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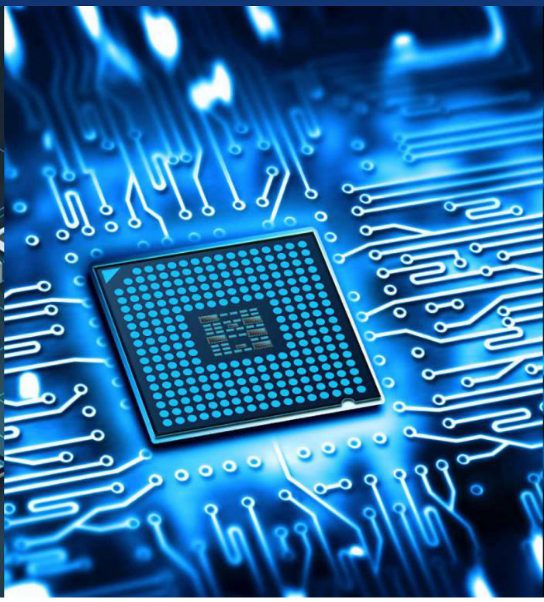


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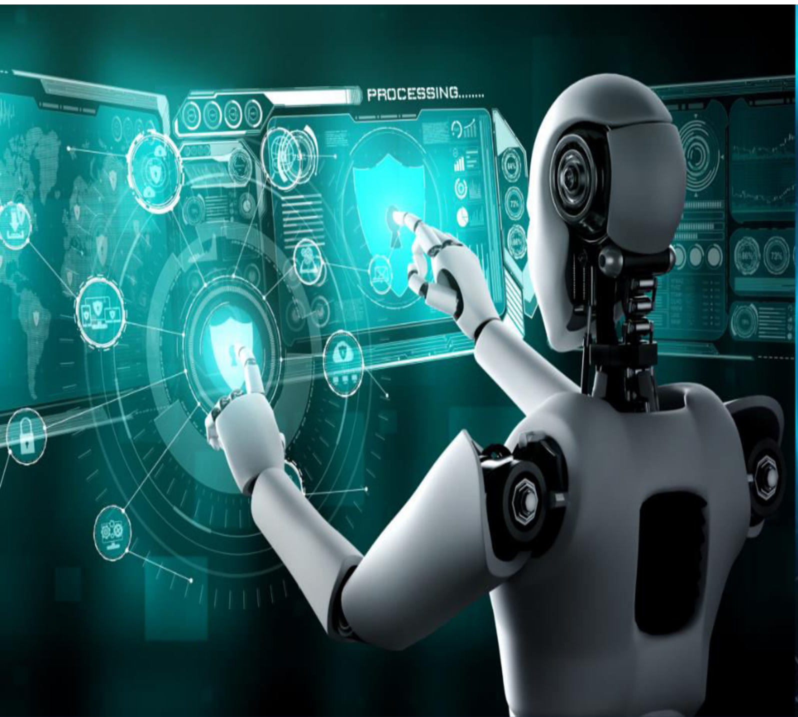

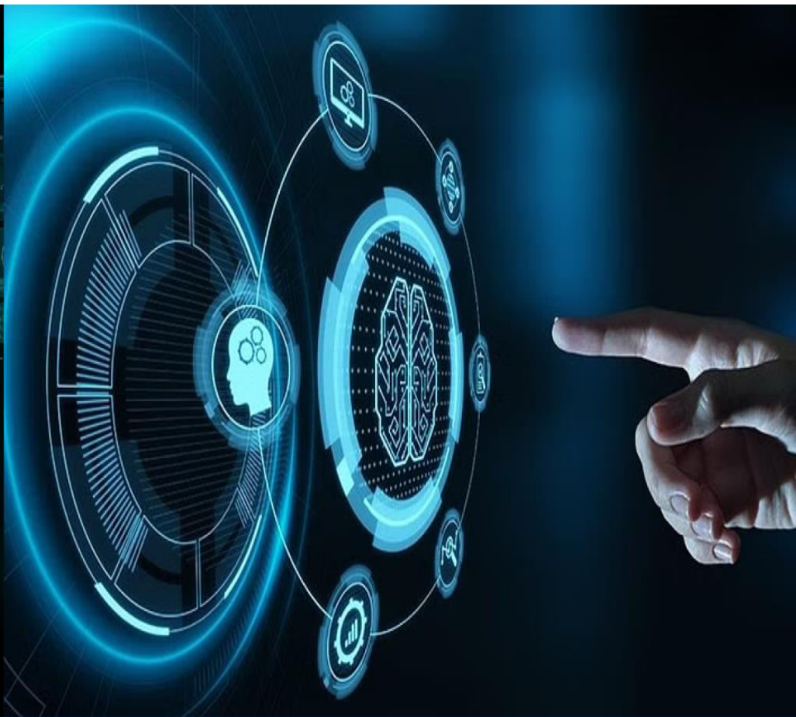

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A Single Band to Double Band Tuneable Metamaterial Absorber for Mid Infrared Applications

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ABSTRACT: In this study, a midinfrared metamaterial absorber was proposed using two perpendicular resonators. The peak absorption position can be tuned by proper arrangement of the perpendicular resonators. The double T configuration exhibits a single peak of absorption at 6.5 µm with absorptivity of 84.8.8% for the transverse electric field (TE). With a slightly changed T configuration of resonators, dual absorption peaks are observed at the wavelengths 6.17 µm and 7.0 µm with an absorptivity 99.6%. Numerical results demonstrate that the absorber is tuneable from single peak to dual peak absorption. The analysis of absorption at different incident angles on the absorber was also presented. The results of this study can be applied in the fields of biosensors and solar energy harvesting cells.

KEYWORDS: Metamaterial; Absorption; Single peak and Multi peak; Mid infrared region

I. INTRODUCTION

Metamaterials are artificial periodic electromagnetic structures that exhibit unique electromagnetic properties that cannot be achieved naturally. Generally, they contain metallic structures in different shapes and produce a resonance effect when electromagnetic waves are incident on them. Thus, they can be used to control electromagnetic wave characteristics and can be utilized in various applications such as sensing [1], energy harvesting [2], antenna [3], EMI shielding,[4] and absorber [5]. Among these, perfect metamaterial absorbers play a crucial role in mid infrared applications such as solar energy harvesting, cloaking technology and thermal imaging [6,7], environmental monitoring, gas sensing [8] and molecular fingerprinting [9,10].

In 2008 Landy et al. first experimentally demonstrated a narrow band metamaterial-absorber which absorbs certain portions of wavelengths [11]. Their findings trigger the use of narrow band metamaterial absorbers in the application of solar energy harvesting, sensors, resonators based on absorption bandwidth [12,13]. Thus, many researchers have been focused on the implementation of narrow bands with single and multi-peak absorption. However, many absorbers have not met the requirements of applications such as high sensitivity and multifrequency spectrum detection [14]. Further, the absorbers are sensitive to the angle of incidence and polarization angle, thus, resulting in reduction in quality of results. Current research has been focused on incident angle-insensitive, polarization-independent, and multifrequency absorption in the visible and IR regions [15,16].

Metamaterial absorbers consist of a dielectric layer sandwiched between the bottom metal layer and a pattern of metal resonators on the top [17,18]. Because of the structure, it is called a metal-dielectric-metal metamaterial absorber. Metamaterial absorbers for different operating frequencies were designed by proper selection of the shape and size of the metal pattern of resonators on the top of the metamaterial absorber [19]. Thus, researchers have been developing different designs of metamaterial absorbers [20,21]. Liu et al. [22] have studied experimentally the absorption characteristics of a cross-pattern metamaterial and find a single band midinfrared absorption 97% at 6.0 µm. The dependence of the perfect absorption on the symmetry of the cross structure has been studied by Chen et. al. and they obtained dual band perfect absorption of 94% by breaking the symmetry of the cross structure [23]. A dual-band perfect metamaterial perfect absorber for molecular sensing was studied using cross shaped metal resonators in the wavelength range from 3µm to 10 µm [24]. A quad band metamaterial absorber was demonstrated by Semih Korkmaz et.al. in the wavelength range from 1.8 µm to 10 µm. The experimental results showed that absorption of the quad band was unity [25]. These studies revealed that a symmetric structure with different layers plays an important role in the realization of metamaterial absorbers. Therefore, it is desirable to develop simple structures that can be useful from single peak to multi peak in the mid infrared region.

In this paper, we propose a new structure to tune single peak absorption to dual peak absorption in the mid infrared wavelength region. Two pairs of perpendicular metallic resonators are employed to manipulate single peak resonance to dual peak resonance. This design takes into account the simple structure, easy fabrication, and lower cost in practical applications. This metal-dielectric-metal metamaterial absorber consists of gold metal and a SiC dielectric layer. The upper meta layer is in two sets of perpendicular resonators placed at a certain distance apart. It is shown that the absorber has a single peak absorption at 6.32 µm with an absorptivity of more than 96.8% at a certain arrangement of resonators. In another arrangement of resonators dual absorption peaks were observed at 6.17 µm and 7.0 µm with an absorptivity of 99.6%. The absorption peaks of the proposed structure remain high even at large angles of incidences, which could provide more efficient absorption for oblique incidences of radiation. The present study of metamaterial absorbers has important application prospects in solar cells, satellite radio thermographs, photodetectors and spectrum imaging.

II. STRUCTURAL DESIGN AND SIMULATION

A Schematic view of the unit cell of the proposed metamaterial absorber is shown in Fig.1(a) and its top view is shown in Fig. 1(b). It contains three functional layers, i.e. the top layer is a pattern of resonators, the middle is a dielectric layer, and the bottom is again a uniform metallic layer. The top and the bottom metallic layers are made of gold. The dielectric behavior of gold is described using the Drude model, where the dielectric function follows $\varepsilon = 1 - \frac{\omega_p^2}{\omega(\omega + i\omega_c)}$. The plasma frequency $\omega_p = 1.2\times10^{16}$ rad/s and the collision frequency $\omega_c = 10.5\times10^{13}$ rad/s are considered within the wavelength rage of 5 µm to 10 µm [26]. Silicon carbide is chosen as the dielectric layer and its dielectric constant and loss tangent are 10.8 and 0.003 respectively. The bottom metallic layer acts to block the transmission.

The length (P) of the square unit cell of the metamaterial is 2.6 µm, and the thickness of the dielectric layer t_d is 0.27 µm. The rectangular resonator length L is 0.8 µm and width W is 0.4 µm. Two metallic resonators are intersecting in such a way that one is vertical, and the other one is horizontal to form a T shape as shown in figure 1. The thickness of the gold layer t_m is 0.1 µm and the vertical distance between two T-shaped resonators is d = 0.4 µm. The proposed structure has period P along the X and Y directions. The absorption coefficient of the proposed structure is calculated by utilizing COMSOL Multiphysics. Floquet period boundary conditions are used along X and Y directions. The transverse electric (TE) waves are applied from the positive to negative Z-direction. The incident angle (θ) is between incident direction and Z-axis, and the azimuthal angle (φ) is the angle between the projection of incident wave on X-Y plane and X-direction. The influence of the shape of the metallic resonators on the absorption of the absorber is simulated and evaluated.

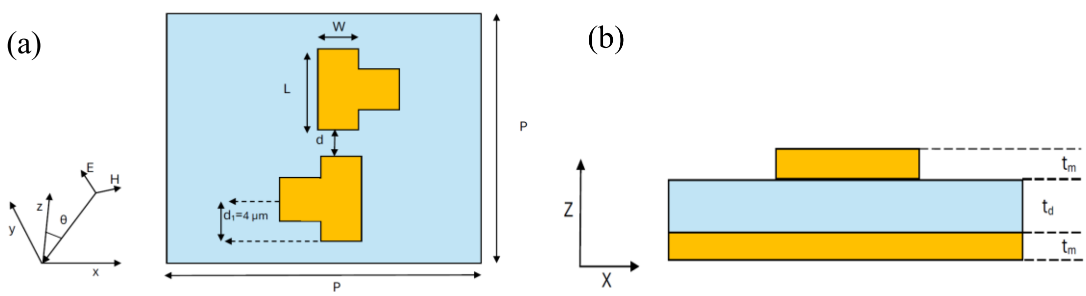

Fig. 1. (a) Top view and (b) cross-sectional view of a unit cell of the double T metamaterial absorber,

The absorption (A) of the absorber is given by $A = 1 - |S_{11}|^2 - |S_{12}|^2$, where S_{11} and S_{12} are the reflection coefficient and the transmission coefficients respectively. The transmission coefficient S_{12} is negligible because the thickness of

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the gold film is much larger than the material's infrared skin depth, hence, the absorption can be determined by using the formula $A=1-|S_{11}|^2$.

III. RESULTS AND DISCUSSION

The absorption spectrum of the double T is shown in Fig. 2 when the incidence angle θ = 0° and azimuthal angle φ = 0° for the TE mode. It can be observed that a single peak of maximum occurs at the wavelength of 6.5 μm with 85% absorption. Now the horizontal resonator is moved on the vertical resonator downwards, and the absorption is calculated and shown in Fig. 3. It is observed that the absorption gradually increases when the horizonal resonator moves downwards. The position of the horizontal resonator is represented by distance parameter d_1 (the distance from the bottom of the vertical resonator to the centre of the horizontal resonator).

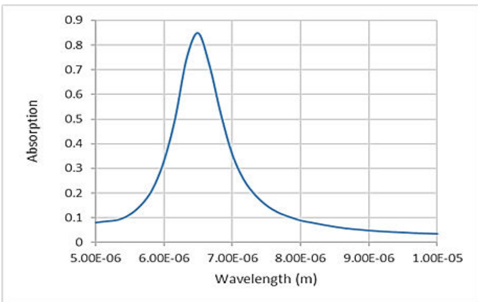
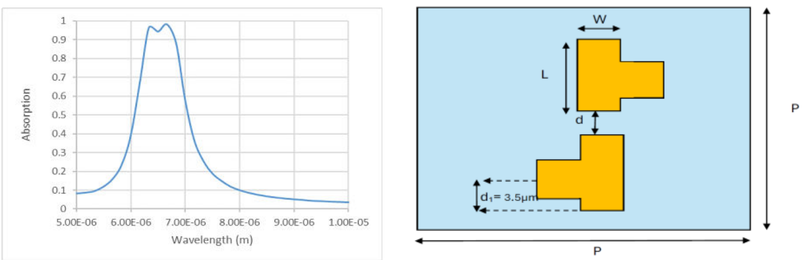


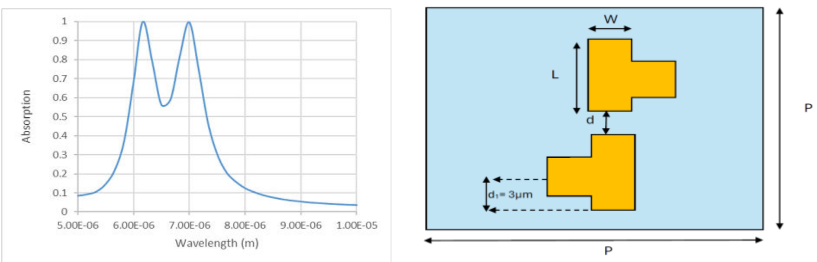
Fig. 2. The absorption spectrum of the double T metamaterial absorber under the incident angle of θ = 0° and φ = 0°for TE mode.

Fig. 3(a) represents the absorption spectrum of the absorber for d_1=3.5 μm at normal incidence. By moving the horizontal resonator downwards, the absorption increases significantly to 98% and the absorption band becomes broad. The absorption band spreads from 6.33 μm to 6.67 μm. Further, by moving down the horizontal resonator to a distance of d_1=3.0 μm, two absorption peaks are observed with 99.8% absorption and shown in Fig. 3(b). The absorption peaks are located at 6.17 μm and 7.0 μm. Thereafter, by moving the horizontal resonator to d_1=2.0 μm, the shape becomes an L. The absorption response is shown in Fig. 3(c). It is observed that two distinct absorption peaks of unit absorption are located at 5.83 μm and 7.5 μm. It is revealed that when the horizontal resonator moves, resonance peaks are affected. It is possible to make a single resonance peak or dual resonance peaks by adjusting the position of the horizontal resonator.

(a)



(b)



(c)

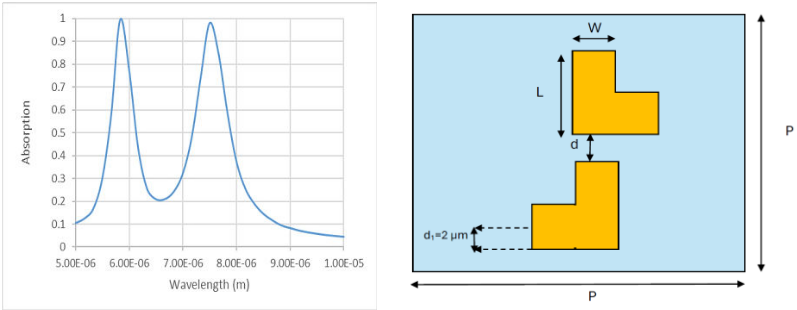


Fig. 3. The absorption spectrum of TE mode of the metamaterial absorber under the incident angle of θ = 0° and φ = 0°for different d_1 values (a) d_1=3.5μm, (b) d_1=3.0μm and (c) d_1=2 μm.

Fig. 4 shows the absorption spectra of various incident angles (θ) and fixed polarization (φ= 0) for a horizontal resonator at the position of d_1=3.5 μm. The absorption shows a single peak with 98.9% at incident angle θ = 0º. As the angle θ increases from 0º to 20º the absorption remains stable without any change. It can be observed that as θ further increases above 20º, absorption peak broadens and a trough in the middle of the absorption is observed, and the overall absorption exhibits a downward trend but remains above 90% for most of the spectrum. As θ continues to increase, above 60º, the spectral absorption continues to decrease. It demonstrates that the design has strong angular stability up to 60º.

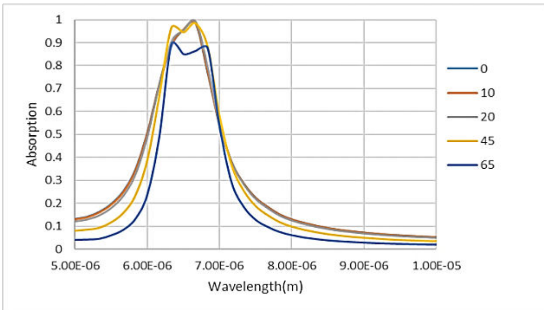


Fig. 4. Absorption spectrum of metamaterial with different incident angles (θ) for TE under the d_1=3.5 μm and $\varphi = 0°$.

We studied the electric field distribution across the metamaterial to understand the phenomenon behind the absorption. Fig.4 and Fig. 5 show the Z- component of the electric field distribution for different d_1 values. Fig. 4(a) shows that the electric field is concentrated at the top corners of the T- shaped elements and weaker field intensities at the bottom of the T shaped elements. Fig. 4(b) shows the electric field on the bottom metallic layer for the same wavelength. It indicates the formation of current loops in the metamaterial at resonance.

(a)

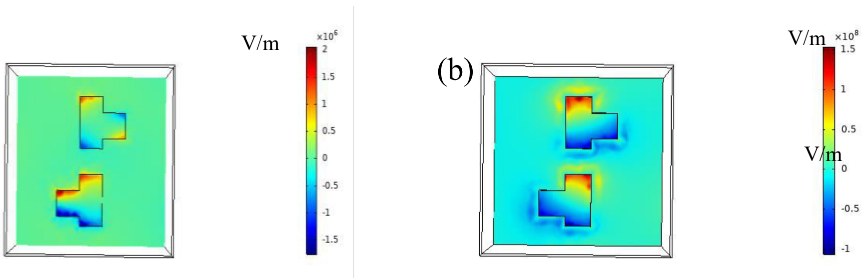


Fig. 4. The z component of electric field distribution at resonant wavelength $\lambda = 6.67$ μm for d_1=3.5 (a) top metal layer of double T and (b) bottom metal layer in TE wave incidence under the incident angle of $\theta = 0°$ and $\varphi = 0°$.

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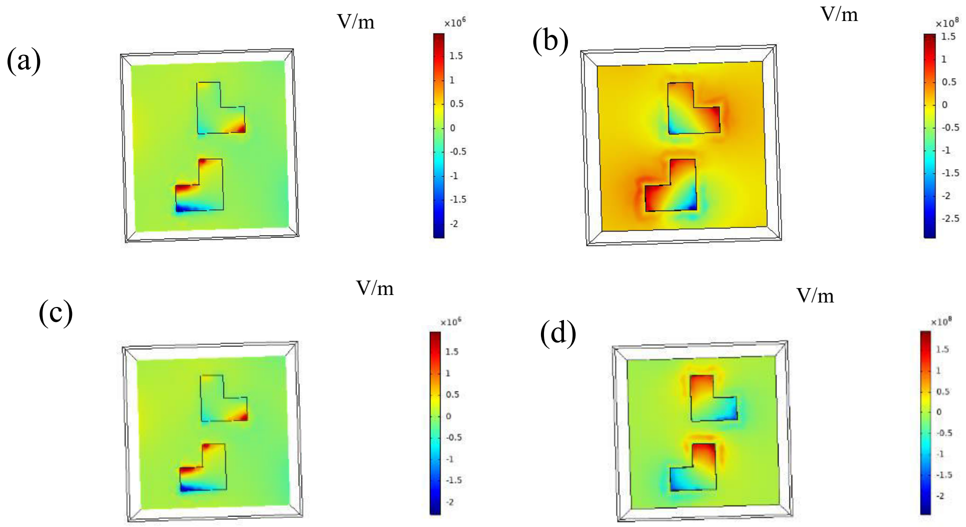

Fig. 5. The z component of electric field distribution at resonant wavelengths λ_1 = 5.83 μm and λ_2 = 7.5 μm (a) and (c) top metal layer and (b) and (d) bottom metal layer for TE wave (d_1 =2 μm, θ = 0° and φ = 0°).

Fig. 5(a) shows that the electric field intensity at the resonant wavelength λ_1 = 5.83 μm, around the top corners of the left L-shaped resonator electric field is strong, while the field is notably weaker at lower of the right L resonator. Fig. 5(b) indicates that the electric field distribution at the bottom metal layer remains phase-opposed relative to the resonators, once again forming two current loops at the corners of the Silicon corbide spacer. The similarity is observed at resonant wavelength λ_2 = 7.5 μm for the top and bottom of the metal layers as shown in figure 5(c) and 5(d). This indicates that different magnetic polariton modes are excited at different wavelengths, which generate different peaks of absorption.

IV. CONCLUSION

We have numerically studied a mid-infrared absorption of the metamaterial composed of the metal-dielectric-metal structure. The absorption peak wavelength and number of absorption peaks were controlled by turning the positions of the resonators. The distance between the absorption peaks significantly increased with adjusting the position of horizontal resonator. Further, certain positions of the horizontal resonator, absorption peaks were merged and become a single absorption peak. The absorption achieved 99.8% in the wavelength range 5μm to 10μm. For the angle of incidence from 0° to 20°, the absorption spectrum of the metamaterial absorber has a slight change with the absorption maintained above 98%. These results demonstrate that the proposed metamaterial tunable absorber has a promising application in the field of energy harvesting and night vision imaging.

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