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A Comparative Analysis of Graphene Based Terahertz Reconfigurable Antennas: A Review

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Abstract

In this paper, an overview of various reconfigurable antenna designs based on graphene material utilized for terahertz applications is presented. Terahertz electromagnetic spectrum is the term used to describe the frequency range between 0.1 and 10 THz. A promising material for THz reconfigurable antennas, graphene has a low skin effect and a built-in ability to tune by chemical or electrostatic gating. This study reviews the development of reconfigurable antenna for terahertz applications using graphene. Due to the conductive nature of graphene, antenna properties including frequency, polarization, and radiation efficiency can be changed. In order to study the attributes of antennas for use in the terahertz domain, numerous structures are evaluated and analyzed in this research. A comparison analysis of reconfigurable antenna in the terahertz region is done in the paper after a brief introduction and literature review.

Keywords: Antenna designs, graphene, terahertz region, complementary split ring resonator, electrostatic gating

INTRODUCTION

Researchers in the field of reconfigurable antenna have become more cognizant of current advancements in wireless communication technology [1]. The field of multifunctional devices has seen rapid advancements. [2]. In addition to improving system performance overall, reconfigurability can lower system costs and size by changing factors including polarization, radiation pattern, and resonant frequency [3]. When the environment changes, a reconfigurable antenna has the flexibility to adapt dynamically for optimal gain and improved performance. Research opportunities in the domains of satellite communications, biomedicine, multiple input and multiple output (MIMO) systems, and numerous other areas are made possible by an antenna's ability to self-adjust in response to external factors. Modern THz applications currently necessitate for dynamically tuning the antenna's far-field features [4]. There are many different approaches to reconfigurability, but one popular approach, the PIN diode, to achieve reconfigurability in the THz range faces many challenges and difficulties because at the high frequency it runs into many technological limitations, such as metals exhibiting dispersive behavior, rectifying diodes having low efficiency, and diodes and antenna having mismatch, so to overcome all these drawbacks an appropriate replacement should be found [5, 6]. Due to its superior mechanical and electrical capabilities as compared to metal, graphene has recently grabbed the interest of many researchers. As a result, many terahertz devices have been presented in the literature [7].

In the terahertz band, graphene and metal are combined to create reconfigurable antennas, with the metal serving as the primary radiator and the

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addition of graphene needed to provide customizable structure [8]. Graphene can be utilized in the design of an antenna as a switch, a ground plane, or a radiator. The conductivity of graphene can be adjusted and is influenced by chemical potential and frequency.

Therefore, using graphene as a switch allows for the operation of antennae in various on/off states [9]. However, the high levels of ohmic losses that graphene exhibits cause efficiency to degrade. Graphene and metal were combined to tackle this issue. The dynamic surface conductivity of the antenna is caused by the combination of metal and graphene. The chemical potential of graphene can be modified to vary antenna parameters such as resonance frequency, polarization, and radiation efficiency [6]. The interactions between all three traits are very difficult to realize.

The current state of the art for reconfigurable THz antennas based on graphene, a burgeoning field of study that has received a lot of attention recently.

Reconfigurable THz antennas have been successfully demonstrated in several studies employing graphene. For instance, by utilizing the electrostatic field effect in 2018, researchers from the University of California, Los Angeles (UCLA) produced a graphene-based THz antenna with a programmable resonance frequency. They demonstrated that the resonance frequency of the antenna could be varied over a wide frequency range by adjusting the gate voltage applied to the GFET.

In another study published in 2019, researchers from the University of Texas at Austin demonstrated a graphene-based reconfigurable antenna that could switch between two distinct resonant modes. They achieved this by using a dual-GFET configuration, where each GFET was used to control a different resonant mode of the antenna.

The development of reconfigurable THz antennas utilizing graphene still faces a number of obstacles despite the encouraging results. These include the incorporation of graphene with additional components and materials, improvement of the GFET design, and creation of trustworthy fabrication methods. The creation of high-performance THz communication and sensing systems has immense potential, but the state of the art in reconfigurable THz antennas employing graphene is still in its infancy.

LITERATURE SURVEY

A rectangular microstrip patch antenna with a slotted ground plane was presented by 1. Anuradha A et al. [1]. The frequency reconfigurable antenna in this study is realized using graphene rather than PIN diodes, which the author has chosen to employ. A gain of 2 dB was attained by altering the graphene antenna's characteristics, which allowed it to operate in a variety of modes with frequency changes from 2.8 to 4.8 THz as shown in Figure 1.

R. K. Kushwaha [2] proposed a graphene-based 2x1 patch array antenna design for the THz band, it was observed that antennas slotted using a complementary split ring resonator (CSRR) which used substrate known as PBG with a dielectric grating performed better than those using homogeneous substrate and PBG substrate (S11=-57.052 dB, Gain=14.69 dB, and directivity=15.5 dB. The antenna with CSSSRR functioned as a resonance patch for the 0.84 to 0.94 THz frequency band. Applications like THz wireless communication and medical imaging are suited for the suggested antenna as shown in Figure 2.

[10] In this paper superstrate configuration loaded with graphene metasurface is discussed which provides more efficient and high-performance antenna. By this design improved radiation properties are achieved by using superstrate layer. Sio2 substrate is required on which metasurface is designed by organizing unit square shape unit cells with a certain periodicity. The low THz range covered by the proposed antenna is 1.44 to 2.84 THz. The suggested antenna offers a 1.4 THz bandwidth and a 35.54 dB return loss at 2.02 THz. With a gain having value of 8.8 dB and radiation efficiency with a

value of 70.14% are attained at 2.747 THz. Additionally, it demonstrates the tighter beam scanning range. Applications for this antenna include satellite communication, video imaging, and biomedical fields as shown in Figure 3.

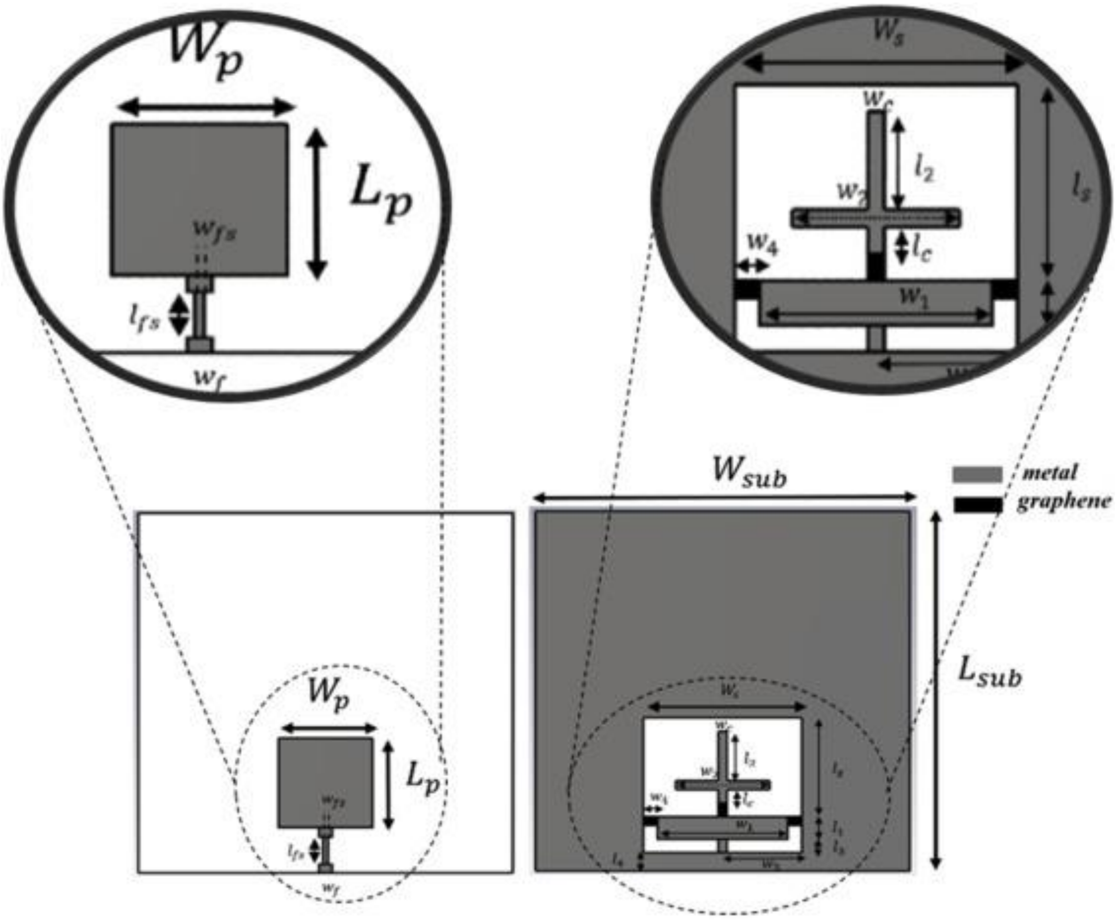

Figure 1. Antenna configuration (a) top view and (b) bottom view [1].

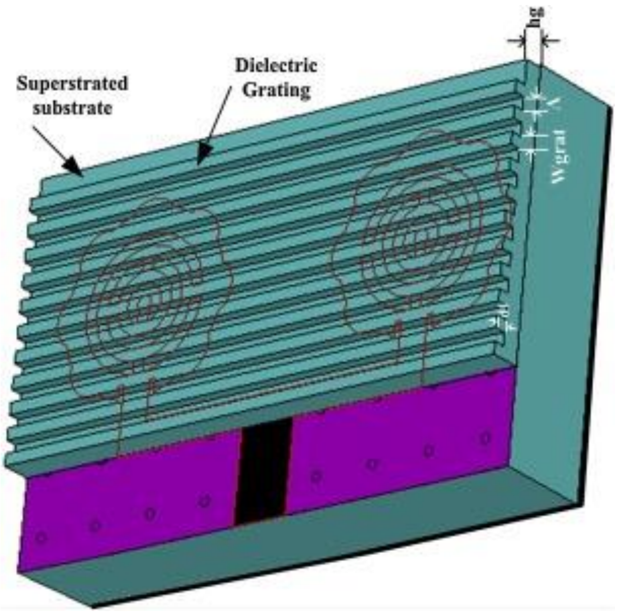

Figure 2. PBG with superimposed dielectric grating structure geometry [2].

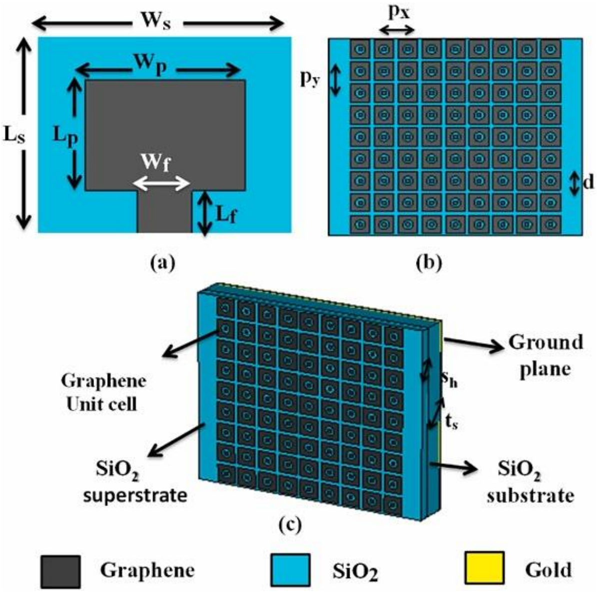

Figure 3. Graphene-based conventional patch antennas, metasurface-loaded superstrate, with the proposed graphene and superstrate structure [10].

[11] For analysis in the THz band, k Moradi developed a reconfigurable antenna that uses a metal and graphene hybrid. Two L-shaped graphene elements are added to the core metal ring in this research to proceed by changing the chemical potential of each of the three graphene elements, which results in various biassing states, the operational frequency of the antenna may be adjusted. The suggested antenna configuration changes the frequency in the 3.82 THz to 5.93 THz range and exhibits a maximum rotation of the radiation pattern as shown in Figure 4.

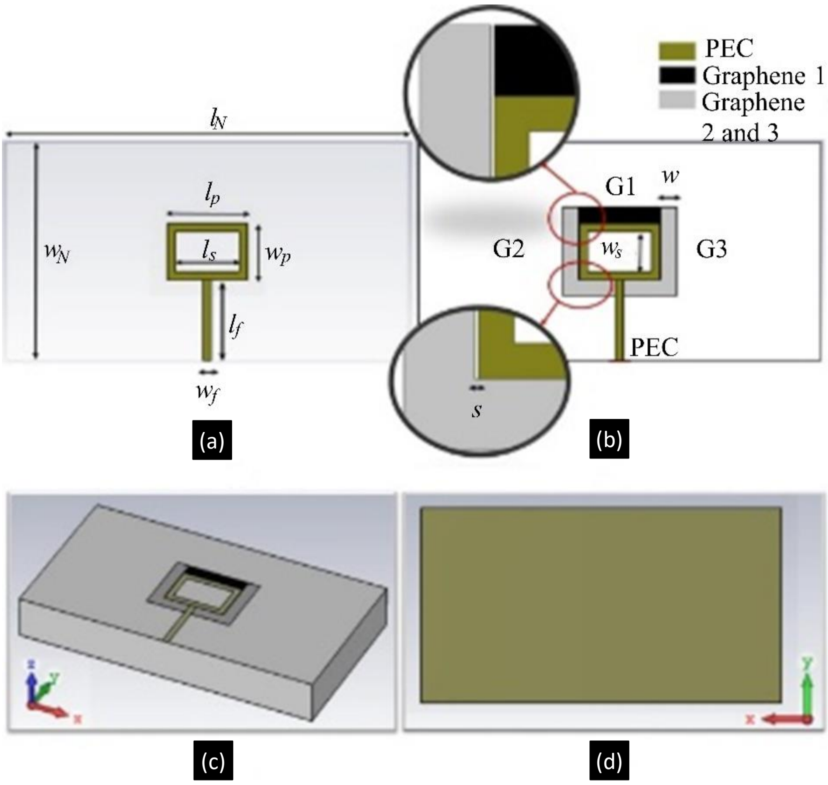

Figure 4. Arrangement of the antenna Metal ring in (a), metal ring with extra graphene strips in (b), 3D image in (c), and antenna's back view in (d) [11].

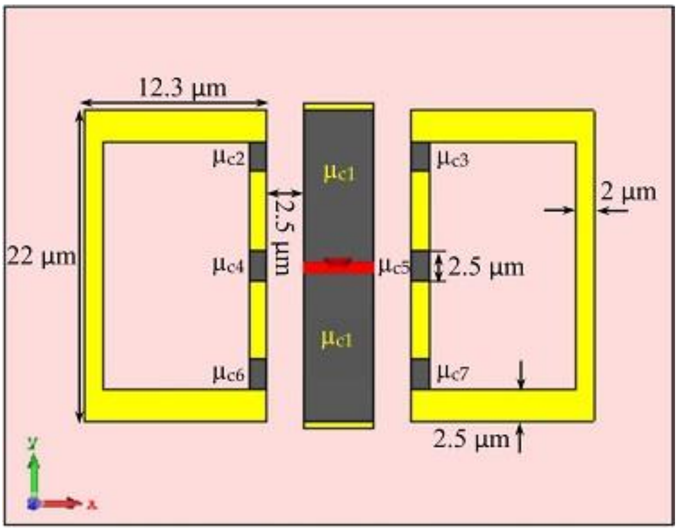

Figure 5. The multipurpose graphene-based THz antenna's shape [12].

[12] In this study, a terahertz antenna with different functions is created using an antenna structure made up of switchable NFRP elements arranged around a radiating graphene element. The various parameters of antenna as polarization, radiation pattern and frequency of the antenna can all be changed by altering the conductivity of graphene. From 1.2 to 1.7 THz, the suggested antenna has a broader frequency bandwidth. The suggested antenna exhibits beam switching in the x direction and polarization switching from LHCP to RHCP at 1.4 THz as shown in Figure 5.

[13] In this paper two types of rectangular patch antenna based on graphene are designed. The results showed that using copper metal leads to a bad reflection coefficient. For improving these results graphene material was used and it has good conductivity and results in better performance as compared to copper metal. Further two patch antennas are designed first with a simple antenna without substrate integrated waveguide (SIW) and second with SIW. Both the designs are simulated on CST software and then is compared with the designs simulated on HFSS. Antenna with SIW cavity shows good results in radiation pattern and gain increases to 5.34 dB at 4 THz compared to antenna design without SIW resulting in gain of 3.12 dB at 4 THz. as shown in Figure 6

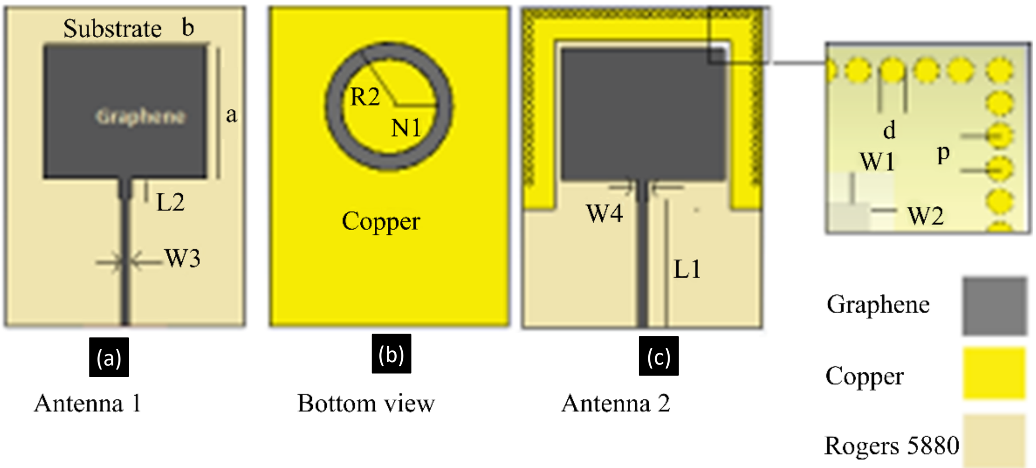

Figure 6. Design of Antenna [13].

[14] A. Abohmra presented a THz-band antenna with potential use in flexible and wearable communications. Low profile wearable antennas can be created by adjusting graphene's chemical potential, relaxation time, and ev parameters, which range from 0.1 to 0.8 ps, respectively. The

suggested antenna has a sizable bandwidth and an adjustable point, which bodes well for wearable antennas operating at THz frequency in the future as shown in Figure 7.

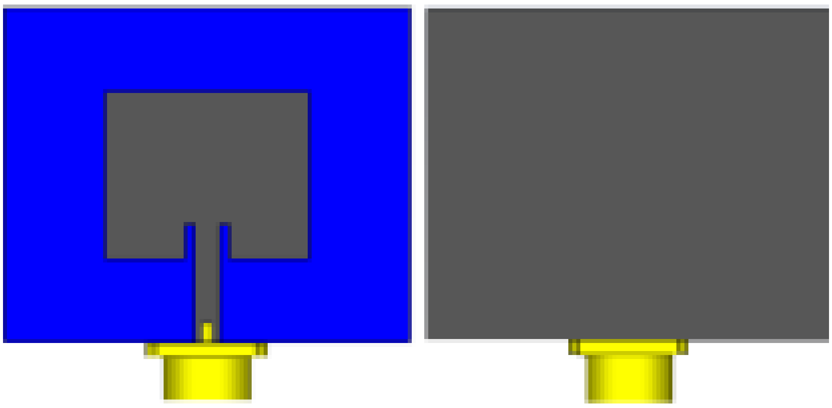

Figure 7. Terahertz graphene antenna that is adjustable for wearable technology [14].

[15] A single antenna that can operate in two separate modes was suggested by the author. It functions as a dual-band reconfigurable antenna in one mode and as a reconfigurable MIMO antenna in another. The antenna is made up of two substrates, 1 and 2, and on substrate 2, there are two rectangular patches that are spaced apart by a specific distance. We are able to tune two ports by adjusting the chemical potential. When chemical potential is applied at that frequency, this antenna now works as a reconfigurable antenna based on graphene as shown in Figure 8.

The antenna functions as a reconfigurable antenna working on dual bands when its ports are tuned to the same chemical potential. The antenna is tuned between the frequencies of 1.45 THz and 2.17 THz in both modes

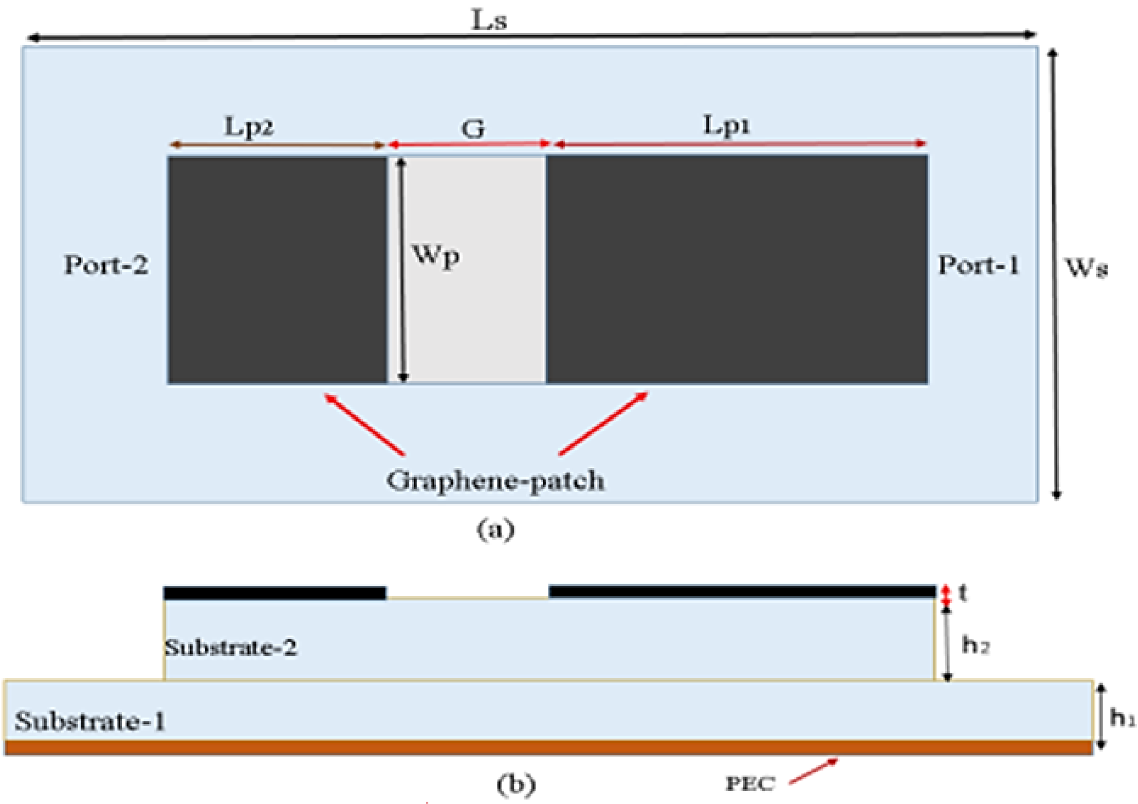

Figure 8. Proposed antenna design [15].

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[16] The graphene-based antenna used in this paper's (1x4) array of reconfigurable patch array is created on a polyimide substrate for the terahertz band. The antenna design exhibits a frequency that can be changed between 0.64 and 0.74 terahertz, with resonance frequency shifting to a higher frequency and return loss increasing as chemical potential increases.

The antenna proposed here is resonating at a frequency of 0.71 THz, a gain of 10.17 dB, a directivity of 12.69 dB, and a 60% efficiency. This antenna design also demonstrates how to change the polarization to linear, RHCP, or LHCP, as well as how to change the radiation pattern as shown in Figure 9.

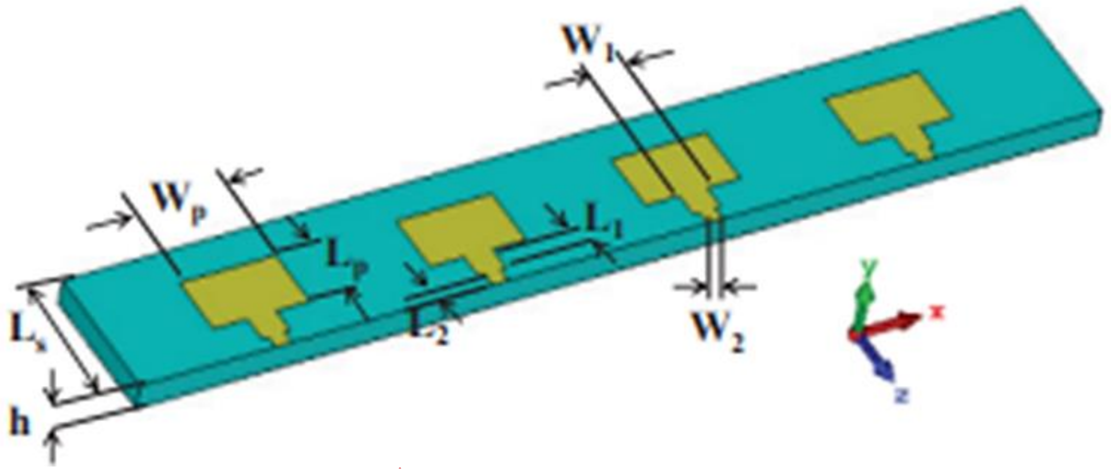

Figure 9. a 1x4 grid of graphene [16].

[17] In this work, a graphene-based microstrip square patch antenna's fermi energy level was controlled to enable the display of a range of radiation patterns, like RHCP (Right-hand circular polarization) and LHCP (Left-hand circular polarization).

Variations in graphene's chemical potential cause changes in the fermi energy level. In terms of matching and polarization, the frequency range between 0.65 THz and 0.7 THz offers the best results. It was possible to get an axial ratio of less than 3 dB, according to a good circular polarization as shown in Figure 10.

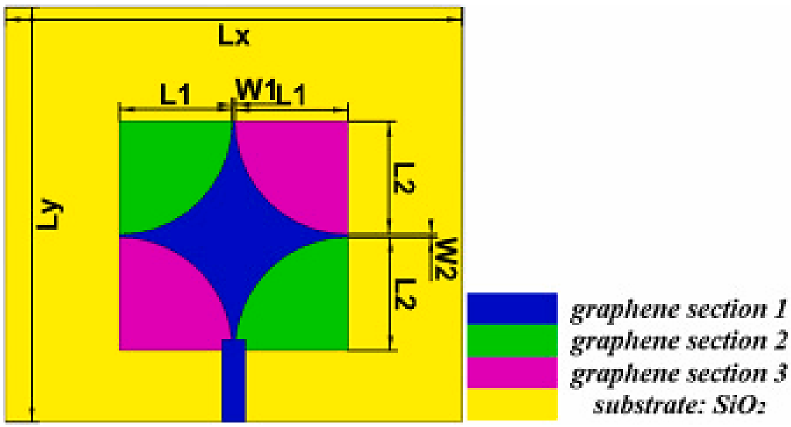

Figure 10. Designed square patch antenna for microstrip [17].

[18] In this study, a reconfigurable. A good axial ratio below 3 dB was noted in the frequency band 0.64 THz-0.69 THz, which likewise displayed the greatest results in terms of polarization and matching as shown in Figure 11.

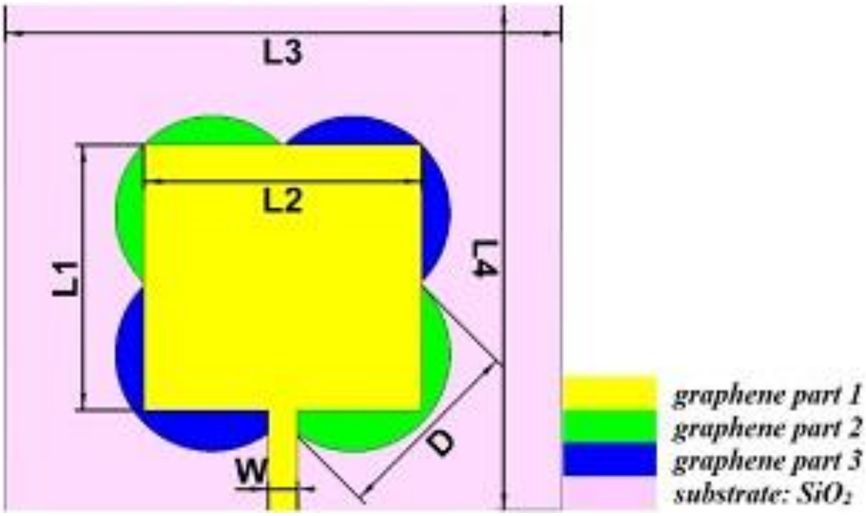

Figure 11. Shape of a four-leaf clover patch antenna [18].

[19] In this study, a 0.5–5 THz low terahertz antenna is designed. As a radiating patch, a very thin sheet of graphene measuring about 0.34 nm is used. The chemical potential of graphene, which ranges from 0 to 2 eV, can be changed to alter the antenna's resonance frequency. It is possible to operate in a triple band at 2.01 THz, 2.74 THz, and 4.52 THZ for a substrate thickness of roughly 37.5 m. Antenna design at 4.52 terahertz exhibits a gain of 1.22 dB and a directivity value of 3.66 dBi. A quad band operation at frequencies 1.73 THz, 2.6 THz, 4.01 THz, and 4.72 THz and a substrate thickness of 45 m. Antenna design has a gain of 1.61 dB and a directivity of 7.17 dBi at 4.72 THz. Investigations are also conducted into how beam steering affects the radiation pattern as shown in Figure 12.

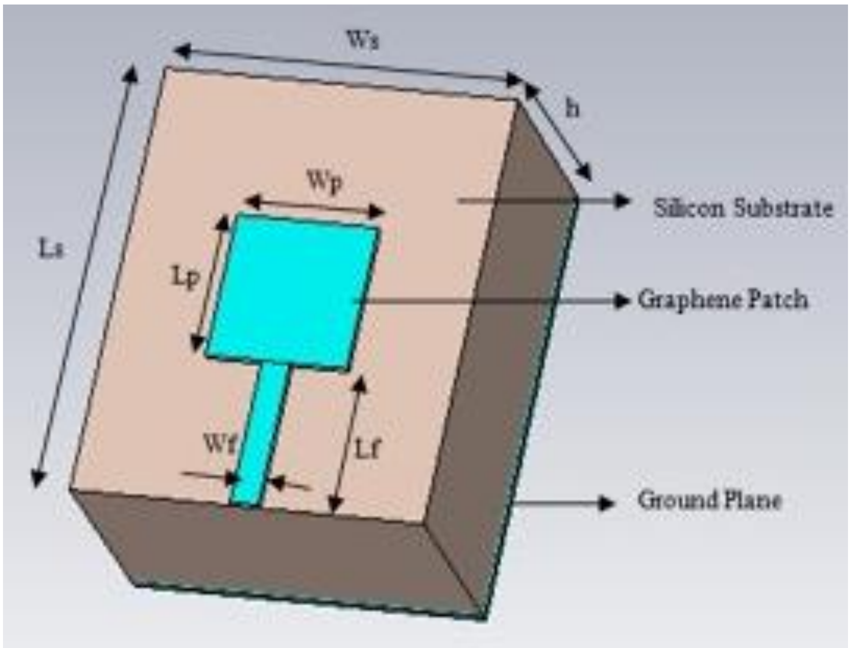

Figure 12. Designed Building [19].

[20] This work presents a graphene-based antenna with dual band reconfigurability for THz applications. In the terahertz band, graphene has outperformed copper. Dual band reconfigurability is made possible at 160 GHz for the first band and 32 GHz for the second band by altering the chemical potential of graphene. The first band experiences a return loss of -22.808 dB and the second band experiences a loss of -44.028 dB when the chemical potential is changed as shown in Figure 13.

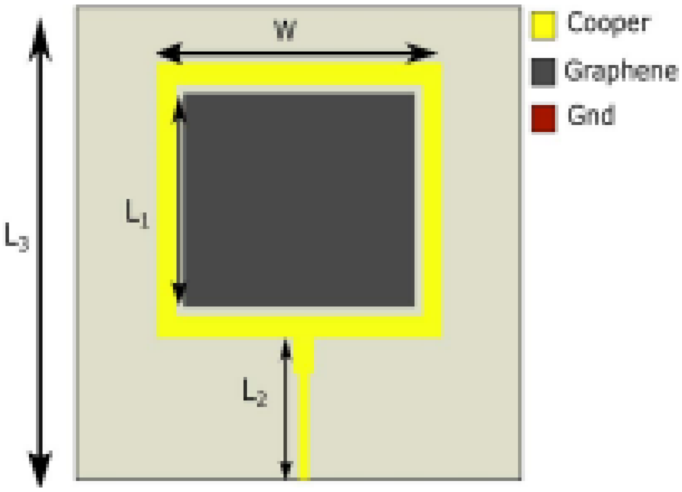

Figure 13. Design of Antenna [20].

We can infer from this review of the literature that graphene-based terahertz antennas can function over a wide range of frequencies, typically between 0.1 and 10 THz. The form, size, and doping amount of the graphene layer can be changed to alter the antenna's operating frequency.

By altering the graphene layer's structure and doping level, linear and circular polarization of graphene-based antennas can be adjusted. We can dynamically change the polarization of the antenna by introducing an external magnetic field or voltage.

The radiation pattern of an antenna can be designed to provide high gain and directivity by taking advantage of the particular geometry of the antenna.

Reconfigurable antenna based on graphene may provide a high degree of control over frequency, polarization, and radiation pattern, making them appropriate for a variety of applications including imaging, sensing, and communication.

or reconfigurable THz antennas, graphene has a number of benefits over currently used materials, including high electron mobility, broadband response, tunability, and compatibility.

Overall, compared to current materials, using graphene for reconfigurable THz antennas has a number of benefits and may enhance the effectiveness, bandwidth, and reconfigurability of THz antennas.

COMPARATIVE ANALYSIS

Recent study in reconfigurable terahertz antenna as seen from the performance comparison in Table 1 have achieved a minimum high gain of 21.22 dB with hexagonal shaped patch and using teflon substrate and graphene material and achieved frequency tuning in the range of 0.448–10 THz with minimum S11 is -53.5 dB and directivity of 21.53 with a radiation effeciency of 93.23 was achieved.

But further enhancement in antenna parameters such as directivity and bandwidth is still required further for upcoming 6G wireless communication.

According to references [16–20], Table 2's performance evaluation of various antenna designs utilising grapene for terahertz transmission demonstrates that the antenna has linear, left-handed circular, and right-handed circular polarisation.. This is insufficient to meet the needs of 6G communication because some applications call for an omnidirectional antenna, and antennas with circular polarisation are preferred. Therefore, more research should be done to develop antenna that have circular polarisation, high gain, low cost, and are small in size.

Table 1. Performance comparison of frequency tuning of reconfigurable antenna

Ref.	Frequency	-10 dB bandwidth	Min S11(dB)	Min VSWR	Max. Directivity	Max Rad. Eff.	Max. Gain	Shape	Substrate	Material
[1]	2.8-4.2 THz		-34 dB				2	Patch antenna	Quartz	Graphene
[2]	0.84-0.9 THz		-57.0515	1.0028	15.5	83.67	14.69	Patch antenna	PBG```	Graphene
[3]	0.448-10 THz	9.552 THz	-53.6	1.0041	21.53	93.23%	21.22 dB	Hexagonal shaped patch	Teflon	Graphene
[10]	1.44-2.84 THz	1.4 THz	-35.54			70.14%	8.9	Patch antenna using metasurface	Silicon dioxide	Graphene
[11]	3.82-5.93 THz						4-6	ring	FR-4	Hybrid of metal and graphene
[14]	resonate 4.546 THz, 4.636 THz and 5.347 THz		42 dB					Patch antenna	Polymide substrate	Graphene
[15]	1.45 THz to 2.17 THz.				4.56				Silicon dioxide substrate	graphene

Table 2. Performance comparison of reconfigurable antenna in terms of polarization

Ref.	Frequency	Radiation pattern	Polarization controlling	Effeciency	Shape	Substrate	Material
[16]	0.64 THz-0.74 THz	82°-115°	Linear, RHCP,LHCP		1x4 array	Polyimide substrate	Graphene
[17]	0.65 THz		Linear, RHCP,LHCP	1.0028	Planar	Silicon dioxide	Graphene
[18]	0.65 THz		Linear, RHCP,LHCP	1.0041	Four Leaf Clover Shaped	Silicon dioxide	Graphene
[19]	0.82–1.07 0.975–1.025 THz		Linear, RHCP,LHCP multiresonant	16-40 %	Planar	Silicon dioxide	Graphene
[20]	1.7, 2.23, 3.26 & 3.41 THZ		Circular Polarization	15-30%	Planar	Silicon dioxide	graphene
[4]	0.607 THz			89.79%	Photonic crystal	Silicon-Air	Graphene
[5]	3.9 THz		High Gain/Ultra Wideband	93.23%	Photonic Crystal & Dielectric grating	Teflon	Graphene

CONCLUSION

It has been investigated if graphene, which has special qualities like high carrier mobility, high thermal conductivity, and huge surface area, could be used as a material for THz antennas. Through external electrical stimulation, graphene-based antennas may be modified, potentially altering their radiation pattern and frequency response. This reconfigurability can boost the antenna's functionality and give it more variety.

Furthermore, the use of graphene in THz antennas has the potential to address some of the current limitations in THz antenna technology, such as low efficiency, limited bandwidth, and poor radiation patterns. Graphene-based antennas can also be integrated with other THz components, such as detectors and modulators, to form complete THz systems.

Overall, the analysis of graphene-based reconfigurable THz antennas suggests that graphene has the potential to improve the performance of THz antennas and advance the development of THz technology, by studying various reference paper it was concluded that more research should be done to design reconfigurable terahertz antenna to meet 6g requirements of antenna having compact size and low cost. The graphene-based reconfigurable antenna in the terahertz band should have high gain, directivity, and circular polarisation is recommended to suit the needs of 6G wireless communication.

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