A Simple Ultrathin Quad Band Polarization Insensitive Metamaterial Absorber for Infrared Applications

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Abstract

A simple ultrathin quad band polarization insensitive metamaterial absorber has been reported in this paper. The unit cell of the proposed structure consists of dipoles of unequal lengths. The structure exhibits absorptions at 18.4 THz, 33.4 THz, 51.4 THz and 75.2 THz with respective absorptivity of 99.2%, 99.4%, 92.2% and 98.2%. Under oblique incidence the structure behaves as an absorber for both TE and TM polarizations so long as the angle of incidence is within 60º. The structure is ultrathin ~ $\lambda/33$ as well as compact in dimension ~$\lambda/8$ periodicity (corresponding to lowest frequency). The proposed quad band metamaterial absorber structure is expected to find potential application in THz spectroscopy, imaging techniques and sensing.

1. Introduction

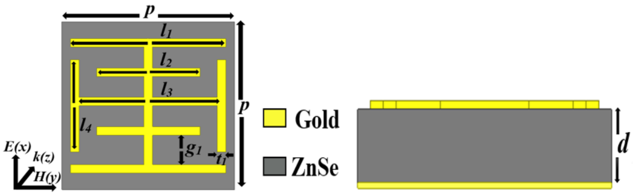
The manipulation of effective parameters by optimizing the dimensions of the sub wavelength lattice have increased the diversification in the applications of metamaterial [1-3]. One of the outstanding effect is perfect absorbers which can be useful in increasing the efficiency in capturing solar energy [4], bolometers [5], and plasmonic sensors [6]. Due to the resonance effect involved in the metasurface structures, most of them are restricted to narrow single band absorber applications which are incapable in many of the optoelectronics applications which demands multiband or broadband absorbers [7]. Recently numerous efforts are applied to increase the number of absorption bands. Stacking of multiple layers as well as use of nested rings have been carried out to realize dual and triple band absorptions [8-9]. In the terahertz regime a few multiband absorbers reported previously; however, either they constitute of multiple layers, or complex single layer structure [10-11]. This demands the requirement of multiband absorbers using simple geometrical structures.
In this paper, we propose a quad band metamaterial absorber which is simple in design and ultrathin in nature. The unit cell of the design is a metal-insulator-metal trilayer pattern. Gold is chosen as the metallic element for the top and bottom layers due to its chemical stability and low losses. ZnSe, an excellent infrared material having good thermal and mechanical properties, has been considered for the dielectric substrate on which the metallic patterning has been done. The geometrical dimensions are optimized to obtain the high quad band absorptions at 18.4 THz, 33.4 THz, 51.4 THz and 75.2 THz. The structure is further analyzed under exposure to THz radiations at different incident angles to study the absorption characteristics and it is found that up to 60□ incident angle, the structure behaves as quad band absorber. Moreover, the structure is polarization-independent in nature.

2. Design of the Structure

The top and side views of the unit cell of proposed structure are shown in Figure 1. The top layer of the unit cell composes of metallic dipoles of different lengths. The bottom layer is a continuous metallic structure. The permittivity of the gold has been modelled using the Drude model given in equation (1).

$$\varepsilon(\omega) = 1 - \frac{{w_p}^2}{w(w + i\gamma)} \qquad (1)$$

The value of plasma frequency w_p and damping frequency γ has been taken from well-known experimental results [12]. The dielectric permittivity of ZnSe in the desired frequency range is a function of frequency [13]. The thickness of top and bottom metallic layer is 0.05 µm. the geometric dimensions of the unit cell as shown in Figure 1 (a) are p = 2.0 µm, l_1 = 1.8 µm, l_2 = 1.1 µm, l_3 = 1.5 µm, l_4 =1.2 µm, g_1 = 0.45 µm, t_1 = 0.1 µm. The directions of electric field, magnetic field and the electromagnetic wave are also shown in Figure 1 (a). The thickness of ZnSe has been optimized to d = 0.40 µm.



(a) (b)

Figure 1. (a) Top view (b) side view of the proposed unit cell of the ultra-thin quad band absorber along with the incident electromagnetic field directions.

3. Simulated Results

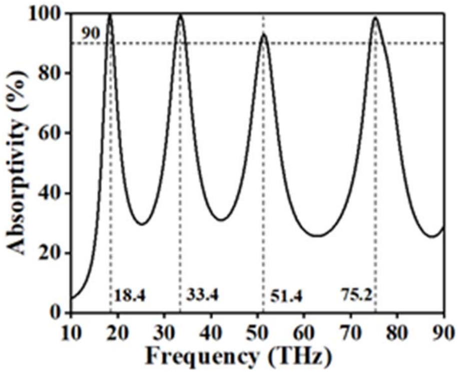
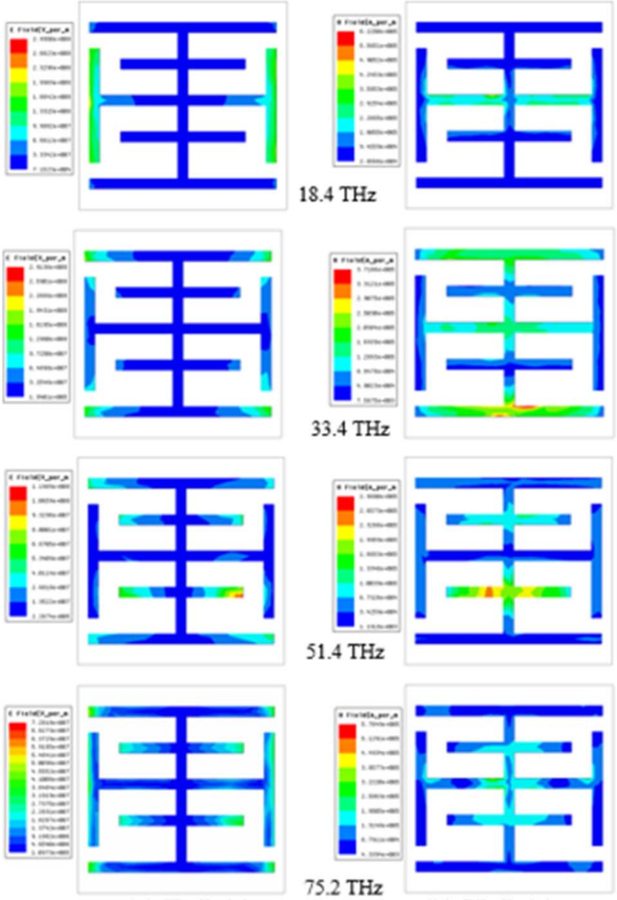


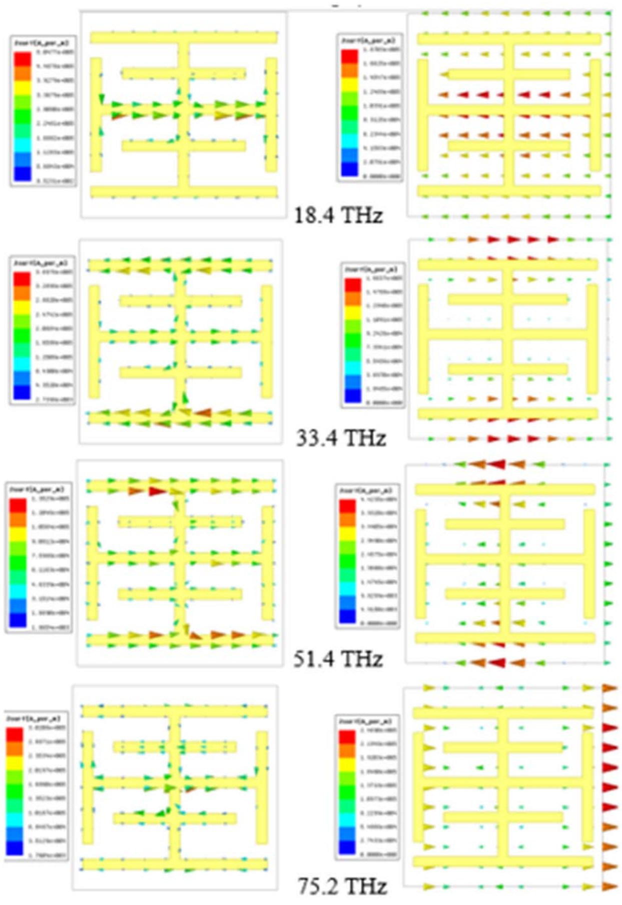
Figure 2. Absorptivity response of the proposed quad band metamaterial absorbing structure whose unit cell's top view is shown in Figure 1.



(a) E-field (b) H-field

Figure 3. (a) Electric field and (b) magnetic field distributions within the structure at 18.4 THz, 33.4 THz, 51.4 THz and 75.2 THz.

The simulation of the unit cell of the structure has been done using Ansys HFSS under consideration of periodic boundary condition. There is no transmission of the incident electromagnetic wave through the structure due to introduction of the metallic layer at the bottom side. Hence, absorption can be realized by minimizing reflection coefficient from the top surface of the structure. Absorption characteristics of the structure is illustrated in Figure 2 from where the quad band absorption at 18.4 THz, 33.4 THz, 51.4 THz and 75.2 THz with absorptivity of 99.2%, 99.4%, 92.2% and 98.2% respectively has been observed.



(a) Top (b) Bottom

Figure 4. Surface current distributions at (a) top and (b) bottom of the structure at 18.4 THz, 33.4 THz, 51.4 THz and 75.2 THz.

The absorption mechanism of the absorber can be explained by studying the electric and magnetic field distributions at the top of the gold surface. The distribution of electric and magnetic fields at 18.4 THz, 33.4 THz, 51.4 THz and 75.2 THz are shown in Figure 3 (a) and Figure 3 (b) respectively. The opposite distribution of electric and magnetic field at each dipoles means the accumulation of opposite charges which is inspired by electric and magnetic resonances at the top surface [14].

The surface current distribution at the top and bottom surfaces of proposed structure at absorbing frequencies are shown in Figure 4 (a) and Figure 4 (b) respectively. The antiparallel circulating current results in the formation of magnetic dipoles which strongly interacts with the incident magnetic field perpendicular to it. The structure on the top actually acts as an electric dipole which is being driven by the electric field of the incident radiation as shown in Figure 4. These two electric and magnetic resonances combine together to form a strong electromagnetic absorption [15]. Properly analyzing the electromagnetic fields and the surface current distribution we can observe that each absorbing band is obtained due to different section of dipoles.

From the reflection coefficient response of the sample with respect to frequency, the effective medium parameters are calculated under normal plane wave incidence [16]. The real parts of effective permittivity and permeability of the medium are shown in Figure 5 (a) while the corresponding imaginary parts are shown in Figure 5 (b). The retrieved real and imaginary parts of effective permeability and permittivity are listed in Table I, which shows that at frequency of 18.4 THz, 33.4 THz, 51.4 THz and 75.2 THz they are nearly equal with respect to each other. This corresponds to impedance matching condition at the perfect absorption frequencies.

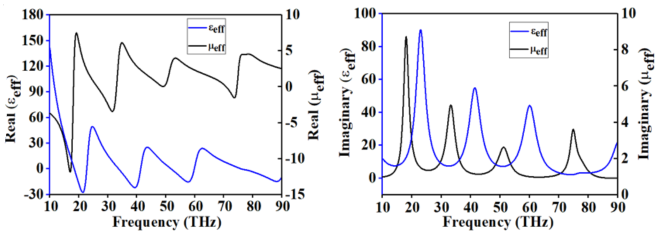
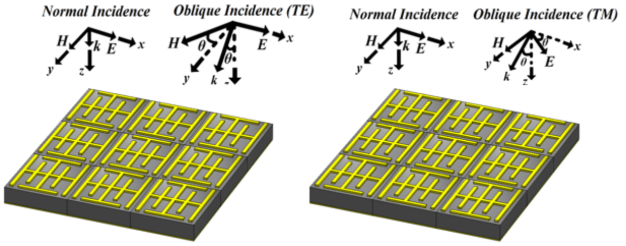


Figure 5: Variations of (a) real and (b) imaginary parts of effective permittivity and permeability with respect to frequency.

Table I: Retrieved constitutive electromagnetic parameters of the proposed metamaterial absorber structure

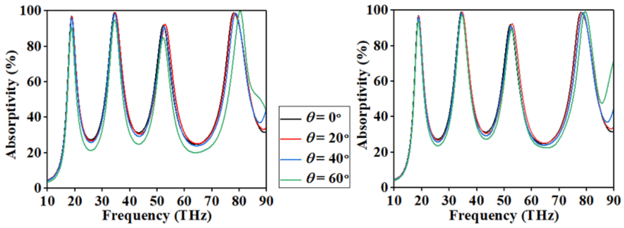
Frequency (THz)	Real Part		Imaginary Part	
	ε_{eff}	μ_{eff}	ε_{eff}	μ_{eff}
18.4	1.02	0.99	9.1	8.9
33.4	1.07	1.03	6.8	7.1
51.4	1.14	0.98	3.5	5.2
75.2	1.05	0.95	3.2	3.8

4. Oblique Incidence Response



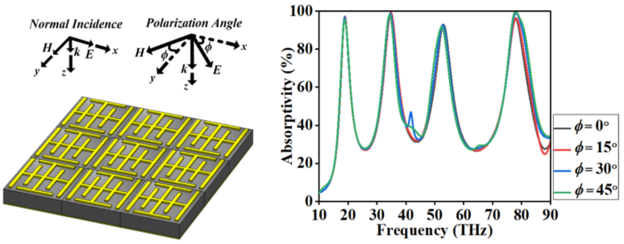
(a) (b)

Figure 6. Set-up of the oblique incidence responses under (a) TE polarization and (b) TM polarization.



(a) (b)

Figure 7. Simulated absorptivity responses for oblique incidence response under (a) TE polarization and (b) TM polarization.



(a) (b)

Figure 8. (a) Set up and (b) simulated absorptivity response for different polarization angles under normal incidence of the proposed structure

The proposed structure whose unit cell shown in Figure 1 is studied for different angles of incidence under TE and TM polarizations. For oblique incidences under TE polarization, the direction of electric field remains constant while the directions of magnetic field vary to make the wave incident on the surface angularly as shown in in Figure 6 (a) [17]. Similarly, for oblique incidences under TM polarization, the direction of magnetic field remains constant while the directions of electric field vary to make the wave incident on the surface angularly as shown in in Figure 6 (b). The absorptivity variations under TE and TM polarization with respect to the frequency are shown in Figure 7 (a) and Figure 7 (b) respectively where it is found that up to 60° incident angle, it is behaving as a quad band absorber. The structure is further studied under polarization angle variation for normal incidence as shown in Figure 8 (a). It is found to be insensitive to polarization of incident wave as evident from Figure 8 (b). Owing to the symmetry of the structure the behavior is studied till 45° polarization angle.

5. Conclusions

An ultrathin and compact quad band polarization insensitive metamaterial absorber has been proposed where absorptivity of 99.2%, 99.4%, 92.2% and 98.2% have been realized at 18.4 THz, 33.4 THz, 51.4 THz and 75.2 THz respectively. The dimension of the period of the unit cell size is ~ $\lambda/8$, which is in the homogeneity limit of the metamaterial. The absorption phenomenon is well explained through the field and surface current distribution. Further the retrieval of effective medium parameters also explains the wave decaying phenomenon in the structure. The structure is studied for oblique incidence variations under TE and TM polarizations where it is behaving as an absorber till 60° incident angles for both cases. Further the structure is studied for different polarization angles where it is found that the structure behaves as an absorber up to 45° polarization angle. These absorption features along with compact and ultrathin nature may be useful in THz spectroscopy, imaging techniques and sensing Application.

7. References

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