Design and Analysis of Metamaterial Electromagnetic Wave Absorbers at THz Frequency

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***Abstract*:** The subject of THz research and technology has advanced dramatically over the previous two decades. In the THz regime, a metamaterial-based absorber is in high demand. Metamaterials (MMs) can be employed as an effective medium by changing the shape to influence the electromagnetic characteristics. All incident radiations at a specific operational frequency are absorbed by a unity absorber, while transmissivity, reflectivity, scattering, and all other light propagation pathways are inhibited. The main focus of this study is on metamaterial-based perfect absorbers (MMPA) in the THz regime. This paper presents an MMPA with two metallic layers and a dielectric. The suggested MMPA is investigated utilising three different materials: gold, silver, and copper, with a comparison between them shown here.

***Keywords*: Absorber, Metamaterial, Terahertz**

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I. INTRODUCTION

Because of the rapid growth of small-scale semiconductor technology, ultra-fast laser technology, and ultra-fast photonics technology in the recent two decades, Terahertz (THz) science and technology has advanced dramatically [1]. The simulation of a metamaterial-based perfect absorber is the focus of this research. In 2008, the invention of the first "perfect metamaterial absorber" was announced. Since then, various metamaterial absorbers with dual-band, multiband, and wideband absorption, polarization insensitivity, and wide angle absorption have been reported in the literature [2] [3], all of which meet the requirements for compact, lightweight, thinner, and bandwidth enhanced metamaterial absorbers. There are two types of electromagnetic (EM) wave absorbers: resonant absorbers and broadband absorbers [2]. Broadband absorbers rely on materials with frequency-independent properties that can interact with incident radiation in a very resonant way at a specific frequency, whereas resonant absorbers rely on materials

with frequency-independent properties that can absorb radiation over a wide bandwidth [4][5]. Each sort of absorber has a limited amount of control over its specific absorption qualities; therefore it's best to focus on developing materials that naturally match the impedance to empty space.

Electromagnetic metamaterials [6] [7] are assemblies of wavelength elements which can be considered as efficient materials having some particular electric permittivity $\epsilon(\omega)$ and magnetic permeability $\mu(\omega)$. People were first interested in metamaterials because novel electromagnetic phenomena could not be achieved with natural materials. Metamaterials have since been discovered to be efficient electromagnetic wave absorbers. Pendry's invention of artificial magnetism in 1999 [6] opened up new avenues for developing negative index materials. Pendry et al. proposed that artificial materials can be designed to demonstrate effective permittivity and permeability by constructing subwavelength features [6].Split ring resonators with a negative dielectric wire media were used to exhibit a negative refractive index [7][8]. This experiment was initially carried out at microwave frequencies, but it has now been shown to work in the radio frequency range as well as the optical domain [9]-[16]. Split rings can be made from a single unit cell or from a large number of sub-units that are arranged to occupy space in one, two, or three dimensions.

Through simulation, Landy et al. suggested the first metamaterial-based absorber with three layers: two metallic layers and one dielectric layer, and observed an absorptivity of A= 99 % at 11.48 GHz. All three layers were made with PCB and photosensitized FR4 epoxy, which is a typical process for making microwave-frequency metamaterials. Antiparallel currents in the cut wire and the ERR's centre wire were used to achieve magnetic coupling. A Lorentz-like magnetic response can be obtained by coupling these antiparallel currents to a time-varying magnetic field. Each of the electric and magnetic responses can be tuned thanks to the integrated architecture. For example, changing the geometry of the ERR can change the frequency location and strength of a Lorentz resonance, but changing the geometry of the metallic structures and the space between them can change the magnetic response [17].

II. SIMULATION OF METAMATERIAL PERFECT ABSORBER

This paper describes the design, simulation, and characterisation of a metamaterial absorber that is resonant at THz frequencies. Metamaterial perfect absorbers, like other metamaterials, are made up of repeating unit cells arranged in two or three-dimensional periodic configurations. With knowledge of material qualities and the assignment of appropriate excitation (i.e., ports) and boundary conditions, the periodic array can be represented by simulation of one unit cell. The simulation was carried out using the COMSOL Multiphysics.

Optical properties are assigned to materials such as metals and insulators that make up the structure during simulations. The Metal is one of the most important components of MPAs that influences resonating behaviour. To achieve acceptable results in the simulation process, it is necessary to have a thorough understanding of metal properties. At low frequencies, such as microwaves, metals like gold and copper can be simulated as good conductors with a specific conductivity value. However, metals used to imitate metamaterials tend to be lossy at higher frequencies, such as infrared or optical, and in this case, the Drude model is frequently used to reproduce their frequency dependent optical properties.

The most essential metric for MPAs is absorptivity, which is defined as the fraction of incident energy absorbed by the material. The absorptivity is defined mathematically as:

$$A(\omega) = 1 - R(\omega) - T(\omega) \qquad (1)$$

where, R (ω) is the reflectivity from the MPA and T (ω) is the transmissivity through the MPA. The reflectivity and transmissivity of a system can be calculated in simulation by using appropriate boundary conditions and excitation. To simulate interaction between electromagnetic waves and a periodic structure, a typical finite difference time domain (FDTD) simulation programme can employ either periodic boundary conditions with plane waves or perfect electric (PE) and perfect magnetic (PM) boundary conditions with waveguide ports. The incident light's polarisation is restricted in the PE and PM boundary conditions, causing the electric field to be polarised along the PE boundary. The existence of two waveguide ports on either side of the structure, which are incident on the structure, excites a TEM wave.A plane wave with a specific polarisation is thrown onto the structure for periodic borders, and all fields and currents are required to be equal at the simulation space's boundaries. The output complex scattering parameters, such as transmission coefficient S_{21} and reflection coefficient S_{11}, are acquired through the simulation process; here, the first subscript signifies the receiving port and the second subscript specifies the excitation port. Then from these complex scattering parameters, R (ω) and T (ω) can be obtained as $T(\omega) = |S_{21}|^2$ and $R(\omega) = |S_{11}|^2$.As a result, the amplitudes of the reflection coefficient S_{11} and the transmission coefficient S_{21} are the most commonly used parameters in MPA computational studies.

III. METAMATERIAL BASED ELECTROMAGNETIC WAVE ABSORBERS WITH FREQUENCY RANGING FROM 1 TO 5 THZ

For this structure the parameters which have been chosen are given in Table 1. The structure was studied separately with Gold, Silver and Copper as one of the metal.

TABLE I. PARAMETERS THAT WERE UTILISED TO CREATE THE SIMULATION MODEL

Parameters	Values
Maximum frequency(fmax)	5[THz]
Minimum frequency(fmin)	1[THz]
Period in X-direction(Px)	36[µm]
Period in Y-direction(Py)	Px
Frequency steps	0.001[THz]
Air thickness(Air_t)	20[µm]
Substrate thickness(Sub_t)	8[µm]
MM length(l)	25.9[µm]
MM line width(w)	3[µm]
MM gap size(g)	1.4[µm]
MM capacitor width	10.8[µm]
Shortest wavelength	C_const/fmax
Longest wavelength	C_const/fmin
Incident electric field	1[V/m]
ramping parameter	0
Output Power	(Px*Py/4/2/Z0_const)[W]

The geometry is chosen first, and then the block is considered. The air thickness (Air_t) and substrate thickness (Sub_t) are chosen as (Air_t+Sub_t) which equals 28 m for the width of the block, Px/2=18 m for the depth, and Py/2=18 m for the height. Now, in order to separate the geometry, the block must be partitioned, with the air region on top and the substrate region on the bottom. Finally, the block was completed and is seen in Fig. 1.

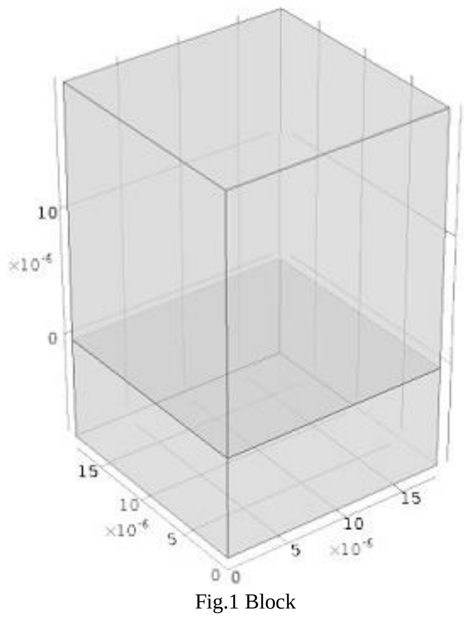


Fig.1 Block

The metamaterial is then built by selecting the work plane in the XY plane. Then, in the model builder, we can see a 2D perspective of the block by selecting the plane geometry. The main structure of the metamaterial is then designed in plane geometry, as seen in Fig.2.

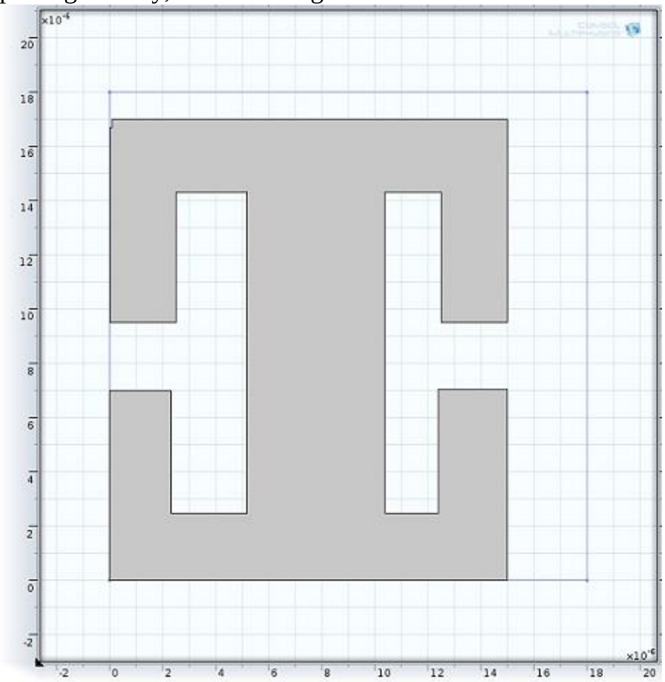


Fig.2 Structure of the metamaterial.

Then by selecting the form union node, we can see our fourth boundary in the graphics window as shown in Fig.3.

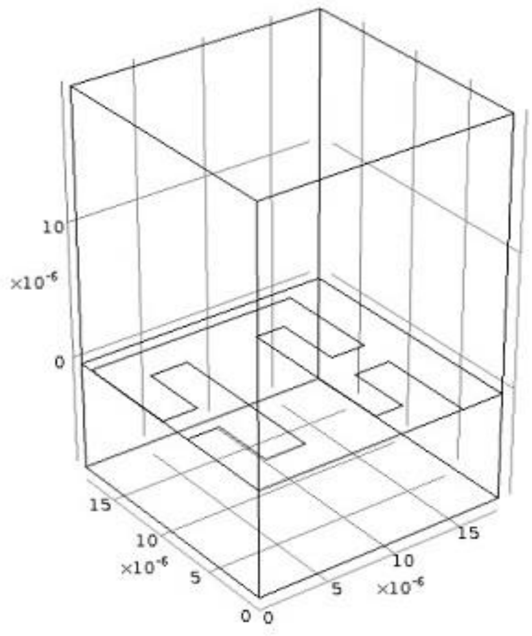


Fig.3 Block containing the fourth boundary condition.

Thicknesses of metamaterial have been chosen as 200nm. Next part is to apply the boundary conditions, i.e. PEC, IBC, TBC etc. and followed by the material properties. The air as the first material on the top of the region is applied and the polyimide as the second material applied to the substrate region with the relative permittivity of 2.88+j0.09, and relative permeability and conductivity as 1. Finally the structure is studied separately with Gold, Silver and Copper material. For that, the region of the metamaterial and the ground plane is considered with the value of electrical conductivity as 4.09 x 10^7 S/m for Gold, 6.30 x 10^7 S/m for Silver and 0.58 x 10^8 S/m for Copper, and the value of permittivity and permeability as 1. The polyimide with permittivity 2.88 – j0.09 is simulated and analysed for the structure with Silver and Copper. The simulated model with the above consideration is shown in Fig 4.

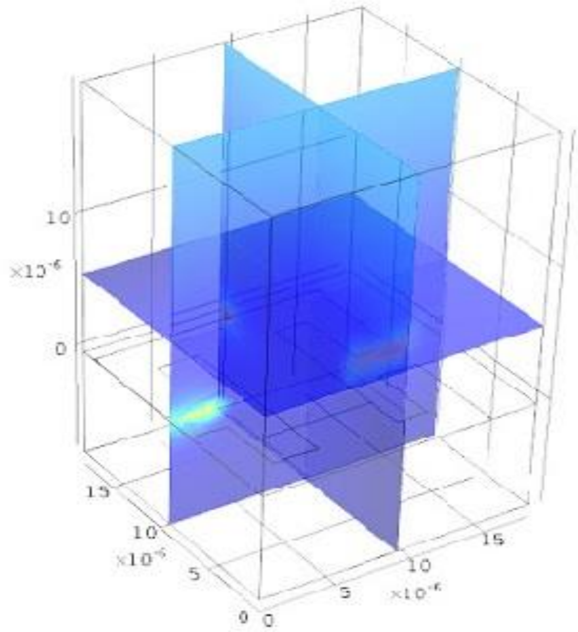


Fig 4. Simulated model

IV. Results and Discussion

For the frequency domain analysis the range of frequencies is selected as 1 THz to 5 THz with a gap of 0.05 THz. After simulation the S_{11} (reflection coefficient in dB) is plotted as shown in Figure 5. For the absorbance, A=1-R-T i.e. A= 1-S^2_{11} - S^2_{21} where S_{21} is zero across the entire frequency range due to the ground plane. Hence, A= 1-$S^2 11$. The absorption in dB is plotted w.r.t frequency as shown in Fig. 5.

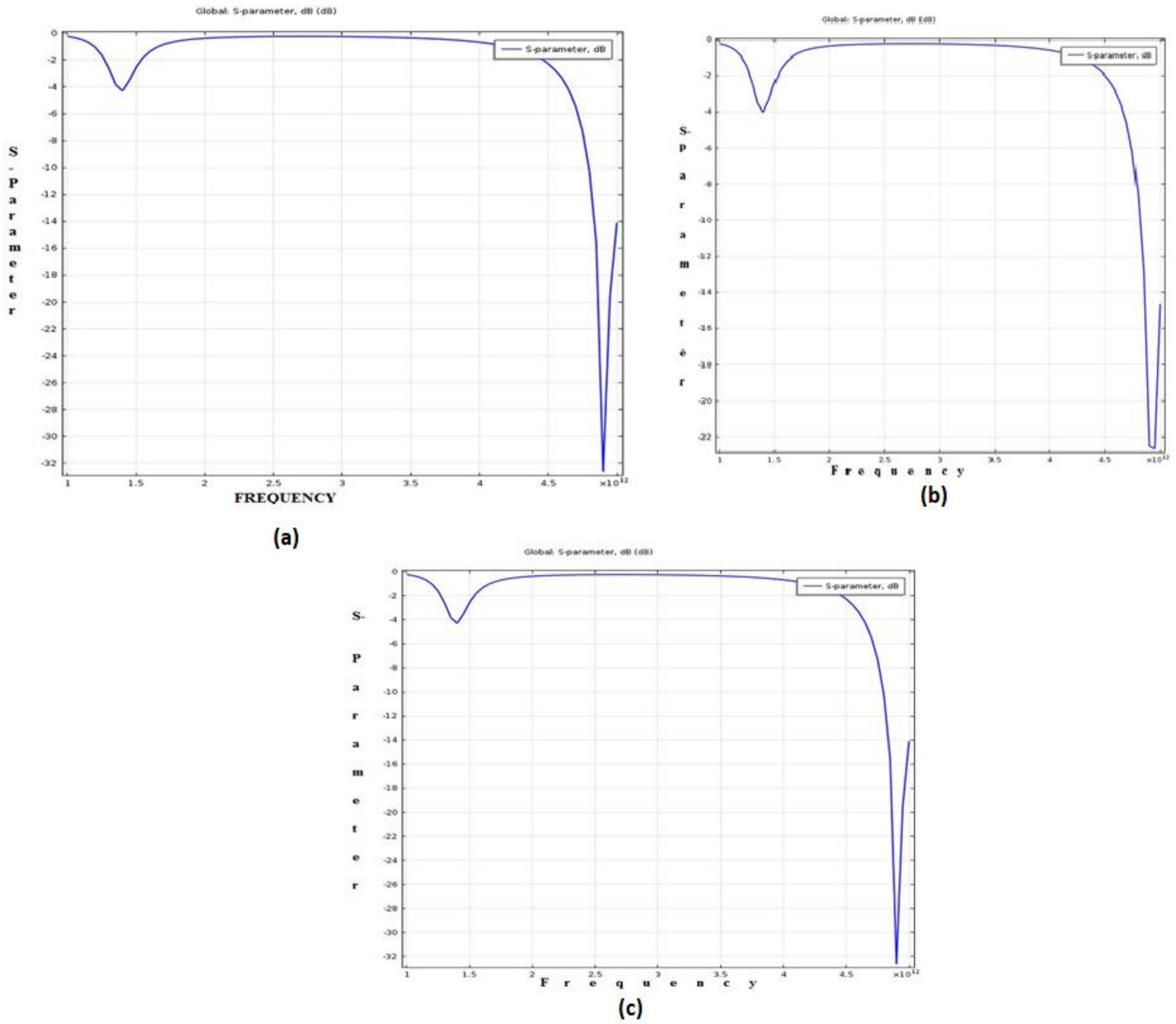
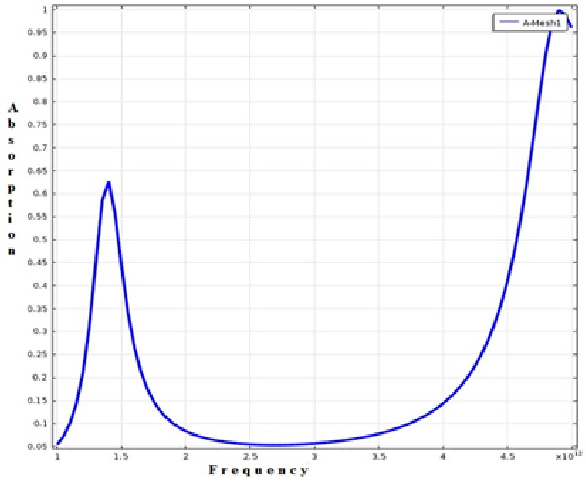
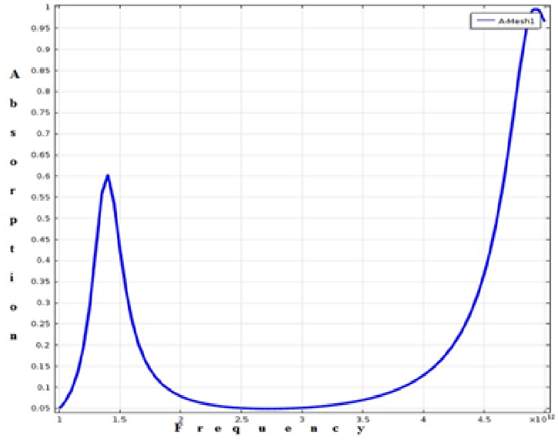


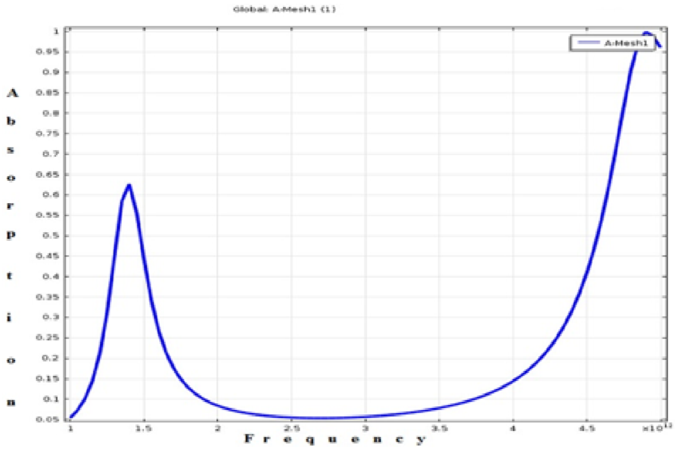
Fig. 5 Reflection coefficient: (a)with Gold, (b) With Silver, (c)with Copper



(a)



(b)



(c)

Fig 6 Absorption plot: (a)with Gold, (b) With Silver, (c)with Copper

The results for reflection coefficient is obtained at -32 dB, -22dB and -32 dB for Gold, Silver and Copper respectively, and the absorbance is unity at around 5THz in all the three cases.

Comparing the above three variations of the model, it is clear that Gold and Copper can give better performance than Silver as it is seen that for both the cases peaks (absorption and reflection coefficient peaks) occurs at 5 THz. But with the use of Gold and Copper the reflection coefficient is better than that of using Silver i.e. at -32 dB.

V. CONCLUSION

The structure is already reported by Landy*et al.* with Cu as the material, taking dimensions as discussed before and their simulations gives an absorptivity of 99% at 11.48GHz.The structure has been modified to operate in THz range, with gold, silver and copper as material.Taking the required parameters, properties of the material, and also applying the boundary condition, we tried to tune the absorption peaks at 5THz.The best result is obtained here is from the gold and copper material, where the absorptivity is 99% at 5THz, with reflection coefficient of -32dB.

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