Design of a Graphene based Miniaturized CPW Fed Antenna for Terahertz Applications

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Abstract. The Terahertz frequency range is of importance for next generation wireless communication applications. In this paper a graphene based CPW feed antenna is designed and simulated for Terahertz applications. The designed antenna comprises of a Graphene patch over a silica substrate. Coplanar Waveguide (CPW) feed is used in this design to reduce the losses. This antenna is designed using High Frequency Structural Simulator (HFSS 11.1) software. Different performance parameters such as return loss, bandwidth, radiation efficiency and radiation patterns are extracted using simulation. The designed antenna resonates at 2.1 THz with a bandwidth of 200 GHz. Further, a modification is done in the radiating patch structure to achieve dual band response with wide bandwidth. The modified antenna resonates at 1.7 THz and 4.1 THz. This antenna produces 500 GHz and 520 GHz bandwidth at 1.7 THz and 4.1 THz respectively. A comparative study is also performed to find the most suitable substrate material for graphene patch antenna. For this study, different substrate materials such as Al_2O_3, BN, Quartz, Si_3N_4 and silicon dioxide are chosen.

Keywords: CPW feed, Gain, Graphene, HFSS, Terahertz

1. Introduction

The Terahertz (THz) frequency range which is also known as sub-millimeter wave contains frequencies from 0.1 THz to 20 THz [1]. Terahertz radiation supports a huge range of application in communication and surveillance field because of its unique properties such as high chemical sensitivity, non-ionizing property, penetration into fabrics and plastics etc. The antennas for THz region must be capable of providing high gain, wide bandwidth and should be low profile and cost effective [2-4]. In the present endeavor, attention has been drawn towards use of 2D materials such as graphene, boron nitride (BN), dichalcogenides (TMDs), silicene and phosphorene as an alternative to metals [5]. Out of these, graphene has appeared as one of the most favorable because of its unique properties such as thin structure, strength, good conductor of heat and electricity than all other materials [6]. The graphene-based antennas present an opportunity to use in the growth of high speed new generation systems for wireless communications [7]. Graphene is a monolayer of carbon atoms and arranged in a honeycomb lattice [8].

The wonderful properties of graphene like toughness, stiffness, wideband optical absorption and multi functionality make it suitable for a wide range of applications in the field of electronics, optics, wireless communication and sensor networks [8]. A graphene based arc truncated square patch antenna for multiband performance was presented in [9]. This antenna produces a bandwidth of around 5 THz. A graphene based antenna resonating in the band 12.2 - 13.8 THz was discussed in and produces an impedance bandwidth of 12.3% [10]. This antenna shows good results in terms of improved bandwidth and gain. Graphene paper based antenna for near field communication was presented in [11]. This antenna promises flexible, stable response and also has advantage in terms of disposal. In [12], a graphene based antenna resonating in the range 2.67-2.92 THz was demonstrated. The performance characteristics show that graphene patch over a Si_3N_4 produce maximum return loss with wide bandwidth response. Graphene based dual band antenna with reconfigurabilty was described in [13]. This antenna was found suitable for imaging and medical applications. Graphene based antenna for IoT sensing applications using water transferrable paper was demonstrated in [14]. It resonates at 2.297–2.510 GHz with 0.7 dBi gain. For applications in millimeter and THz frequency range, doped graphene based antenna was presented in [15]. The rectangular and elliptical shaped antenna resonates at 1.291 THz and 1.488 THz respectively. These antennas produce higher gain, better radiation efficiency and tunable resonance. A comparative study was conducted in [16] to find the best suitable substrate material for graphene patch antenna. It was found that silicon substrate shows maximum return loss value with satisfactory VSWR value. A grounded coplanar waveguide feed array antenna with 32 elements for various wireless communication applications was shown in [17]. An octagon shaped antenna for frequency response in the range of 0.75- 10 THz was discussed and analyzed in [18]. In [19], the combined theory of graphene physics and plasmonics was presented. Graphene based metasurface can be used as polarization converter in spectroscopy as described in [20-22]. In [23], Graphene metamaterial based active plasmonic filters for THz applications was discussed. This band-stop filter consists of single and double layer of graphene. To obtain tunable absorption using graphene material a study was presented in [24], which makes design suitable for filters.

To find application of graphene based antenna in the THz region, a simulation based study was carried out in the present paper.

The antenna structure and design specifications are discussed in Section 2. Simulation results and analysis is

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presented in Section 3. Section 4 contains specifications and radiation characteristics of modified antenna structure. Comparative study of various substrate materials is described in section 5. Conclusion and future scope are given in Section 6.

2. Antenna configuration

The antenna design consists of a rectangular shaped silicon dioxide substrate as shown in Figure 1. A rectangular patch of graphene material is placed over the substrate of 3 µm height. Coplanar waveguide feed is designed to excite the patch [25, 26]. CPW feed is used here as it is easy to fabricate, offers reduced radiation losses, can be easily mounted and there is no requirement of vias or holes, as ground and patch both on same plane [27, 28]. The dimension of radiating patch is calculated using transmission line model [29]. According to this model, the effective dielectric constant is given by

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-0.5} \quad (1)$$

To design antenna resonating at higher TM_{02} mode, the patch length L should be $\lambda_{d,}$ where λ_d is the dielectric wavelength. [30]. The resonant frequency of the dominant TM_{20} mode can be expressed as [30].

$$f_r = \frac{c}{L\sqrt{\epsilon_r}} \quad (2)$$

The effective patch width can be calculated by the following equation [30]

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (3)$$

Where, c is the velocity of light, ϵ_r is permittivity of the substrate.

The dimension of patch is calculated by keeping resonating frequency as 2.1 THz. Further optimization is performed to optimal dimensions of patch and substrate. While calculating various dimensions of antenna as indicated in Figure 1 are summarized in Table 1.

3. Simulation results and discussion

The antenna is designed over a silicon dioxide substrate using HFSS 11.1 software. The Figure 2 shows that antenna resonates at 2.1 THz frequency with a bandwidth of 230 GHz with a return loss of -13.6 dB.

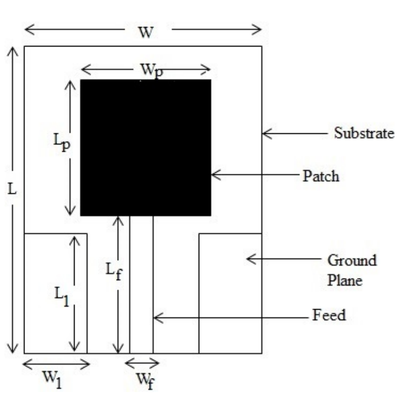

Fig. 1. Antenna structure

Table 1. Antenna dimensions

Parameter	Dimension (µm)
L	105
W	65
L_p	55
W_p	42
L_f	38
W_f	6
L_1	30
W_1	25.5

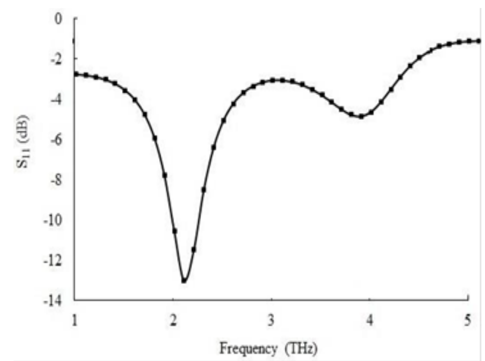

Fig. 2. Simulated return loss versus frequency curve

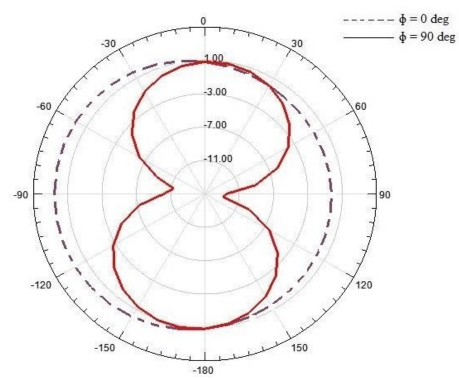

Fig. 3. Simulated radiation pattern at 2.1 THz

The radiation pattern plot in Figure 3, displays that it is directional in one plane and almost uniform in perpendicular plane, which is desirable for wireless devices. The simulated radiation efficiency of this designed antenna is 90%.

4. Modified antenna structure

To make the designed antenna resonate at multiple frequencies a slot is created on the radiating patch as presented in Figure 4. By creating slots, the RF signal has two paths to travel which leads to new resonance higher or lower in frequency. Also with the help of slots proper impedance matching and wide bandwidth can be achieved. Here, a slot of dimensions L_s = 10 µm and W_s = 20 µm is created on the graphene patch. Rests of the dimensions are kept constant as indicated in Table 1.

The modified antenna gives dual band response. It resonates at 1.7 THz and 4.1 THz frequencies with return loss of -16.9 dB and -12.7 dB respectively. It produces bandwidth of 500 GHz and 520 GHz at 1.7 THz and 4.1 THz frequencies as illustrated in Figure 5. In comparison to

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the original design, this modified antenna resonates at dual bands. In terms of bandwidth also modified antenna gives better result than the original antenna shown in Figure 2.

5. Comparative study of different substrate materials

From the literature survey, it was found that various substrate materials can be used for graphene based patch antenna. The choice of appropriate dielectric substrate material is critical for graphene antenna as the substrate dielectric constant and thickness significantly affect the impedance matching and hence the resonant frequency of the antenna.

From the literature it is found that still there are many dielectric materials such as Si_3N_4, Al_2O_3, BN, SiO_2 and quartz available which can improve the radiation properties of grapheme based antenna.

Figure 6 shows that for different substrate materials the designed antenna gives dual band response. It can be seen that two significant band are achieved by using silicon dioxide as substrate material.

The performance comparison of various substrate materials in terms of resonating frequency, return loss and obtained bandwidth is summarized in Table 2. It can be seen that by using silica as substrate two significant bands can be obtained with higher bandwidth than other materials. Silica substrate based antenna produces dual band response at 1.7 THz and 4.1 THz with 500 GHz and 520 GHz bandwidth respectively. The radiation properties make this antenna appropriate for use in wireless communication such as WLAN and WPAN for next generation. According to Table 3, in terms of simulated radiation efficiency also silicon dioxide based antenna gives better results than other substrate materials.

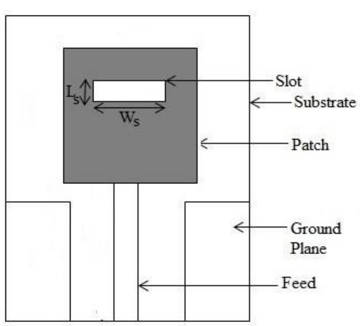

Fig. 4. Modified antenna structure

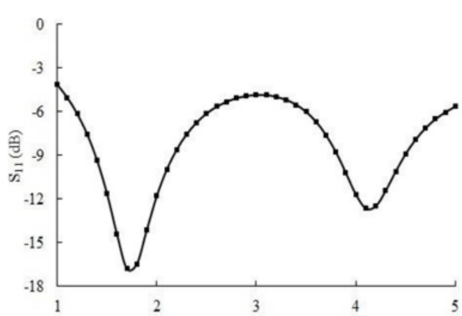

Fig. 5. Simulated return loss versus frequency curve for modified design

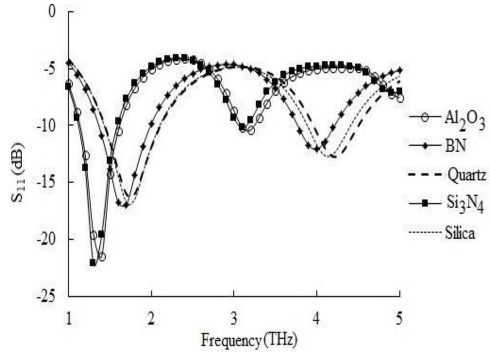

Fig. 6. Return loss curves for different substrate materials

Table 2. Performance comparison of graphene patch CPW fed antenna for different substrate materials

Substrate Material	Dielectric Constant εr	Resonating Frequencies (THz)	Return Loss (dB)	BW (GHz)
Al_2O_3	9.1	1.4	-21.5	400
		3.1	-10.2	150
BN	4.6	1.6	-16.8	500
		4	-12	41
Quartz	3.78	1.7	-16	610
		4.2	-12.8	520
Si_3N_4	9.5	1.3	-22.1	305
		3.1	-10.2	50
SiO_2	4.0	1.7	-16.9	500
		4.1	-12.7	520

Table 3: Performance comparison of graphene patch CPW fed antenna for different substrate materials in terms of radiation efficiency

Substrate Material	Resonating Frequency (THz)	Radiation efficiency
Al_2O_3	1.4	96 %
BN	1.6	96 %
Quartz	1.7	95.4 %
Si_3N_4	1.3	95 %
SiO_2	1.7	97 %

The radiation patters for different substrate materials is simulated and presented in Figure 7. It can be seen that radiation patterns are almost uniform in one plane and directional in orthogonal plane. While comparing the performance of graphene based patch over copper in terms of radiation pattern it was found that the graphene based antenna shows stable radiation pattern with higher efficiency than copper.

6. Conclusion

In this paper, a graphene based rectangular patch antenna over a silica substrate has been designed and analyzed. The antenna is compact in size and resonates at 2.1 THz with a 230 GHz bandwidth. Further, a modification is done so that antenna gives dual band response. The modified antenna resonates at 1.7 THz and 4.1 THz with 500 GHz and 520 GHz bandwidth respectively.

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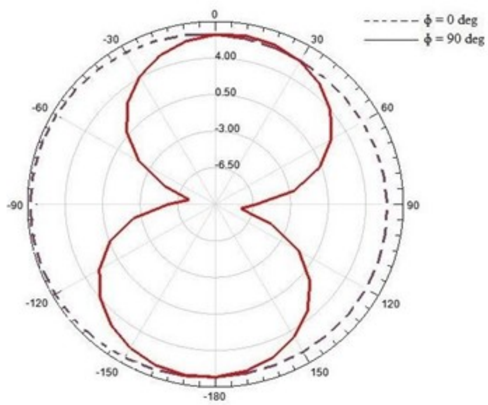
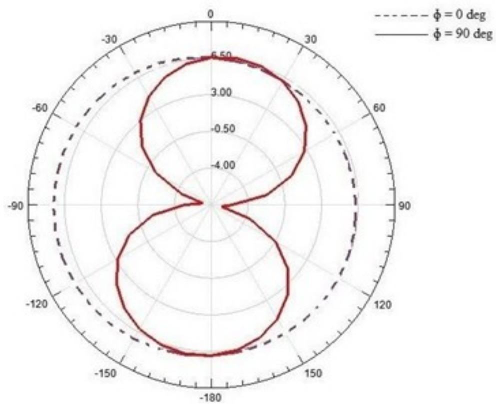
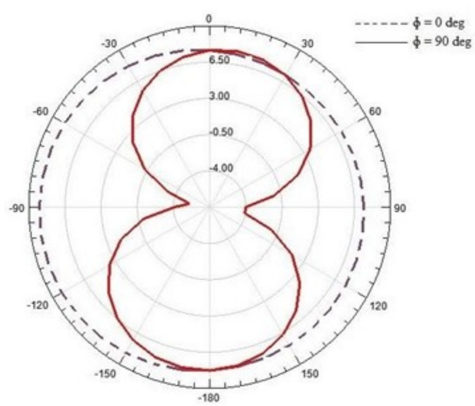


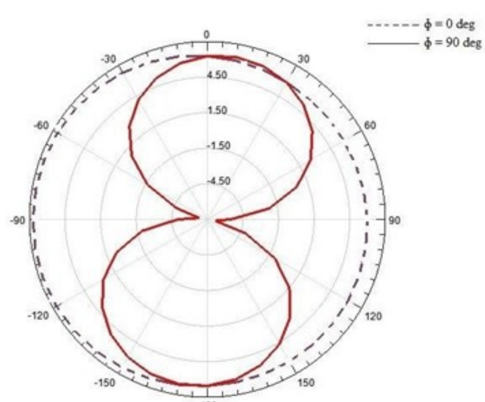
(a)



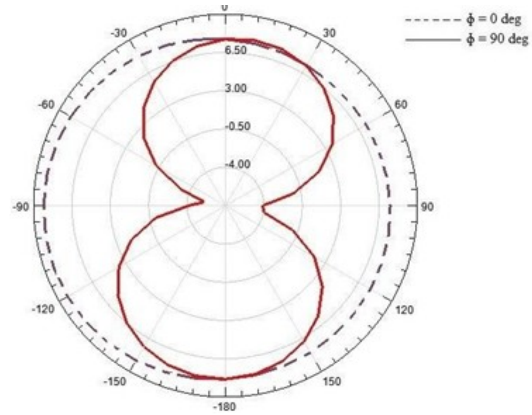
(b)



(c)



(d)



(e)

Fig. 7. Radiation pattern (a) Al_2O_3 at 1.4 THz, (b) BN at 1.6 THz (c) Quartz at 1.7 THz (d) Si_3N_4 at 1.3 THz (e) Silica at 1.7 THz

The radiation characteristics and compact structure makes this antenna suitable for applications in wireless communication with high data rates and in highly secure military applications. A comparative study is also performed to find the best suitable substrate material for graphene based antenna. It was found that silicon dioxide is the most appropriate material as it gives better performance in terms of bandwidth and radiation efficiency than other materials. Future scope includes fabrication and testing of the antenna.

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