

'GPA'- A Comparative Study of Novel Graphene Patch Antenna with Conventional Copper Patches and different Substrates for Performance Improvement at Dual Band Terahertz Regime

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Abstract:

The novel Graphene Microstrip Patch Antenna 'GPA' at Dual Band Terahertz frequency operation requires productive nanomaterials to work inside the mm wave and terahertz bands. In this research module, graphene material is utilized as patch for conductivity improvement in two basic types of metallic antenna ie 'rectangular' and 'circular' shaped microstrip patch antenna. Also, it was studied that Graphene is best alternative in comparison with traditional conventional metallic patches made of 'Copper' and other metals. The surface conductivity of graphene material is first demonstrated preceding the outline. Next, various graphene models and their relating surface conductivities are registered in light of various pre disposition compound doping. The graphene based receiving wires demonstrated significant upgrades for most parameters of radio wire than that of the traditional reception apparatus. Other than that, the higher synthetic possibilities coming about because of higher biasing voltages additionally brought about this pattern. At last, the curved fix graphene reception apparatus showed best radiation efficiency than traditional patches.

Keywords: HFSS, CST, GPA, GNR, CNT.

1. Introduction

Improvement of THz radio antennas is generally late [1]. Other than considering their proficiency upgrades from the point of view of electromagnetism, understanding their physical and materials science viewpoints is additionally urgent [2]. The swarming expanding of remote interchanges range and requests for transmission capacities have brought about the abuse of MM and TeraHertz (THz) groups possibly for applications in spectroscopy, detecting and identification imaging, [3]. Since most materials retain THz radiation, THz signals distinguished utilizing a reception apparatus might be utilized as a part of sub-atomic spectroscopy or fingerprint identification in detecting explosives, medications, substance and organic weapons. The constrained range because of highway misfortune and low recipient affectability requires the accessible episode influence at an indicator to be boosted utilizing an effective receiving antenna.

A few past examinations have explored THz patch substrates of antenna, many had worked on its several

parts and prototypes [4], for example, gold and platinum. THz reception apparatuses must be proficient to guarantee high pick up, other than being wideband, scaled down in size and financially savvy. Photoconductive receivers are recommended for such applications. Notwithstanding, the regularly poor impedance coordinating between these reception apparatuses and their photo mixers frequently prompts the debasement of receiving antenna effectiveness.

Another option to beat this downside is to use microstrip fix radio antennas [5]. Their normal use as leading materials in the mm-wave and THz recurrence groups is because of their high conductivity and anti-oxidization conduct in air [6]. Be that as it may, metals are regularly lower in conductivity in the THz frequencies than in DC or microwaves.

Despite what might be expected, metallic thin film might be inclined to smaller scale breaks [7]. Nanomaterials, for example, graphene and Carbon Nanotubes (CNTs) are reasonable choices to beat metallic misfortunes in these applications. For instance, the resistivity of a solitary divider (SW) CNT is lower than that of a strand gold with a similar width, making it a noteworthy rousing element in using CNTs for creating nanoantennas [9, 10]. These prompts expanded entrance of field in metals, high surface protection and thusly, debasement of the radiation efficiency in metallic THz reception apparatuses [7, 8]. In any case, its high (20 k ω to 10 M ω) impedance confounds coordinating between CNT RF gadgets and other regular 50 Ω RF gadgets, for example, metal multilayers on dielectrics or metal semiconductor hetero structures. Despite the fact that 50 Ω impedance can be accomplished utilizing packaged CNTs, controlling this procedure is fairly intricate. It is additionally a promising material for creating the remote correspondence frameworks of cutting edge [12], which require high portability, low power and broadband activity [13]. Unexpectedly, graphene, other than its incredible conductivity, likewise includes controllable and tuneable 50 Ω impedance [14]. Graphene nanoribbon (GNR) can be conceivably connected in remote nano-sensors and gadgets working in the THz band [15, 16]. At the point when coordinated with flexible dielectric substrates, GNR can likewise defeat the inclination of miniaturized scale breaks in metallic thin films for conformal receiving wires. For instance, a

conformal microstrip fix comprising of two parallel electric conduits isolated by a dielectric material was proposed in [17], created by thin film affidavit and nanolithography methods [18]. Other than tackling the confuse issues in the THz administration [4], this essential topology is additionally generally utilized because of its scaling down capacity and conformality [10]. In the interim, an investigation at first glance conductivity of the graphene sheet and the outline of a GNR-based fix was talked about in [19]. A graphene-based rectangular microstrip fix THz receiving wire utilizing a Silicon Dioxide (SiO₂) substrate was displayed in [14]. The proposed radio wire reverberated at 0.75 THz and highlighted 5.09 dB and 86.58% pick up and radiation effectiveness, individually. A straightforward graphene reception apparatus was additionally contemplated inside 5.66 to 6.43 THz band. Its radiation proficiency and pick up were observed to be 37.17% and 3.27 dB, individually, at 6 THz reverberation [20]. Other than that, quartz substrate was utilized to outline a tunable triangular graphene-based receiving wire for task at 2.60 THz. The subsequent pick up and radiation efficiency, approved numerically, were 5.97 dB and 82.7% when one-sided with a 0.5 eV concoction potential [21]. From the writing survey, it is approved that graphene displays fantastic properties as far as info impedance coordinating, recurrence configurability, and stable radiation examples and impedance after tuning [22].

In this paper, an examination of the changes in the level of surface conductivity and impedance by means of concoction doping or potential biasing is performed. Two diverse graphene-based radio wires are examined as far as radiation effectiveness, pick up, directivity and reflection coefficient. To accomplish this goal, the graphene layer's surface impedance is first displayed numerically in view of various doping (biasing). These surface properties are then connected on the two graphene-based reception apparatuses: a rectangular and a curved fix radio wire that encouraged utilizing microstrip transmission lines. It has been watched that the advancement of the circular fix created a greatest radiation proficiency and pick up of 96% and 7.21 dB, individually, by means of a 0.5 eV compound potential. They, by a wide margin, are the best qualities detailed in open writing examined numerically. The association of the paper is as per the following. Segment 2 depicts the demonstrating of the recurrence subordinate properties of the graphene-based surface conductivity. Next, the parameters are actualized on the proposed reception apparatuses in the accompanying segment. Other than the surface properties, in this segment the impacts of the geometrical parameters on the reception apparatus execution in the outline and numerical reenactment are likewise examined. The outcomes are exhibited and talked about in Section 4 before some finishing up comments.

2. Designing Of 'Graphene Patch Antenna'- 'GPA'

The graphene monolayer is a two-dimensional material composed of carbon atoms bonded in hexagonal structures. It can be represented by an infinite sheet with

surface conductivity, which can be modelled via Kubo formula [23].

$$\sigma(\omega) = \sigma_{intra}(\omega) + \sigma_{inter}(\omega) \quad (1)$$

where j is the imaginary unit, q_e the electron charge, k the reduced Plank constant, K_B the Boltzmann's constant, T the temperature, μ_c the chemical potential, and ω the operating angular frequency. Scattering rate $\Gamma = 1/2\tau$ represents its loss mechanism and τ the relaxation time. The value of τ in previous literature ranges between 10–11 and 10–14 [5]. In this work, the utilized τ is 3 10–12 [23, 24]. The two terms of the surface conductivity are calculated using Eqs. (2) and (3). The first term (intraband term) dominates the value of total conductivity in the range of frequency below 5 THz, whereas the second term (interband term) has no significant effect on the total surface conductivity within this band (see Figure 1(a)). Figure 1(b) shows the effect of changing graphene chemical potential μ_c on the surface conductivity. It depends on the carrier density, which can be controlled by gatevoltage, electric bias field, or chemical doping. Increasing μ_c leads to the increase in graphene surface conductivity, which shifts antenna resonances to higher frequencies. The shifting of antenna resonance, due to changing μ_c enhances flexibility for the design of tuneable antennas, especially within the THz band.

The ariationof μ_c enables the resonant frequency tunability feature. Meanwhile, thevalue of the chemical potential μ_c is electrically controlled by varying the bias voltage (gate voltage, V_g) on the graphene layer. The relation between chemical potential and the bias voltage is explained by the following formula.

The model of single layer graphene material can be made by 2-Dimensional surface conductivity. We derive surface conductivity as in equation 5

$$\sigma(\omega, \mu_c, \tau, T) = -j \frac{q_e^2 K_b T}{\pi h^2 (\omega - 2jT)} \times \left\{ \frac{\mu_c}{K_b T} + 2 \ln(e^{\frac{-\mu_c}{K_b T}} + 1) \right\} \quad (2)$$

where ' ω ' is angular frequency ' μ_c ' is chemical potential ' T ' is scattering rate also called transportrelaxation time. ' K_b ' is Boltzmann constant and ' h ' is plank constant in reduced state. The intraband relation gives higher accuracy for low Thz frequencies. When considered $\mu_c=0$ ev at room temperature of approx 300K we get following simplified equation.

$$\sigma(intra) = j \frac{q_e^2 K_b T}{\pi h^2 (\omega)} [2 \ln(2)] \quad (3)$$

$$\sigma_{inter}(\omega) = \frac{e^2}{4h} \left[H\left\{\frac{\omega}{2}\right\} + i \frac{4\omega}{\pi} \int_0^\infty \frac{H(\varepsilon) - H\left(\frac{\omega}{2}\right)}{\omega^2 - 4\varepsilon^2} d\varepsilon \right] \quad (4)$$

where ' e ' is electron charge ' μ_c ' is chemical potential ' T ' is scattering rate also called transport

relaxation time. 'K_b' is Boltzmann constant and 'h' is plank constant in reduced state.

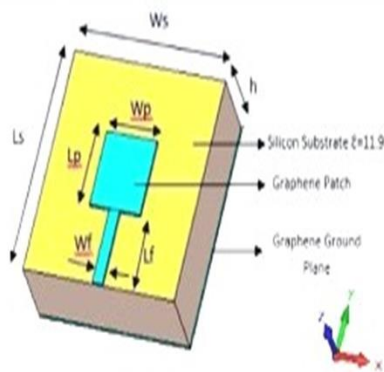


Fig. 1. Rectangular Patch Antenna Design with Microstrip Line Feeding

The above figure demonstrates the design overview of novel “Graphene Microstrip Patch”- GPA. It has rectangular patch made with graphene material having ‘L’ and ‘W’ as length and width of the patch, L_f and W_f as length and width of microstrip line feeding. L_s and W_s as length and width of substrate.

TABLE 1. DESIGN PARAMETERS DIMENSIONS OF NOVEL ‘GPA’

Parameters Resonant Frequency Patch width	Symbol fr W	Value 1.291 THz 80 μm
Patch Length Substrate length and width	L	$W \times \frac{3}{4}$ $2 * L \times 2 *$
Substrate thickness	h	W/20
Substrate dielectric constant	εr	3.5
Length of the microstrip feed line	Lf	$(L/2 + L_g)$
Width of the microstrip feed line	Wf	W/10
Length of the inset gap of the microstrip feed line	Lg	L/10
Width of the inset gap of the microstrip feed line	Wg	Wf/10

Here ‘SiO₂’ is used as substrate material. ‘h’ is the height, also called thickness of substrate used. Graphene material is also used as infinite ground plane of antenna. Table 1 demonstrates the design parameters of ‘Novel GMPA’ of graphene as its patch and having rectangular architecture of length $L = 10.71 \mu\text{m}$ and width $W = 14.87 \mu\text{m}$ along with micro-stripline feeding. Substrate used is silicon dioxide (SiO₂) having dielectric constant ‘ $\epsilon_r = 3.9$ ’ and having thickness ‘ $h = 1.8 \mu\text{m}$ ’. Feeding is given by simple microstrip line of dimension $L_f = 8.595 \mu\text{m}$ and $W_f = 2.664 \mu\text{m}$ as its length and width.

The substrate is made of silicon dioxide material having length $L_s = 27.9 \mu\text{m}$, Width $W_s = 66.67 \mu\text{m}$ and height $h = 1.8 \mu\text{m}$

3. Geometrical Parameters Novel of ‘Graphene Patch Antenna’- ‘GPA’

The graphene-based microstrip patches antenna depicted in Figure 3 consists of a conducting patch and a feeding line on top of a thin layer of dielectric substrate ($2.2 \leq \epsilon_r \leq 12$) [17]. The ground plane is placed on the bottom of this layer. The conducting patch generally can be designed using different shapes [26]. Two typical microstrip patch antenna topologies are chosen for their simplicity and ease of fabrication: a rectangular-shaped and an elliptical-shaped patch antenna, and both models are used to validate the calculated surface properties in the previous section. The thickness of the thin polyimide substrate, which separates the radiating patch from the ground plane must comply with its traditional limitation of $h \leq \lambda$ and $0.003\lambda \leq h \leq 0.05\lambda$. It is to prohibit the generation of surface waves in the classical metallic patch antennas [17]. To study the geometrical effect on the behavior of both (rectangular and elliptical) antennas, the width and length of rectangular patch are made equal to the major and minor axes of the elliptical patch, respectively, in a way that both patches are designed with symmetrical dimensions (width and length of the patch, substrate, strip feedline and inset feed gap), which are kept constant for both patches so that satisfactory reflection coefficient will be produced. The differences in shape imply that different surface areas will be produced for different patch antenna types.

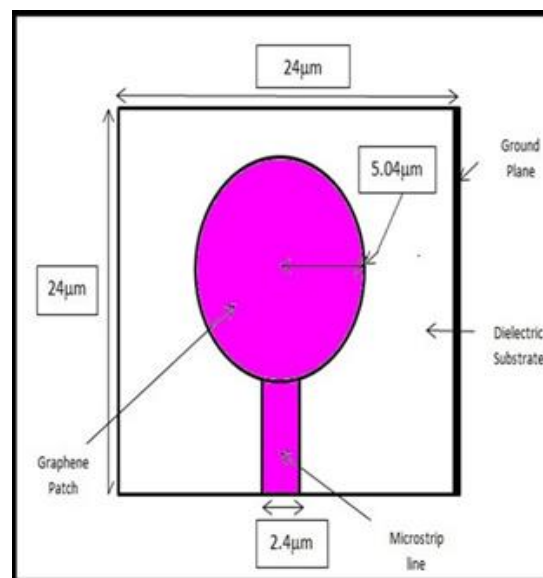


Fig. 2. Graphene Circular Patch Antenna Design with Microstrip line Feeding

To design a rectangular patch antenna, the resonant frequency is selected as $f_r = 1.290 \text{ THz}$, and the thickness of the polyimide substrate is $h = 4 \mu\text{m}$. The other dimensions of the rectangular patch are computed and approximated as listed in Table 1. The rectangular and elliptical patch antennas are simulated over the 0.3 THz to 3 THz frequency band using pure copper as conducting layers and polyimide as its substrate. To simplify the analysis, the dispersion of polyimide substrate is not considered in simulations. It is also the default setting for this particular material in the simulator’s library.



Fig. 3. Cross Section of Both Antennas

4. Results and Discussions

The pure copper-based patch antenna (Patch1) resonance frequency (f_r) is 1.291 THz, which is then decreased to 1.278 THz when the pure copper conducting layers are replaced using tt0. Resonance is increased to 1.296 THz and 1.299 THz when the conducting materials are replaced by tt1 and tt2, respectively. This means that the resonance can be tuned by increasing or decreasing the chemical potential. The simulation results for the graphene-based antenna.

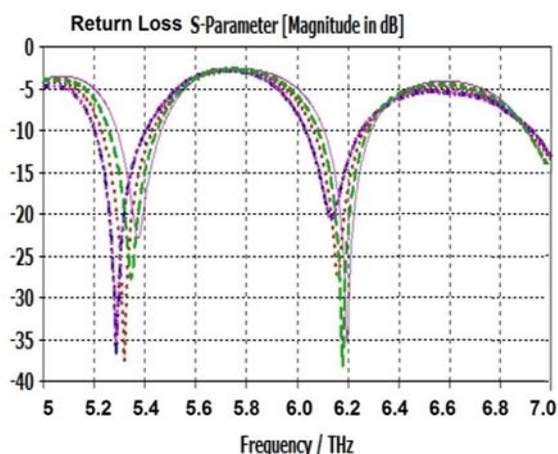


Fig. 4. S_{11} Graph showing Return loss of Circular Patch Antenna, Different Color Showing Diff Substrates Green (SiO_2), Blue (BN), Orange (Si_3N_4), Pink Dotted (Polyimide), Pink Dark (Quartz)

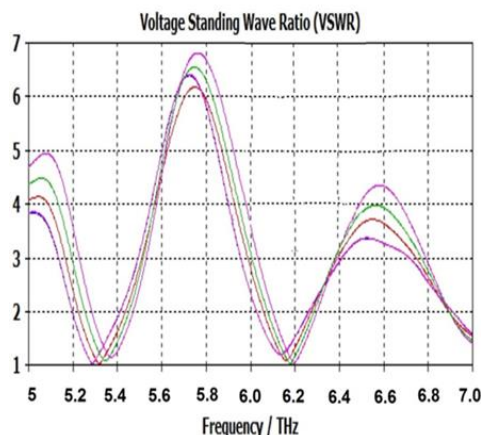


Fig. 5. VSWR Curves of Circular Patch Antenna, Different Color Showing Diff Substrates Green (SiO_2), Blue (BN), Orange (Si_3N_4), Pink Dotted (Polyimide), Pink Dark (Quartz)

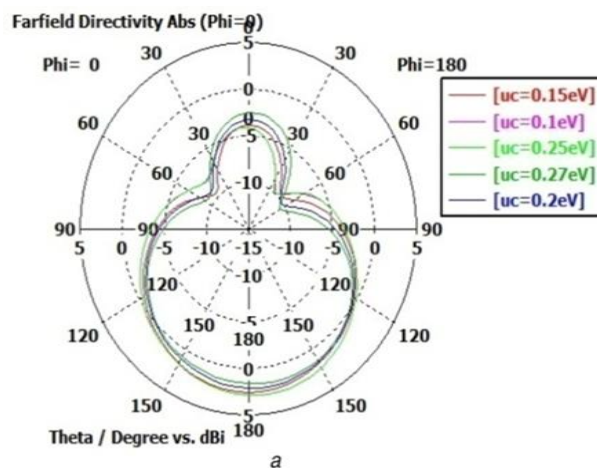


Fig. 6. Shows Directivity at Different Chemical Potential

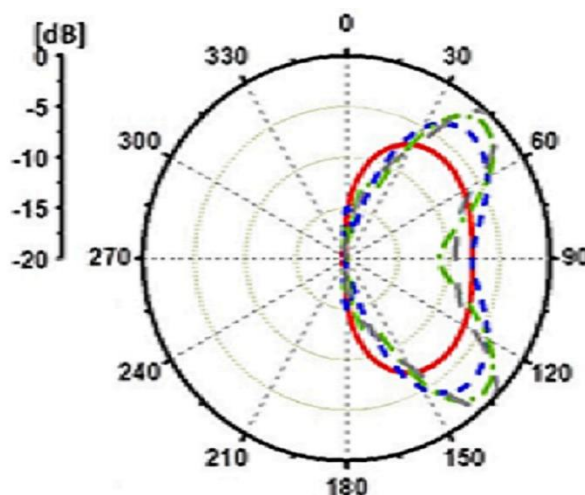
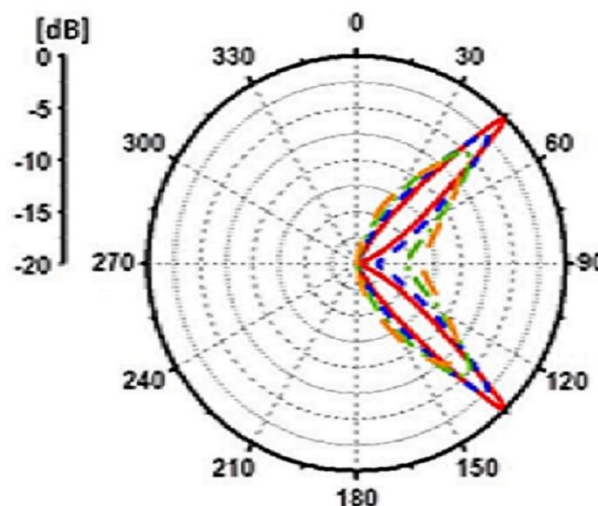


Fig. 7 (a)



7 (b)

Fig. 7 (a) and (b). Shows Radiation Pattern

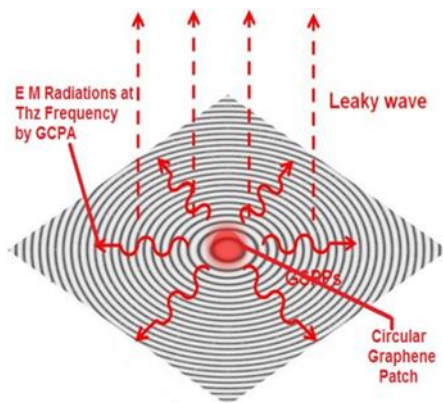


Fig. 8. Shows Directive Radiation and Leaky

5. Conclusions

The modeling and characterization of graphene-based antennas operating in the millimeter-wave and Terahertz bands have been presented. The modeling starts by numerically determining the surface impedance for a thin graphene layer using the Kubo formula. Next, these values are validated against two graphene-based microstrip antennas with different radiator topologies. The performance of the two antennas is determined by modeling and benchmarking them against their corresponding topology made using copper conductors in a commercial electromagnetic solver, CST Microwave Studio. The effect of different chemical potentials on the performance of both antennas is then studied by determining their surface properties (conductivities and impedances) prior to implementation and evaluation on these antennas. It is observed that the performance of the antenna with doped graphene as conducting elements indicates good improvements in terms of reflection coefficient, radiation efficiency, directivity and gain. For rectangular and elliptical antennas designed to resonate at two different frequencies (1.291 THz and 1.488 THz), the latter consistently indicates better performance than the former. The gain and radiation efficiency improvements for the graphene-based elliptical patches when biased using small levels of voltages (V_1 and V_2) are also relatively higher than the prototype with copper conducting elements. Besides higher gain and radiation efficiency, it is also demonstrated that biasing enables the graphene-based antennas' resonance tuneability. Thus, we have seen that performance of novel 'GPA' is more in comparison to conventional patch antenna which is metallic.

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