Optically transparent efficient terahertz patch antenna for space applications

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An optically transparent and efficient microstrip patch antenna were designed in Meshed configuration and radiation characteristics were calculated in the Terahertz region. The proposed antenna consisted of Graphene, a transparent conducting material used as a radiating patch as well as a ground plane separated by the 15- micron thin polyimide material. A patch of dimension (1.36×0.102) mm was created from which a rectangular array pattern of 7×7 was etched away from the patch layer each with a size of (0.084×0.118) mm. Based on see-through effect and material properties, the proposed structures provide sufficient optical transparency of greater than 97%. The proposed design has yielded an efficiency and gain of 75% and 6dB respectively at 0.675 THz. The proposed antenna is also compared with the conventional antennas operating in a terahertz band. The antenna is simulated by using the computer simulation technology (CST) which is based on the finite element method. This antenna is designed with the objective of enabling its use in space applications to provide optical transparency for the solar cell and making compact devices.

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1. Introduction

Infrared region finds importance in many applications and in particular far infrared region. It is also known as terahertz gap, It useful in imaging, materials identification, and security and so forth. Antennas operating at these wavelengths could be utilized as heat blocking structure, in thermal energy harvesting and space wireless communication [1-4]. With reduction in size of the occupation of antennas, solar cell and other space instruments in the same. One way of reducing space occupancy is to design an antenna which provides optical transparency thereby integrating it with a solar cell. Choice of transparent conducting material in a specific design is a challenging task which however could provide a better optical transmission with efficient antenna design. This meshed patch antenna structure helps development of optical transparency through use of graphene in the Terahertz region which can be used in electronic components such as optical antenna [5-7], light emitting diodes [8], solar cells [9]. Graphene is a thin layer of a pure carbon tightly packed layers bonded together in a honeycomb lattice. Recently it has attracted the attention of the research community due to its good optical [10] and electronic properties. Its unique characteristics have promoted its use in, Graphene potential applications in many fields, ranging from ultra-high-speed transistors devices to optically transparent solar cells [11].In [12] Elakkiya et al. have designed meshed structures for infrared energy harvesting applications which provide transparency to visible light for integration into the solar cell which might affect the performance of the device due to the depression of a considerable amount optical transparency. In this project the authors has taken polyimide as the substrate, it has a dielectric constant of 3.25 at 0.675THz was provides excellent transparency to microwave and is unaffected mainly by radiation. Traditional polyimide films provide good transparency which is also related to the thickness of the material [13-14]. This optically transparent material, enables freedom of movement for light inside the meshed structure was it improves the current distribution and gain value [15]. Normally microstrip patch antenna is a low profile antenna which enables its use in the satellite and aircraft applications [16-17]. A decrease in the dielectric constant value of the substrate triggers an increase in the fringes field [18]. So a low dielectric constant value of the substrate is preferred here, with the substrate being polyimide which has a dielectric constant value is 3.25 of 0.675THz frequency which also has good optical transparency.

2. Microstrip patch antenna design

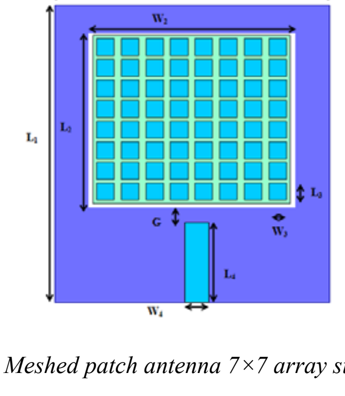

Fig. 1. Meshed patch antenna 7×7 array structure

The proposed antenna has Graphene, a transparent conducting material used both as a radiating patch and a ground plane separated by a 0.015mm polyimide substrate. Patches of square and rectangular shapes are mostly preferred due to the ease in that fabrication and good radiation characteristics [19-20] and in a natural rectangular patch antenna fringes [21] occur only in the edges of the patch. Electromagnetic radiation [22] depends mainly on the fringes. There are variations seen in the fringes field, depending upon the effective dielectric constant, patch dimensions and the thickness of the substrate material [23].

3. Meshed patch antenna design

The proposed meshed patch structure is shown in Fig. 1. The basic patch structure has a dielectric material between the ground plane and a patch structure. This paper proposes a meshed patch structure that is highly compatible with solar cells and these antennas can be directly integrated with the solar cells [24]. These structures are similar to the conventional patch antennas except that the openings in their mesh structure are utilized for the offer of optical transparency [25]. The design parameters of optically transparent meshed patch antenna are shown in Table 1.

Table 1. Design parameters of optically transparent meshed patch antenna

Design	Parameters	Size(mm)
7×7 Meshed Patch Antenna	Patch width, Length ($W_2 \times L_2$)	1.36×0.102
	Substrate thickness(h)	0.015
	Substrate Width and Length($W_1 \times L_1$)	0.336×0.302
	Small Square Width and Length($W_3 \times L_3$)	0.084×0.118
	Distance between the Patch and the Feed	0.136
	Feed Width and Length ($W_4 \times L_4$)	0.036×0.057mm

The openings in the patch allow light to go through while the mesh can still be designed into effective radiators. The gap between the two meshes should be very thin. The width and the length of the above-meshed patch structure are (1.36×0.102) mm. The general equation for calculating the resonant frequency of the rectangular microstrip patch antenna is given by [26] (1).

$$f_r = \frac{c}{2(L+2\Delta L)\sqrt{\varepsilon_{eff}}} \tag{1}$$

where L is the length of the rectangular patch, c is the velocity of light and ε_{eff} is effective dielectric constant, when the excited fields at the edges of the patch undergo fringing. The effective dielectric constant (without meshed structure) is calculated by using the following formula (2).

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left(1 + \frac{12h}{w}\right)^{-0.5} \tag{2}$$

The general formula for calculating the width (W), of the rectangular patch is given by (3).

$$W = \frac{c}{2f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-0.5} \tag{3}$$

where ε_r is the dielectric constant of substrate material (polyimide, $\varepsilon r = 3.25$)

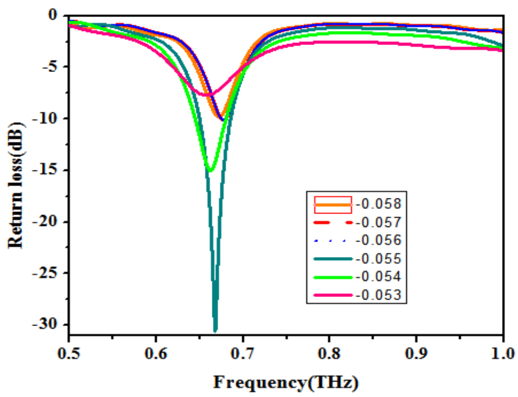

Fig. 2. Frequency versus Return loss(S_{11})

4. Materials properties

The approximate values of transmission (patch and ground plane) in the visible spectrum region is 97.7% for Graphene. Both have high transparency rate and so this antenna allows the maximum light inside the structure. Graphene can be considered as a two-dimensional material and is described by surface conductivity σ_g. For lower THz frequency and at room temperature, the conductivity of the monolayer Graphene can be described as

$$\sigma_g(\omega, E_F, \Gamma, T) = j\frac{e^2 k_B T}{\pi\hbar^2(\omega + i\Gamma)}\left(\frac{E_F}{k_B T} + 2\ln\left(e^{-E_F/k_B T} + 1\right)\right) \tag{4}$$

Here, E_F is the Fermi level, Γ is the scattering rate, ω is the radian frequency, T is the environmental temperature, e is the charge of an electron, k_B is the Boltzmann's constant, and $\hbar = h/2\pi$ is the reduced Planck's constant. In our simulation, we assume a fixed environmental temperature being room temperature with T = 300 K, and the scattering rate Γ = 0.66 meV, thus at given radian frequency ω and Fermi level E_F, the conductivity of the monolayer graphene is calculated using to the above formula indicated in this paper[27].

5. Results and discussions

The proposed design enhances the performance parameters of the antenna such as gain, radiation efficiency, and optical transmission. The antennas are designed to resonate at 0.675 THz by using a commercially available CST simulator. This technique is primarily used for computing the effective dielectric constant, antenna impedance and the surface current distribution of the meshed patch antenna in the THz band.

Fig. 2 shows the antenna return loss in relation to the height of the feed. The author has taken a different analysis, on the basis of a decrease in the feed height from 0.058mm to 0.053mm.A better return loss and radiation characteristics were observed. When the feed height was 0.057mm and the return loss was -10.25dB.The corresponding surface current distribution, gain, and radiation characteristics were seen as maximum only at this feed height.

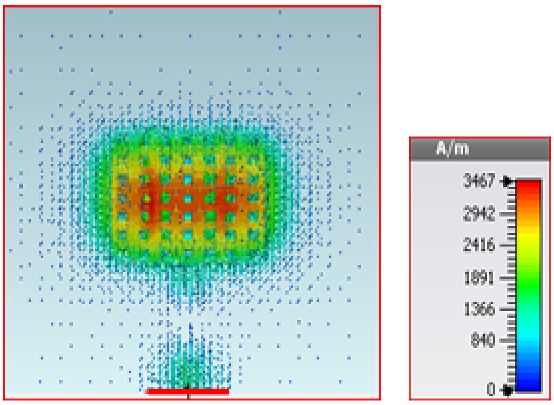

Fig. 3. Surface current flow

The surface current distribution for the meshed patch structure at the frequency of 0.675THz is shown in Fig.3.The current flow was maximum for the feed height kept at 0.057mm. The intensity of the Electric field was maximum at the edges of the patch and decreases during movement towards the patch structure normally. Here the surface current flow was maximum at the inner sides of the meshed structure. Therefore an automatic increase the Optical Transparency variation in the height of the feed line led to adjustments at the antenna parameters. When the height of the feed line was 0.057mm, efficiency was 75% which is high compared to all other feed height analyse.Simulations of the antennas were performed using CST Microwave studio software. Choice of a substrate in the specific design is a challenging task. The selected substrate should provide a the better optical transparency, flexible operation, and should have electrical properties, mechanical properties, chemical resistance, availability, and reduces cost. In this work, Polyimide chosen as a substrate would provide excellent transparency. The frequency versus return loss characteristics is shown in Fig. 2. The proposed meshed patch transparent antenna (7×7) had a peak gain of 6dB at 0.675THz frequency and variations with respect to frequency are plotted in Fig. 4.Thecorresponding surface current distribution at the resonant frequency is shown in Fig.3 was observed. A better current distribution at the desired frequency. The meshed patch antenna had a high directivity of 7.28dB at 0.675 THz frequency.

Table 2. Height vs. radiation efficiency for the proposed meshed structure

Height of the Feed(mm)	Efficiency (%)
0.053	67
0.054	70
0.055	72
0.056	73
0.057	75
0.058	64

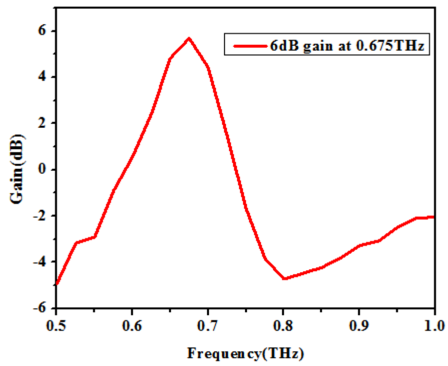

Fig. 4. Frequency versus gain

Table 3. Radiation characteristics of the proposed antenna at different height of the feed

Height of the Feed(mm)	F (THz)	S_{11}(dB)	Gain (dB)	Directivity (dB)	Efficiency (%)
0.053	0.675	-7.6	5.53	7.4	67
0.054	0.675	-15	5.88	7.38	70
0.055	0.675	-30	5.9	7.34	72
0.056	0.675	-10.1	5.97	7.28	73
0.057	0.675	-10.25	6	7.28	75
0.058	0.675	-9.8	5.49	7.46	64

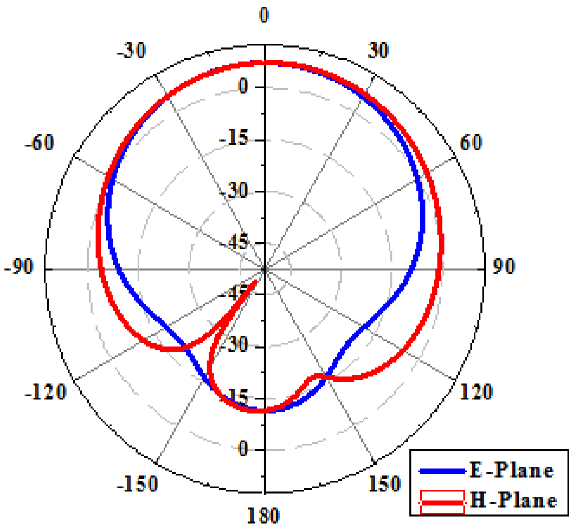

Fig. 5. Radiation pattern a) E-plane b) H-plane

The radiation pattern, for the proposed configuration is shown in Fig. 5. The pattern leads to the observation of unidirectional radiation characteristics in the proposed structure. The meshed patch antenna had a high directivity of 7.28dB at 0.675 THz frequency which is shown in Fig. 5. The radiation characteristics such as radiation efficiency, directivity and, gain of all the antennas are listed and compared. Details are in Table 3. The improved performance of the (7×7) meshed transparent antenna was compared with that of the previous optically transparent antenna and summarized in Table 4. The proposed structure has better radiation efficiency with high gain compared to previously reported works.

Table 4. Comparisons of proposed optically transparent patch antenna with previous work

Design parameters	**Proposed antenna**	**[28]**	**[29]**	**[30]**
Optical Transmission T (%)	97.7	92.3	47.5	70
Effective dielectric constant (ε_{eff})	3.25	2.98	6	6
Resonant frequency(THz)	0.675	2.15	1.4	2.1
Gain(dB)	6	4.97	1.95	0
Radiation Efficiency (%)	75	79	43	68

6. Conclusion

In this paper, an optically transparent microstrip patch antenna at terahertz frequency has been investigated. The substrate of thickness 0.015mm was selected on the basic of the analysis of the optical transmission, antenna design procedure and the effective dielectric constant of the polyimide substrate was kept as 3.25 at 0.675THz. A transmission of ~97% was obtained in the visible wavelength region. The proposed configuration shower a better performance in terms of high gain of 6dB with good return loss characteristics. A modified feeding technique was adopted for the improvement of the radiation efficiency of the antenna and achieved the value of 75% with a higher optical transparency.

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