



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 13, Issue 3, March 2024

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

Perpendicular Rectangular Gold Strip Metamaterial: A Dual-Band Mid-Infrared Absorber for Wide-Angle Operation

B. Vineetha¹, I. Reshma¹, M P Srinivasa Rao²

U.G. Student, Department of Electronics and Communication Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh, India¹

Professor, Department of Basic Sciences and Humanities, GMR Institute of Technology, Rajam, Andhra Pradesh, India²

ABSTRACT: We introduce a novel mid-infrared perfect metamaterial absorber characterized by wide-angle operation, and dual-band absorption. This absorber is composed of perpendicular rectangular gold strips placed on a dielectric substrate with an opaque gold ground layer. Through numerical simulations, we observe two absorption peaks approaching unity, attributed to magnetic polariton modes at distinct resonant wavelengths. Furthermore, our structure exhibits stable absorption across a broad range of incident angles (θ) for both transverse electric (TE) and transverse magnetic (TM) waves, particularly at azimuthal angle (ϕ) = 0°. This innovative design holds promise for applications in infrared spectroscopy and imaging by serving as an effective absorbing element.

KEYWORDS: Metamaterials, Absorption, Magnetic polariton, TE and TM waves.

I. INTRODUCTION

Metamaterials are synthetic materials crafted with specifically designed electrical permittivity and magnetic permeability [1]. They have gained significant attention due to their unusual properties like the Doppler effect, negative refractive index, perfect lensing, left-handed behaviour, electromagnetic wave cloaking, and perfect absorption [2-3]. A noteworthy advancement is the creation of a "perfect" absorber, achieving near-unity absorption through metamaterials, initially proposed by Landy et al. [4]. Utilizing intrinsic loss and employing suitable structural designs, various perfect metamaterial absorbers have been developed, spanning wavelengths from the microwave [5] to the optical [6] regimes. Strategies for mid-infrared absorbers encompass composite grating absorbers [7], photonic crystal absorbers [8], and broadband nanoresonator absorbers [9]. Liu et al. [10] designed a single-band mid-infrared absorber with a cross-pattern metamaterial, while Ye et al. [11] explored the omnidirectional and polarization-insensitive properties of the cross structure. Recognizing the limitations of single-band infrared absorbers in applications like spectroscopy and imaging [12], researchers have focused on developing dual-band or multi-band infrared absorbers. Liu et al. [13] studied a dual-band absorber by laterally assembling a subunit to the original cross-pattern unit cell, and Chen et al. and other [14-15] investigated a dual-band perfect absorber with a symmetrical structure.

Despite these efforts, achieving absorption with a simple structure has not been demonstrated in prior research. In this study, we propose a dual-band, wide-angle, and mid infrared metamaterial absorber using a T-shaped structure. The absorber exhibits two distinct nearly 100% absorption peaks. We identify the dual-band absorptions as the result of magnetic polariton modes produced at two distinct resonant wavelengths by analyzing the electric field distribution at resonant wavelengths. Furthermore, we also investigate the wide-angle stability of the perfect absorber under both TE and TM modes of incidence.

II. DESIGN OF METAMATERIAL ABSORBER

Figures 1(a) and 1(b) show the unit cell of a T-shaped metamaterial absorber. The T-shaped metal strips and bottom metal layer are made from gold and the Drude model dielectric function $\epsilon_m = \frac{1-\omega_p^2}{\omega(\omega+i\omega_c)}$ is used. The plasma frequency (ω_p) and the collision frequency (ω_c) are taken as 1.2×10^{16} rad/sec and 10.5×10^{13} rad/sec respectively. With a loss

tangent of 0.003 and a dielectric constant of 10.8, the SiC layer is selected as the dielectric layer between the T-shaped metal strips and the bottom metal layer. The gold layer has a thickness (t_m) of $0.1 \mu\text{m}$ while the SiC layer has a thickness (t_d) of $0.27 \mu\text{m}$. The lattice period of the structure is $\Lambda = 2.6 \mu\text{m}$ in both the x and y directions. The vertical distance between two perpendicular metal strips is $d_1 = 0.4 \mu\text{m}$. The rectangular gold strips have width w and length l of $0.4 \mu\text{m}$ and $0.8 \mu\text{m}$, respectively. COMSOL Multi physics, based on the finite element technique, was used to calculate the transmission and reflection coefficients of the proposed structure [16]. The transverse electric (TE) wave that is being considered here has an incidence angle of θ to the z-direction and is impinging on the structure in the x-z incident plane is shown in figure 1(a). A transverse magnetic (TM) incident wave, on the other hand, would have a magnetic field that is directed along its path and an electric field on the x-z plane. In both the x and y directions, periodic boundary conditions are applied.

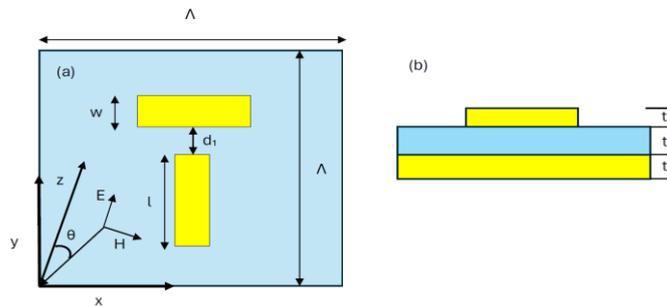


Fig. 1. (a) Top view and (b) side view of a unit cell of the T-shaped metamaterial absorber

III. RESULTS AND DISCUSSION

The absorption (A) is estimated by using $A=1-|S_{11}|^2$, where $|S_{11}|$ is the reflection coefficient. Here, the absorption depends only on the reflection coefficient because the thickness of the metallic strip is much greater than the skin depth in the infrared region. Figs. 2(a) and 2(b) show the absorption spectra of the T-shaped structure with various incidence angles (θ) for both the TE and TM waves.

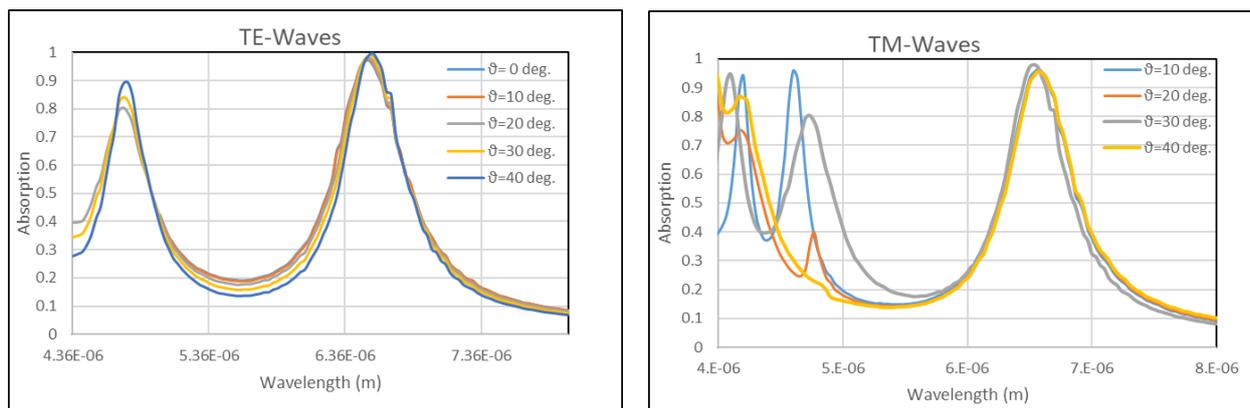


Fig.2 Absorption spectra of single T-shaped metamaterial with different incident angles for (a) TE configuration and (b) TM configuration,

Two absorption peaks are observed for TE waves for various incidence angles. It is seen that the increase in incidence angle increases the absorption. The perfect absorption of 99.79% is achieved at a wavelength of $6.56 \mu\text{m}$. The second absorption peak is obtained at a wavelength of $4.76 \mu\text{m}$ and the highest absorption is 89.35% at the incidence angle of 40° . The second absorption peak is more influenced by the angle of incidence than the first peak. Similarly, there are two or more absorption peaks observed for TM waves. The highest absorption (97.18%) is observed at wavelength $6.56 \mu\text{m}$.

μm for the angle of incidence 30° . It is observed that an increase in the angle of incidence reduces the number of peaks and absorption.

The electric field distribution of the TE mode at resonant wavelengths $\lambda_1 = 6.56 \mu\text{m}$ and $\lambda_2 = 4.76 \mu\text{m}$ on the rectangular strips and bottom metal layer are shown in Fig. 3 and Fig. 4, respectively, for an incidence angle of 40° . It is observed in Fig. 3(a) that the electric field distribute mainly at the bottom region of vertical strip and a weak field is found at bottom of the horizontal strip at wavelength $\lambda_1 = 6.56 \mu\text{m}$. The electric field distribution on the bottom metal layer at the same resonant wavelength is shown in Fig. 3(b). These fields are just opposite in sign compared with those on the metal strips. This field distribution indicates that one induced current loop around the SiC dielectric is formed. This feature of the distribution of the electric field shows that magnetic resonances are produced in T-shaped metal strips by the excitation of magnetic polaritons.

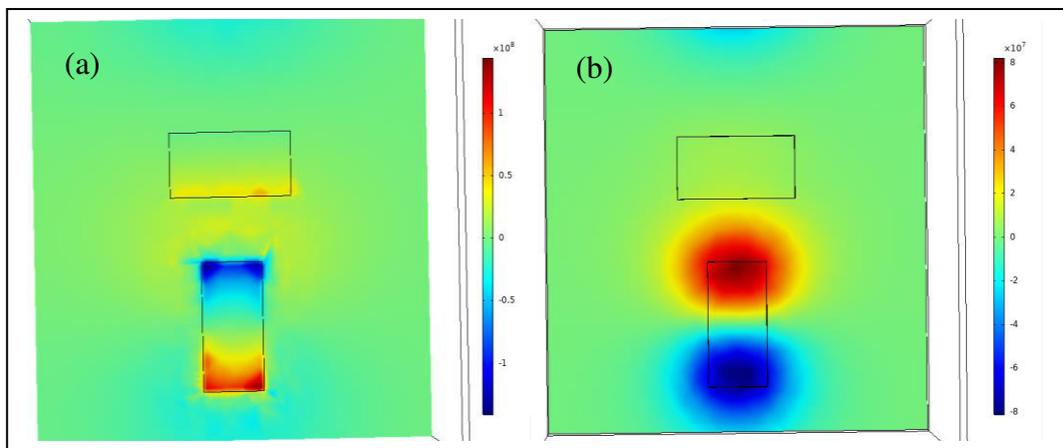


Fig. 3 The z component of electric field distribution at resonant wavelength $\lambda_1 = 6.56 \mu\text{m}$ on (a) top of perpendicular strips and (b) bottom metal layer in TE incidence under the incident angle of $\theta = 40^\circ$.

In the same way, we investigate the Z- component of electric field at resonant wavelength $\lambda_1 = 4.76 \mu\text{m}$. Fig. 4(a) shows that the electric field is concentrated at bottom of the horizontal metal strip. In Fig. 4(b), we can see that the electric field distribution at the same resonant wavelength on the bottom metal layer is opposite when compared with that on the metal strips. This means that one induced current loop around the SiC dielectric is formed. This indicates that different magnetic polariton modes are excited at the different resonant wavelengths, which generate absorption bands.

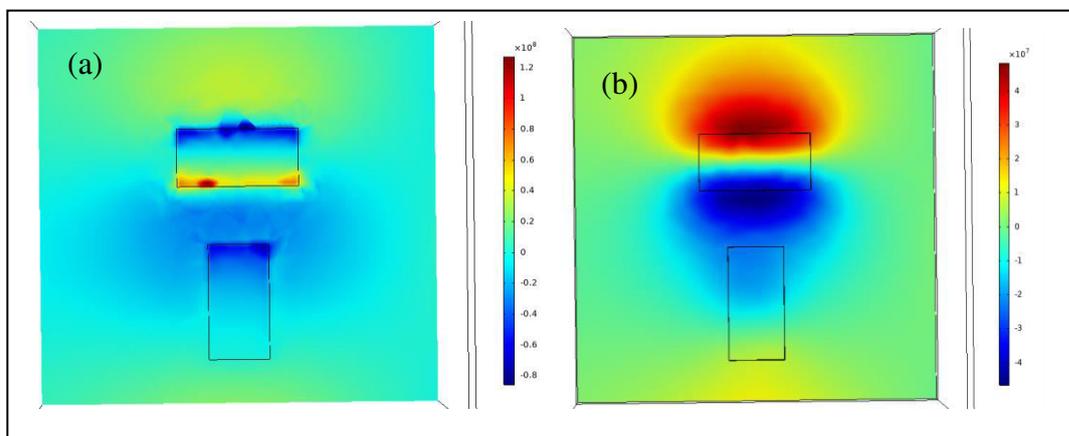


Fig. 4 The z component of electric field distribution at resonant wavelength $\lambda_2 = 4.76 \mu\text{m}$ on (a) top of perpendicular strips and (b) bottom metal layer in TE incidence under the incident angle of $\theta = 40^\circ$.

The stability of absorption bands has been further investigated for the TE and TM waves, at $\varphi = 0^\circ$, with incidence angle θ ranging from 0° to 40° (shown in figure 2). When θ changes from 0° to 40° in TE waves, a dual band absorption up to 99.79% is accomplished and the maximum absorption is attained at $\theta = 40^\circ$ for wavelength $\lambda_1 = 6.56 \mu\text{m}$. In TM mode, triple absorption peaks are observed when θ varying from 0° to 40° . The maximum absorption 95.52% at wavelength $\lambda_1 = 6.56 \mu\text{m}$ is observed for $\theta = 40^\circ$. The reduction of absorption intensity observed for the lower wavelengths. With the incident angle larger than 30° , different absorption peaks at lower wavelengths merge into one.

IV. CONCLUSION

The absorption characteristics of T-shaped metamaterial absorber in the mid infrared region have been investigated numerically. This metamaterial consists of a SiC dielectric layer sandwiched between T-shaped rectangular gold strips and a gold ground plate. Two distinct absorption peaks are observed at an incident angle of $\theta = 40^\circ$. Analysis of the z component of the electric field profile within the absorber reveals that the perfect absorptions arise from magnetic polariton modes formed at different resonant wavelengths. Moreover, the absorber demonstrates stability across a range of incident angles for both transverse electric (TE) and transverse magnetic (TM) wave incidences. This dual-band infrared absorber holds promise for applications in thermal detectors and infrared imaging.

REFERENCES

- [1] D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, "Composite medium with simultaneously negative permeability and permittivity," *Phys. Rev. Lett.* Vol. 84(18), pp. 4184–4187, 2000.
- [2] Pendry JB. Negative Refraction Makes a Perfect Lens. *Phys Rev Lett* , Vol. 85(18),pp. 3966–9, 2000.
- [3] Houck AA, Brock JB, Chuang IL. Experimental Observations of a Left-Handed Material that Obeys Snell's Law. *Phys Rev Lett*, Vol.90(13), pp. 137401, 2003.
- [4] N. I. Landy, S. Sajuyigbe, J. J. Mock, D. R. Smith, and W. J. Padilla, "Perfect metamaterial absorber," *Phys. Rev. Lett.* Vol.100(20), 207402, 2008.
- [5] F. Ding, Y. Cui, X. Ge, Y. Jin, and S. He, "Ultra-broadband microwave metamaterial absorber," *Appl. Phys. Lett.* 100(10), 103506, 2012.
- [6] S. J. Hao, J. Wang, X. Liu, W. J. Padilla, L. Zhou, and M. Qiu, "High performance optical absorber based on a plasmonic metamaterial," *Appl. Phys. Lett.* Vol. 96(25), 251104, 2010.
- [7] J. Mason, S. Smith, and D. Wasserman, "Strong absorption and selective thermal emission from a midinfrared metamaterial," *Appl. Phys. Lett.* Vol. 98(24), 241105, 2011.
- [8] G. C. Devarapu and S. Foteinopoulou, "Mid-IR near-perfect absorption with a SiC photonic crystal with angle controlled polarization selectivity," *Opt. Express*, Vol. 20(12), pp.13040–13054, 2012.
- [9] W. Dai, D. Yap, and G. Chen, "Wideband enhancement of infrared absorption in a direct band-gap semiconductor by using nonabsorptive pyramids," *Opt. Express*, Vol. 20(104), pp. A519–A529, 2012.
- [10] X. Liu, T. Starr, A. F. Starr, and W. J. Padilla, "Infrared Spatial and Frequency Selective Metamaterial with Near-Unity Absorbance," *Phys. Rev. Lett.* Vol 104(20), pp. 207403, 2010.
- [11] Y. Q. Ye, Y. Jin, and S. He, "Omnidirectional, polarization-insensitive and broadband thin absorber in the terahertz regime," *J. Opt. Soc. Am. B*, Vol. 27(3), pp. 498–504, 2010.
- [12] P. R. Christensen, B. Jakosky, H. H. Kieffer, M. C. Malin, H. Y. McSween, Jr., K. Nealson, G. L. Mehall, S. H. Silverman, S. Ferry, M. Caplinger, and M. Ravine, "The Thermal Emission Imaging System (THEMIS) for the Mars 2001 Odyssey Mission," *Space Sci. Rev.* Vol.110 (1–2), pp.85–130, 2004.
- [13] X. Liu, T. Tyler, T. Starr, A. F. Starr, N. M. Jokerst, and W. J. Padilla, "Taming the Blackbody with Infrared Metamaterials as Selective Thermal Emitters," *Phys. Rev. Lett.*, Vol.107(4), 045901, 2011.
- [14] K. Chen, R. Adato, and H. Altug, "Dual-Band Perfect Absorber for Multispectral Plasmon-Enhanced Infrared Spectroscopy," *ACS Nano*, Vol. 6(9), pp.7998–8006, 2012.
- [15] Abdulkarim YI, Mohanty A, Acharya OP, Appasani B, Khan MS, Mohapatra SK, Muhammadsharif FF and Dong J, "A Review on Metamaterial Absorbers: Microwave to Optical". *Front. Phys.*, 10:893791, 2022.
- [16] Lijun Meng, Ding Zhao, Qiang Li, and Min Qiu, "Polarization-sensitive perfect absorbers at near-infrared wavelengths", Vol. 21, *Optics express*, pp. A111-A122, 2013.



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  ijirset@gmail.com



www.ijirset.com

Scan to save the contact details