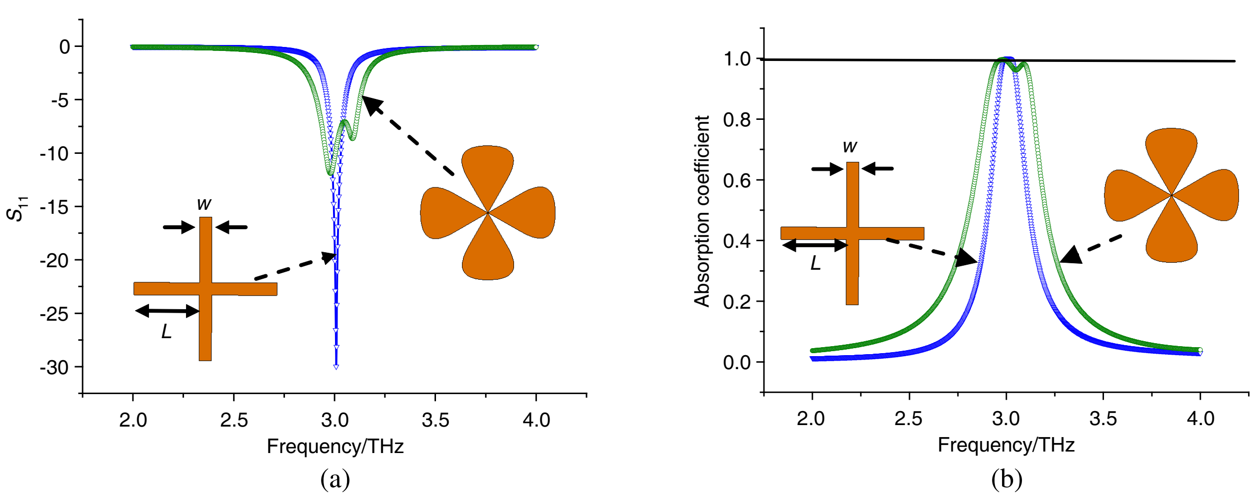

Figure 3: The comparison of reflection coefficients and absorption coefficients of cross patch and cross fan-shape patch.

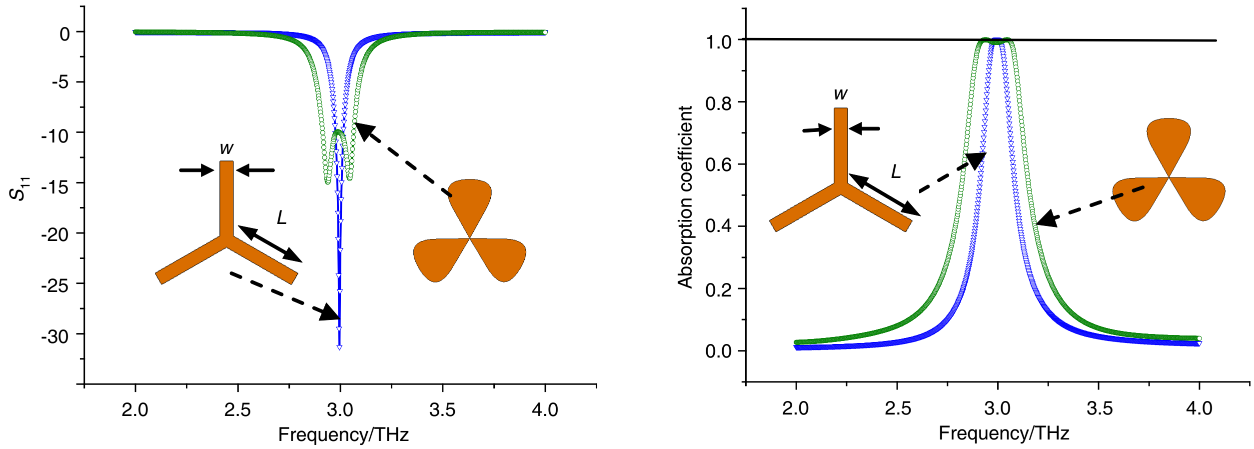

Figure 4: The comparison of reflection coefficients and absorption coefficients of three-leg patch and three-leaf fan-shape patch.

by a reflection below −8 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 absorber.

The simulation results show obvious bandwidth improvement. In Fig. 3(a), the calculated −5 dB reflection coefficients bandwidth in the frequency range from 2.95 THz to 3.06 THz corresponding to a relative bandwidth of 3.67% for conventional cross cell, and the −5 dB relative bandwidth is calculated to be 7.67% for proposed cross fan-shaped cell, which indicating an expanding of relative bandwidth over 100%. In Fig. 4(a), the calculated −5 dB relative bandwidth of reflection coefficient is 2.67% for traditional three-legged cell, corresponded −5 dB bandwidth of proposed three leaf fan-shaped cell reaches 7.67%, which is more than 170% that of the traditional three-legged structure. The absorption coefficient A are depicted in Fig. 3(b) and Fig. 4(b) corresponds to cross fan-shaped and three leaf fan-shaped are also calculated out according to absorption formula $A = 1 - S_{11}^2$, which are all above 90% over the frequency range of interest.

4. CONCLUSIONS

Broadband THz absorption elements have been achieved by our proposed structure. Design and numerical investigations are presented for the new broadband nearly perfect absorbers with fan-shaped element structures in this article. An improvement of bandwidth by using proposed the structure resulted in the wide-band behaviour have been observed. Two examples of proposed structures of absorber are studied, and the results exhibit a high absorption peak over a wide range of resonant frequency. The work presented provides an efficient method to decrease the number of elements and layers of multresonate wideband absorber compared to conventional element structure used previously.

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