GRAPHITE BASED METAL FREE ABSORBER FOR MULTIBAND AND ENHANCED ABSORPTION

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ABSTRACT

Terahertz absorbers are important for improving the performance of terahertz based technologies in a wide range of applications. Terahertz absorbers are the materials or devices that absorb electromagnetic radiation in the range of terahertz frequency (typically between 0.1 and 10 terahertz). There are many applications of terahertz absorbers which include security screening, energy harvesting, communication, sensing etc. In this paper we have implemented a technique for the generation of multiple bands and enhancement of the absorption in a graphite based absorber. The generation of multiple absorption bands is supported by the aspect ratio of the graphite sheet. For the enhancement of absorption the notches and slots are introduced later in the graphite sheet. By varying the different physical parameters of the absorber we can control the generated multiple absorption bands separately. Moreover the proposed structure is metal-free, polarization insensitive and can operate with a wide value of incident angle. The work represents a way to implement the metal-free absorber structure.

Keyword : - *Absorbers, Terahertz, Absorption, Aspect ratio, Enhancement.*

1. INTRODUCTION

Terahertz frequency is the band of frequencies that lies between microwave and infrared regions of the electromagnetic spectrum, and the range of frequency is between 0.1 and 1 THz [2]. Terahertz waves are capable of penetrating into non-metallic substances like fibres, clothing, plastic and ceramic [3]. The terahertz frequency devices has got wide range of applications in the field of medical diagnostic, spectroscopy and security and this is what makes the study of terahertz devices popular [2]. THz waves cannot penetrate through biological tissues because of the non-ionisation nature of them. Researchers are studying the THz spectrum and developing devices which can be used in various applications.

In the recent days, the implementation of different THz devices requires the absorbers with different specifications [7]. These absorbers are needed in the applications like THz imaging, spectral analysis and sensing. The requirement of clinical and engineering applications need the absorbers which work effectively in 0.5-5 THz frequency range [1]. Traversing the literature reveals the drawbacks such as (1) need for the search of a new material for the implementation of absorber which can replace the metals at THz frequency, (2) implementation of the absorber which exhibits a multiband response, (3) implementation of technique which enhances absorption with multiband response and (4) maintaining the polarization insensitivity in multiband structure. In order to find the remedies for these research issues, a graphite-based absorber is numerically analysed and implemented in this work.

2. DRAWBACKS IN EXISITING ABSORBERS

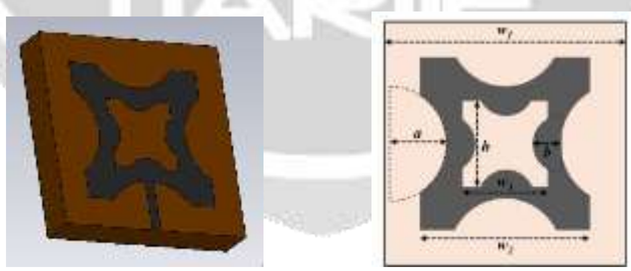
When coming to the practical cases the performance of the devices is degraded by the absorption losses in the materials and finding the natural material with high absorption coefficients are difficult. Because of this issue there is a requirement to develop an absorber which reduces the absorption losses in material. Taking this as a motivation, a number of single, dual and multiband absorbers have been implemented [4,5,6]. As the applications are getting advanced there happened a requirement for the implementation of multiband absorbers. A dual-band absorber was implemented based on the metamaterial. Obtaining the high absorption in a single band absorber is easy, but the implementation of multiband absorption with high absorptivity is a difficult task. A multiband absorber was implemented with the absorption around 50% or less [5]. Some multiband metamaterial–based absorbers have been implemented, but these are sensitive to polarization.

Finding a polarization insensitive multiband absorber with high absorptivity is a challenging task. Several structures have been designed by researchers for reducing the absorption losses in material. Furthermore, the natural materials alone provide low value of absorption. The high absorption is generally obtained either by combining the different layered structure of different materials or by engraving the different shapes of the unit cell. Few sheets of carbon material which is called as graphene provide the small absorption alone. Combining these layered carbon materials with metals/dielectrics and metamaterial improves the absorption peaks [10,11,12]. However, as already discussed, the use of multilayered structure including metal/dielectric/metamaterial may have some limitations in the fabrication. Thus, the absorption enhancement remains another challenge.

3. PROPOSED DESIGN AND METHODOLOGY

Considering their electrical properties in the THz band, the research has been going on from a decade on the sp2 carbon materials. Recently, it was analysed that the family of carbon materials can be an essential element for the implementation of THz devices and an antenna has been implemented for lower THz applications. Many costlier metals do fail in their electrical properties at high temperature. But graphite provides the electrical properties better than many costly metals with great performance in high-temperature environment. So, in order to utilize the properties of graphite material, especially at the THz frequency spectrum, the metallic structures can be replaced by the graphite material-based devices.

In the proposed absorber, the higher-order modes are generated by selecting an appropriate aspect ratio of the graphite sheet. The notches and slots are introduced in the graphite sheet for absorption enhancement. The resonant frequency of the generated multiple bands can be shifted so that either they can be merged to provide the wide absorption band or the multiband response with sufficient guard bands. Moreover, the proposed structure is polarization insensitive and operates with wide value of the incident angle. The absorber structure is made symmetrical in all the directions; hence, it remains insensitive to polarization of the incident wave for both TE and TM modes. The proposed absorber provides the high absorption with multiband response and polarization insensitivity with the utilization of non-metallic graphite material and provides a way to implement the metal-free structure.



(a) (b)

Fig 1: (a) 3D view of the absorber, (b) Parametric view

The geometry of the multiband graphite– based absorber is shown in the above figure. Two graphite sheets are separated by a dielectric layer of silicon dioxide material ($\epsilon_s = 3.8$) having thickness d = 14 μm and edge w1. For the implementation of the THz absorber, the stack of sp2 carbon nanomaterial which can be said as graphite is selected with the thickness t and relaxation time $\tau = 1 \times 10^{-12}$s at room temperature T = 300 K. The value of t can be selected as per the desired results ("Absorber Performance Analysis"). In the proposed structure, the final results are reported with t = 300 nm which is equivalent to the stack of around 900 two-dimensional nanosheets of planar carbon material.

Parameter	W1	W2	W3	a	b	h	t	d
Dimension(μm)	90	65	25	18	10	28	0.2	14

Table : Dimensions of the proposed absorber

The evolution process of the final absorber structure is shown in Fig. 2. There are six steps followed to obtain the final structure. In the first step, the absorber contains two graphite sheets placed at either side of the dielectric layer of silicon dioxide as shown in Fig. 2a. The edge size of the top graphite layer is kept w2 while the bottom of the dielectric is fully covered by the graphite layer. The dimensions of the graphite sheet are selected for the generation of multiple bands as it is recently reported that the graphite with an appropriate dimensions can generate the multiple resonance in the lower THz band.

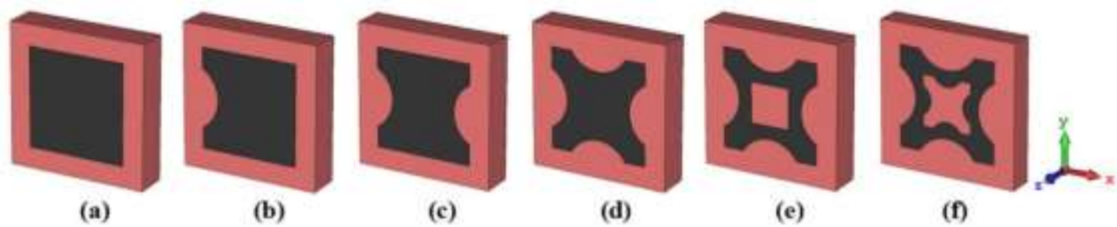


Fig 2: Evolution of the structure of absorber

In the top layer of graphite, a semi-circular notch is created with the radius a as shown in Fig. 2b. The radius of the semi-circular notch is mapped form the edge of the substrate for simplicity in reproduction of the model. The structure of absorber-3 (abs-3) is obtained by making the notched structure symmetrical about y-axis as shown in Fig. 2c. In the fourth step, the abs-4 is made with a fully symmetrical structure having four semi-circular notches in the top graphite sheet along all the edges as shown in Fig. 2d. Figure 2 e shows final structure of the absorber with rectangular slot in the centre of the graphite sheet placed at the top. The structure of absorber can further be modified in the form of abs-6 as shown in Fig. 2f for obtaining the desired results for any specific application at the THz frequency. The structure of abs-6 can be obtained by placing the semi-circles of graphite with the radius b as shown in Fig. 2f.

DESIGN EQUATIONS:

The surface conductivity (σ_g)can be expressed as the sum of intra-band conductivity (σ_{intra}) and inter-band conductivity (σ_{inter}) :

$$\sigma_g = \sigma_{intra} + \sigma_{inter}$$

$$= \frac{2e^2K_BT}{\pi\hbar^2}\ \frac{i}{\omega+i\tau^{-1}}\ ln\left[2\ cosh\left(\frac{E_F}{2K_BT}\right)\right] + \frac{e^2}{4\hbar}\ \left[\frac{1}{2}+\frac{1}{\pi}\ arctan\left(\frac{\hbar\omega-2E_F}{2K_BT}\right) - \frac{i}{2\pi}\ ln\frac{(\hbar\omega+2E_F)^2}{(\hbar\omega-2E_F)^2+4(K_BT)^2}\right]$$

Where,

e is the charge of an electron,

K_B is the Boltzmann constant,

$\hbar$ is the reduced Planck's constant,

T is the operation temperature (T = 300 K),

ω is the angular frequency of the incident wave,

τ is the relaxation time of carrier and

E_F is the Fermi level of graphene.

According to the Pauli Exclusion Principle ($E_F \gg K_B T$ and $E_F \gg \hbar\omega$), σ_{inter} can be simplified :

$$\sigma_{inter} = \frac{e^2}{4h}\left[\frac{1}{2} + \frac{1}{\pi}\left(-\frac{\pi}{2}\right) - \frac{i}{2\pi} ln1\right] = \frac{e^2}{4h}\left[\frac{1}{2} - \frac{1}{2}\right] = 0$$

Then, the σ_g can be expressed as:

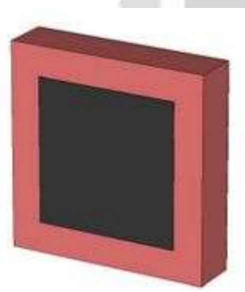
$$\sigma_g = \sigma_{intra} + 0$$

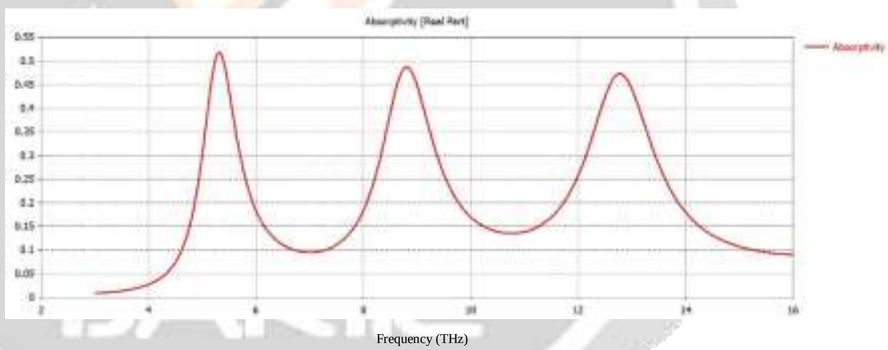
$$= \frac{2e^2 K_B T}{\pi h^2}\,\frac{i}{\omega + i\tau^{-1}}\, ln\left[2\cosh\left(\frac{E_F}{2K_B T}\right)\right]$$

$$= \frac{2e^2 K_B T}{\pi h^2}\,\frac{i}{\omega + i\tau^{-1}}\left(\frac{E_F}{2K_B T}\right) = \frac{e^2 E_F}{\pi h^2}\,\frac{i}{\omega + i\tau^{-1}}$$

4. RESULTS

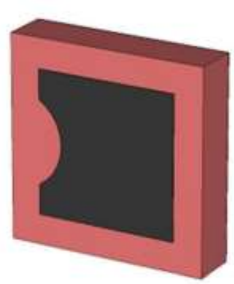
Structure **Absorption curve**

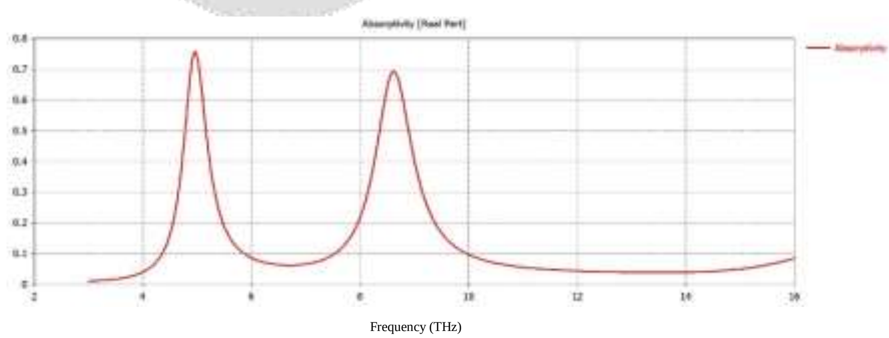




Structure 1

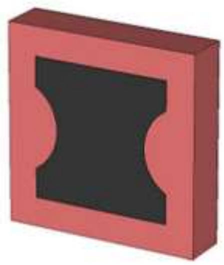
The absorption curve of structure-1 shows three significant peaks at 5.3, 8.9 and 12.8 THz resonant frequencies. But the highest absorption is only 52% which is at 5.3 THz frequency. This structure generates multiple absorption bands but with less absorptivity.



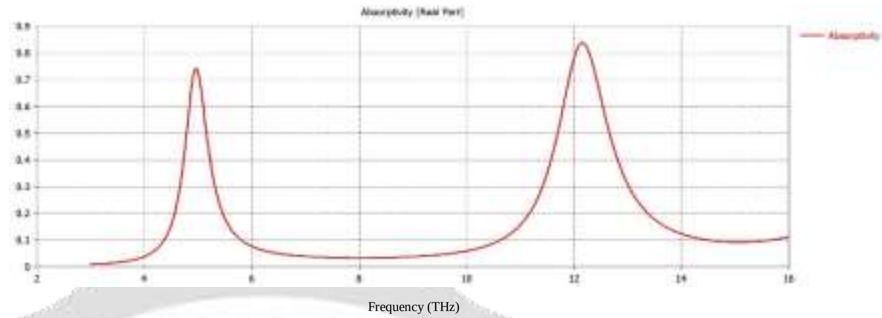


Structure 2

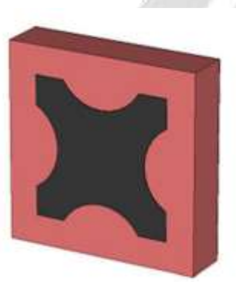
The absorption curve of structure-2 shows two significant peaks at 5, 8.7 THz resonant frequencies. The highest absorption peak is 75% at 5 THz frequency which is far better than the previous absorption peak in structure 1. This is because of the introduction of semi circular notch in one side of the graphite sheet.



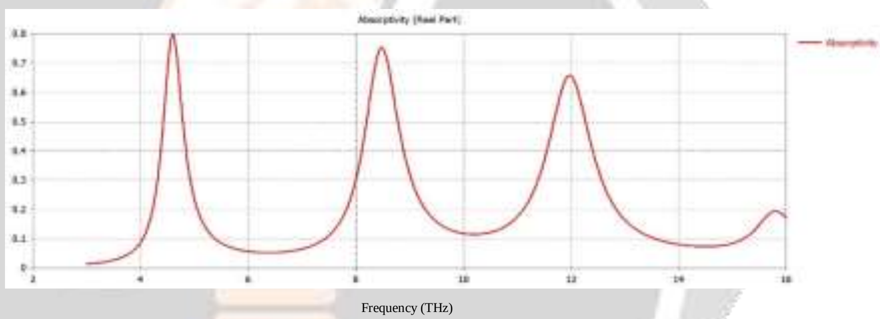
Structure 3



The absorption curve of structure-3 shows two significant peaks at 5, 12.2 THz resonant frequencies. The highest absorption peak is 84% at 12.2 THz frequency which is increased by 9% when compared with the previous absorber structure. This is because of the introduction of another semi circular notches on another of graphite sheet.

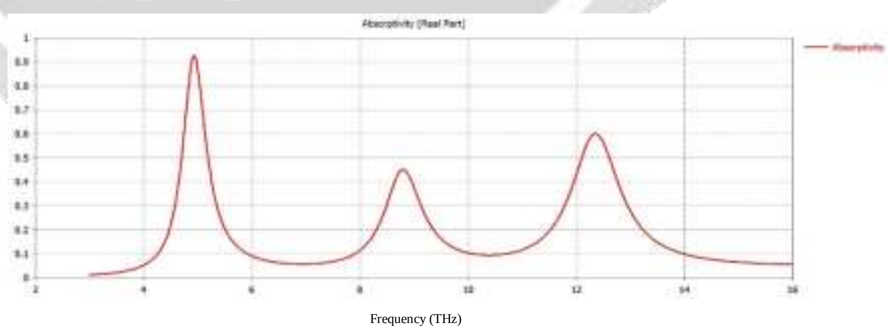


Structure 4



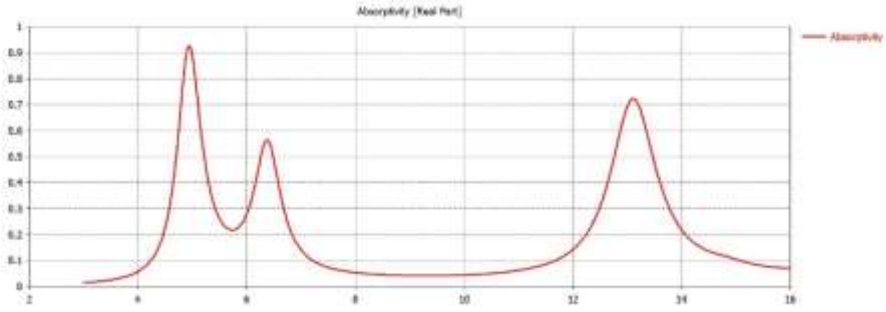
The absorption curve of structure-4 shows three significant peaks at 4.6, 8.5 and 11.9 THz resonant frequencies. The highest absorption peak is 80% at 4.6 THz frequency. This structure provides three resonant frequencies with significant absorption because of the introduction of another semi circular notches on another of graphite sheet.

Structure 5



The absorption curve of structure-5 shows three significant peaks at 4.9, 8.8 and 12.3 THz resonant frequencies. The highest absorption peak is 92% at 12.2 THz frequency which is increased by 12% when compared with the previous absorber structure. This is because of the introduction of square notch in the centre of graphite sheet.

Structure 6



The absorption curve of structure-6 shows three significant peaks at 4.9, 6.3 and 13.2 THz resonant frequencies. The third absorption peak is improved when compared with the previous absorber structure. The introduction of semi circular graphite discs inside the square notch helped in achieving 3 significant absorption peaks with 92% being the highest.

5. CONCLUSION

We have implemented a terahertz absorber by overcoming all the drawbacks present in the existing absorbers like metal heating issues, inability to generate multiple absorption bands, polarization sensitivity etc. The terahertz absorber generates multiple absorption bands. The absorber is metal free and polarization insensitive. The insertion of the slots and notches in the graphite sheet interacting with the electromagnetic wave provides the high value of absorption either over the multiple bands or for a wideband. The generated multiple absorption bands have been controlled separately by varying the different physical parameters of the absorber structure.

6. REFERENCES

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