Graphene based Multiband Frequency THz Antennas for UWB Applications

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Abstract- In recent times the graphene has been the point of attraction for the wireless communication technology researcher's because of its novel mechanical, thermal, chemical, electronic and optical properties. Due to its unique characteristics, graphene has given increase to an excess of potential applications in many miscellaneous fields, ranging from ultra high-speed transistors to transparent solar cell. This paper discusses the performance of various graphene based THz antennas having silicon dioxide as dielectric substrate, having dielectric constant 4. Analysis of each is done and compiled using HFSS and CST to show relative performance.
Keywords – Graphene, Antipodal Vivaldi antenna, Arc truncated antenna, bowtie antenna, CST, HFSS, Ultra wideband.

I. INTRODUCTION

Nanomaterial research is therefore a step forward to explore the properties of such materials that can be used for betterment of science & information technology [1-2]. It has been observed that the materials with structure at the nanoscale often have several unique optical, electronic and mechanical properties. Nanotechnology is paving a pathway to the engineering community to design nanoscale components with extraordinary functionalities [1]. Nanomaterial will enable a plethora of long-awaited applications in many fields of our society ranging from healthcare to homeland security, environmental, industrial development, biomedical, military fields and wideband THz communication and many more [3]. There are two key factors cause the properties of nanomaterials to be special: their quantum effects and their structure. Their tiny structure are make them a unique materials as they have a greater relative surface area than other materials and this can modify or improve properties such as strength and electrical characteristics or reactivity [1],[4]. A technical research report gives idea about its cost is as:- "Nanotechnology: A realistic market assessment (NAN031D) from Business Communications Company (BCC) research (www.bccresearch.com), the global market value for nanotechnology is an estimated $15.7 billion in 2010, but is expected to increase to nearly $50 billion in 2025" [1],[4-5]. However, as per nanotechnology, the nanomaterials can be of three types according to dimensions i.e. one dimensional, 2 dimensional or 3 dimensional. Furhter, the nanofilms, monolayers, nanosheets are one dimensional, the nanowires, nanofibers, nanotubes are two dimensional and nanoparticles, quantum dots are three dimensions in nanometers. The other nanomaterials such as nanosilver, nanogold, metal oxides, titanium dioxide and quantum dots are also give the classification of nanomaterials [6].The rest of the paper is organized as follows. Importance of graphene material is explained in section II. Graphene based different THz antenna and results and discussion are presented in section III and IV respectively. Concluding remarks are given in section V.

II. IMPORTANCE OF GRAPHENE MATERIAL

Graphene is the new two-dimensional nanomaterial. This two-dimensional material which is the parent of all graphitic carbon forms is strictly expected to comprise a single layer but there is considerable interest in investigating two-layer and multiple-layer graphene as well. Antenna can either use stack of monolayer graphene sheets or monolayers separated by dielectric sheet can also be used. Before monolayer graphene was isolated by Andre Geim and Kostya Novoselov in 2004, it was theoretically believed that two-dimensional compounds could not exist when separated due to thermal instability but later research suggests that it is actually due to the fact that the carbon to carbon bonds in graphene are so strong and small that they prevent thermal fluctuations from destabilizing it [7-8]. Graphene is an allotrope of carbon in the form of a two-dimensional, honey-comb lattice in atomic scale in which one atom forms each vertex. It can also be considered as an indefinitely large aromatic element. Graphene is about 200 times stronger than the strongest material steel. Graphene also conducts heat and electricity efficiently and is nearly transparent. Graphene also shows nonlinear and large diamagnetism even greater than graphite and can be levitated by Nd-Fe-B magnets [9-10].

Researchers have identified the bipolar transistor effect, ballistic transport (property of charge carriers to travel submicrometre distances without scattering) of charges and large quantum oscillations in the material. Scientists

have theorized about graphene for years. The global market for graphene is reported to have reached $9 million by 2012 with most sales in the semiconductor, electronics, and batter energy and composites industries. Suspended graphene also showed "rippling" of the flat sheet, with amplitude of about one nanometre. Atomic resolution real-space images of isolated, single-layer graphene on SiO2 substrates are available via scanning tunnelling microscopy. The essence of modern-day communication systems is being able to transmit and receive signals between any two places or people with high data rates. To date, it is still not very clear how nanomachines will communicate. The miniaturization of a traditional antenna to meet the size requirements of nanomachines would impose the use of very high radiation frequencies [11-12].
Very little attention has been given to explore the pioneering approach of using novel nanomaterials having simple and plane structure of THz antenna with highly directive and better gain for ultra wideband (UWB) application.
Graphene is the new two-dimensional nanomaterial [13-17]. This two-dimensional material which is the parent of all graphitic carbon forms is strictly expected to comprise a single layer but there is considerable interest in investigating two-layer and multiple-layer graphene as well [18-20]. Antenna can either use stack of monolayer graphene sheets or monolayers separated by dielectric sheet can also be used. Very little attention has been given to explore the pioneering approach of using novel nanomaterial graphene having simple and plane structure of THz antenna with highly directive and better gain for ultra wideband (UWB) application.
A comprehensive review has revealed that a lot of research such as graphene based antipodal Vivaldi antenna, arc truncated and bowtie antenna based work has been carried out for designing graphene antennas that hamper their direct application in the micro and nanoscale. Which however suffer from limitations such as their complexity, energy consumption, narrow bandwidth, high attenuation, low gain, low directivity, low power-handling capability and many more are overcome using graphene material which raises the question about the feasibility of wireless THz communication among nanodevices [21].

III. GRAPHENE BASED DIFFERENT THZ ANTENNAS

The graphene based antipodal nanoantennas have good features of high directivity, return loss with broad bandwidth, good impedance matching and reasonable good gain. Moreover, the resonant frequency of antipodal nanoantennas is lower than slotted bowtie antenna and arc truncated THz antenna [22-23]. Silicon dioxide, SiO2 as dielectric layer for a design of antipodal nanoantennas having choice of graphene material is essential to the proposed design. The values of optimized parameters for the proposed graphene based antipodal antenna are obtained as given in Table 1. .The cross-sectional view of front and back graphene based antipodal Vivaldi nanoantennas are shown in Fig. 1 and Fig. 2.

Table 1: Dimensions of graphene based antipodal vivaldi terahertz nanoantenna.

Parameters	Values (m)
A	16
MW	1.42
La	43
Wa	55
r1	0.106
B	2.3
r2	3.984*r1 = 0.422304
Graphene Thickness	0.01
ML	27.7
PC_Thickness	0.25
K	3.4
Subw	57
A1	-2.5
B1	1.96
Icl	0.7
G	1
W1	0.5
Graphene Temperature	293 K
Graphene Chemical Potential ( )	0.5 eV
Graphene Relaxation time ( )	3 ps

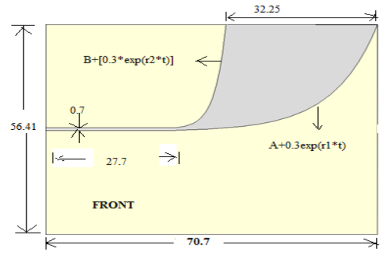

Fig. 1. Front view of Graphene based antipodal Vivaldi antenna

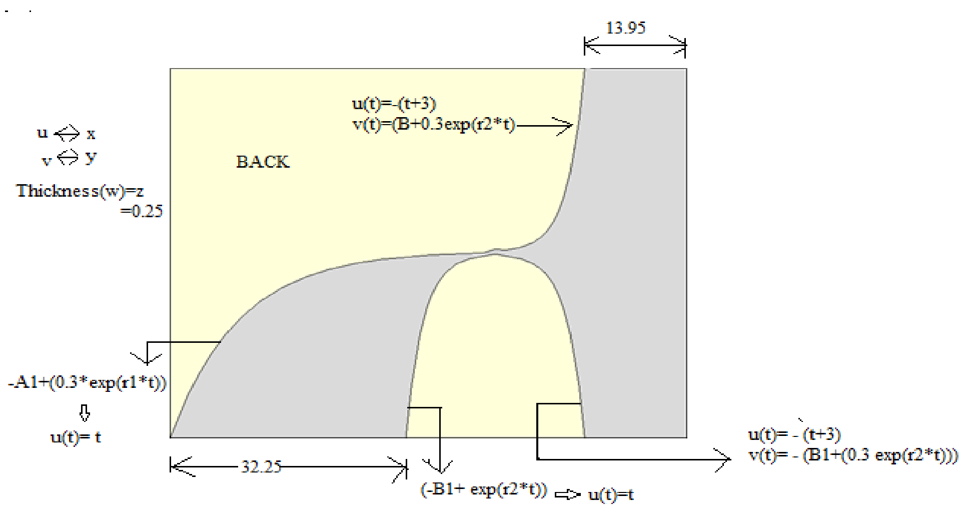

Fig. 2. Back view of Graphene based antipodal Vivaldi antenna

The microstrip line fed square patch antenna consists of a conducting patch with opposite arc corner truncation and a ground plane separated by a thin dielectric substrate of silicon dioxide is designed. The microstrip transmission line is matched to patch antenna via a quarter-wavelength microstrip transmission line with the characteristic impedance selected to match the load. The side length of square patch is "Lp", printed on a silicon dioxidesubstrate of thickness "h", having a relative dielectric constant of "εr" as shown in Fig.3. The microstrip line fed antenna is designed here to operate at 13 THz, 15 THz and 18 THz. The dimensions of graphene based arc truncated antenna are mentioned in Table 2.

Table 2: Dimensions of graphene based arc truncated terahertz square patch antenna.

Parameter	Value
Substrate length and width(Ls × Ws)	14 m × 14 m
Substrate thickness (h)	1.8 m
Substrate dielectric constant (Silicon dioxide SiO2 ,εr)	4.0
Side length and width of square patch (Lp × Wp)	5 m × 5 m
Patch height (Δ)	10 nm
Length and width of feed	1.2 m×1 m
Length and width of λ/4 transformer	0.5 m ×3.5 m
Radius of arc truncation (R)	0.7 m

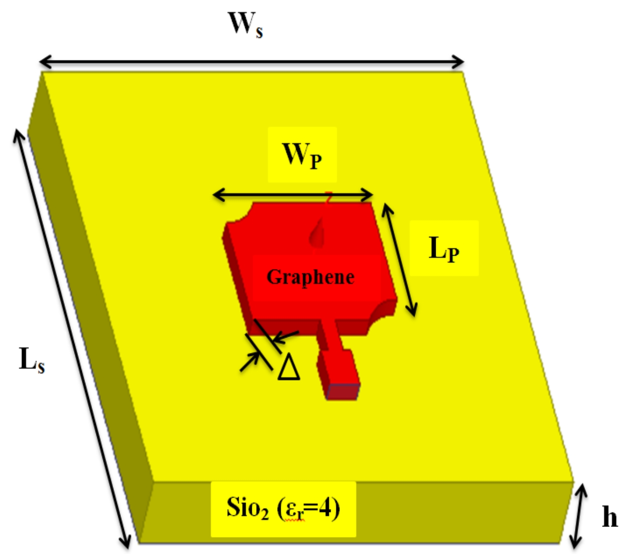

Fig. 3. Graphene based truncated patch antenna

The dimensional parameters of the proposed antenna are selected to operate in the frequency range of 1-15 THz as described in Table 3.

Table 3: Dimensions of graphene based slotted bowtie terahertz patch antenna.

Parameter	Value
Substrate length and width (Ls × Ws)	40 m × 40 m
Substrate thickness (h)	m
Substrate dielectric constant (Silicon dioxide SiO_2 ,εr)	4.0
Inner width and outer width of bowtie antenna (WI × Wo)	0.22 m × 7.89 m
Bowtie Patch height (Δ)	1 nm
Port gap width	0.44 m
Arm length of bowtie antenna (LA)	8.76 m

The inner width of slotted bowtie antenna is "WI", outer width of bowtie antenna Wo, and arm length of bowtie antenna LA printed on a silicon dioxide substrate of thickness "h", having a relative dielectric constant of "εr" with substrate length of Ls and width of Ws as shown in Fig.4. The graphene based slotted bowtie antenna is designed here to operate at 7.1 THz, 11.1 THz and 13.1 THz. The resonant frequency for bowtie antenna matching to various modes can be given by [19-20]

$$f_r = \frac{ck_{mn}}{2\pi\sqrt{\varepsilon_r}} = \frac{2c}{3a\sqrt{\varepsilon_r}}\sqrt{m^2 + mn} \tag{1.1}$$

Where a is the side length of the bowtie strip, c is velocity of light in free space = 3×10^8 m/s, fr is the resonance frequency, kmn is the resonating modes m and n are modes given by

$$k_{mn} = \frac{4\pi\sqrt{m^2+mn+n^2}}{3a} \tag{1.2}$$

The dominant resonant frequency for lowest order mode is hence given by [21][24]

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}} \tag{1.3}$$

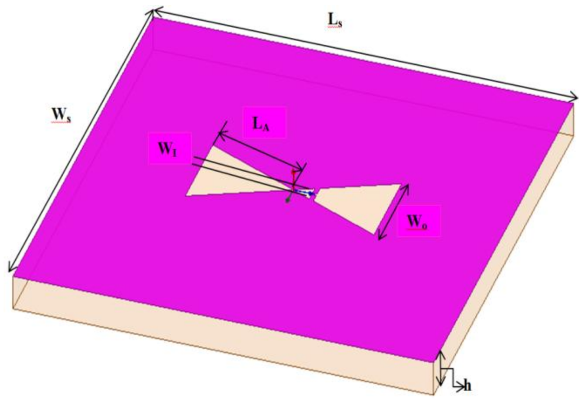

Fig. 4. Graphene based slotted bowtie patch antenna

IV. RESULTS AND DISCUSSION

Therefore, the antenna can be well applied to ultra wideband system and imaging applications [19]. The proposed antenna design consists on zigzag arrangement [12]. The simulated return loss (S11) (in dB) verus frequency (in THz) plot for the antenna design with 3 µm substrate thickness of SiO2, after the optimization in frequency range 1-5 THz. The skin depth is also significant in determining the return loss, wide bandwidth, highly directive and reasonable gain at terahertz frequency. Further the multi ultra wideband resonance can be obtained by carefully selecting the novel material for antipodal Vivaldi antenna and substrate [3]. The prototype antenna structure has been simulated using Computer Simulation Technology (CST) software version 2016 [14]. As a result of improvements made to the structure of the antenna, the use of a graphene layer on SiO2 capping layer is adequate for the coverage of multiband of operation in the frequency bands are 1.44-2.4 THz, 2.9-4.11 THz, 4.4-4.45 THz and 4.59-5 THz under the impedance matching criterion as shown in Fig.5. For the present analysis T = 293K, τ is transport relaxation time taken as τ = 3ps with effective chemical potential µc is 0.5 eV [16] will be achieved the ultra matching for ultra wideband antenna for the wireless communication wideband response at different multi frequency bands. For the proposed design the impedance bandwidth achieved is in range 50 GHz to more than 1.21 THz at different resonant frequency bands. Due to its large bandwidth, it can be used as a sensing antenna in some applications.

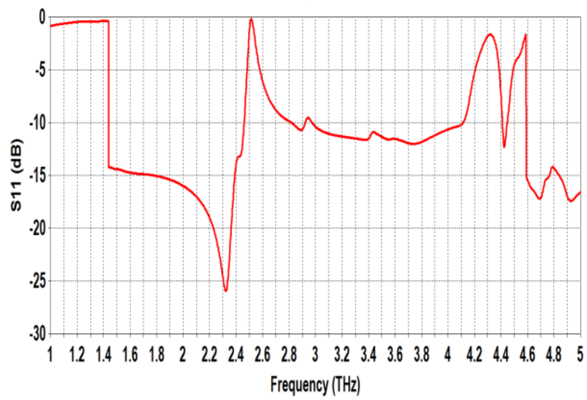

Fig. 5. Return loss versus frequency for the antipodal Vivaldi antenna.

From the Fig. 6, it is clear that, the antenna operates between 10 THz to 20THz and gives three resonant frequencies at 13 THz, 15THz and 18THz for different values of patch length at h= 1.8µm.The plot shows return loss value of S11 = -14.2497 dB at resonating frequency 13.0 THz (with green colour dotted dashed line), S11 = -17.5422 dB at resonating frequency15.0 THz (with purple colour dotted line), and S11 = -15.2360 dB at resonating frequency 18.0 THz (with red colour solid line). For the proposed design the impedance bandwidth achieved is 1.39 THz at 13.0 THz, 1.36 THz at 15.0 THzand more than 5THz at 18.0 THz. Fig.3 depicts the wideband behavior at 18THz resonating frequency.

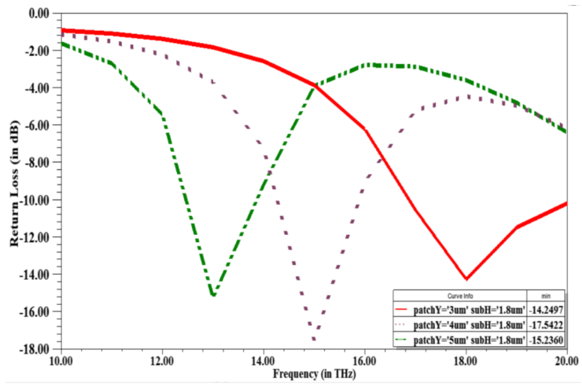

Fig. 6. Return loss curves, for different patch lengthat h=1.8 µm

Fig. 7 shows the frequency response of the computed return loss (S11) for the proposed antenna. The slotted bowtie antenna operates between 1 THz to 15 THz and gives three resonant frequencies (fr) at 7.1 THz, 11.1 THz and 13.1 THz at their respective frequencies band (FB)in Table 1.2.The plot shows return loss value of S11 = -30.4978 dB at resonating frequency 7.1 THz, S11 = -18.0104 dB at resonating frequency 11.1 THz, and S11 = -22.0171 dB at resonating frequency 13.1 THz. The antenna provides the impedance bandwidth of 2.8823 THz at 7.1 THz, 1.5868 THz at 11.1 THz and 1.7173 THz at 13.1 THz. The bandwidth (BW) was reduced due to losses.

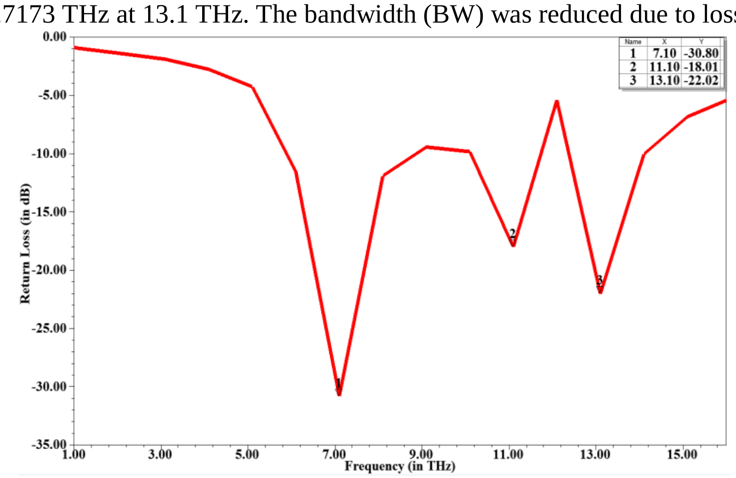

Fig. 7. Return loss curve, for slotted bowtie antenna at h=3 µm

The Graphene is a flexible and transparent conductor that holds great promise for various material and device applications, including photovoltaic cells, solar cells, graphene sensors, optical electronics light-emitting diodes (LEDs), light emitting diodes (LCDs) touch panels super capacitors– energy storage and smart windows or phones. According to information from Changzhou, China-based 2D Carbon Graphene Material Co., Ltd, graphene-based touch panel modules have been sold in volume to cell phone, home appliance manufacturers and wearable device. For instance, smart phone products with graphene touch screens are already on the market. In 2013, Head announced their new range of graphene tennis racquets. As of 2015, there is one product available for commercial use: a graphene-infused printer powder. Many other uses for graphene have been proposed or are under development, in areas including biological engineering, electronics, light weight and strong composite materials, filtration, photovoltaic and energy storage. Graphene is often produced as a powder and as a dispersion in a polymer matrix. This dispersion is supposedly suitable for advanced composites, lubricants, oils, paints, functional fluids, coatings, batteries, capacitors and thermal management applications, packaging, solar cells, display materials, inks 3D-printers' materials, and barriers, films. In 2016, researchers have been able to make a graphene film that can absorb 95% of light incident on it. It is also getting cheaper; recently scientists at the University of Glasgow have produced graphene at a cost that is 100 times less than the previous methods. In August 2, 2016, BAC's new Mono model is said to be made out of graphene as a first of both a street-legal track car and a production car.
As compared with previous work in Table 4 graphene based arc truncated and bow-tie THZ antenna on silicon dioxide substrate (εr= 4) presented by Gaurav Bansal et al. [22-23] is able to achieve lower resonating frequency band 1-5 THz at multiband for UWB applications.

Table 4: Comparison of the proposed graphene based antipodal Vivaldi antenna with different graphene based nanoantennas

.Parameters	Proposed antenna on antipodal vivadi THz antenna			[22] on arc truncated THz antenna			[23] bow-tie THz antenna		
Numerical Technique (Software)	FIT (CST)			FEM (HFSS)			FEM (HFSS)		
Chemical potential	0.5 eV			0 eV			0 eV		
Relaxation time	3 ps			0.1 ps			0.1 ps		
Resonating frequency, fr (THz)	2.31	Wideband	wideband	13	15	18 (wideband)	7.1	11.1	13.1
Frequency band (THz)	2.9-4.11	4.4-4.45	4.59–more than 5	2.5-13.89	14.4-15.76	16.9-more than 20	5.96-8.84	10.17-11.26	12.35-14.07
Bandwidth (THz)	1.21	0.05	more than 6	1.39	1.36	More than 5	2.88	1.59	1.71
Gain (dB)	6.48			7.10			17.5		
Directivity (dB)	8.3			7.2			18.1		
VSWR	1.1			1.4			1.28		

V. CONCLUSIONS

Graphene will change the world as it is a promising material for new types of systems, circuits, and devices where several functions can be combined into a single material. Major issues faced presently are regarding the manufacturing of graphene. But it is not very far in coming future when we will be able to produce it easily and in quantities. As graphene is just a mere combination of the abundantly present element carbon, so it will be cheap as compared to present technologies. Carbon structure provide it a biodegradable nature i.e. graphene revolution will not bring environmental hazards with it. It will give the new face to modern technology.

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VI. CONFLICT OF INTERESTS

The authors declare no conflict of interest, financial or otherwise.

VII. ACKNOWLEDGEMENTS

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