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Small Size Inset Fed Microstrip Terahertz Antenna for Wireless Network Communication

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Abstract: — A small size terahertz microstrip antenna using graphene with tunable resonant frequency is proposed. Graphene's tuning ability is used to make antenna reconfigurable. We have included and applied more exact modeling of changeable graphene surface conductivity and used MATLAB codes to generate and characterize the conductivity of graphene and same is applied to simulation software. Designed patch antenna is simulated using electromagnetic high frequency simulator. Proposed antenna shows multibands operation, better performance in terms of return loss, directivity and reduced size. Reduced size is very much suitable for future era applications such as wireless networks on chip and wireless nano sensor network.

Keywords: Graphene, terahertz antenna, Inset feed, reconfiguration, multi bands.

I. INTRODUCTION

Graphene Properties and Surface Plasmon Polariton Mode (SPP) Wave Propagation:

Graphene is a single layer carbon crystal developed from graphite, which has dominated recently the research society due to its exceptional properties [1–3]. Among many researchers, only little research work found the antenna applications of graphene [4–8]. Due to exceptional electromagnetic, mechanical properties and tunable characteristics of the material in reconfigurable designs, graphene is widely used in numerous THz applications. Foremost challenge in using graphene material as a nano component is to mathematically model the material that would give better THz frequency properties. It has been noted that very few authors have worked on determining mathematical solution for changeable graphene surface conductivity which is essentially preferred for exact modeling of graphene based terahertz antennas.

From literature reading it is evident that the electromagnetic fields for metallic antenna are controlled by classical Maxwell's equations, the graphene however is represented by a surface conductivity arising from a semi-classical intraband mode and quantum-dynamical interband mode [9]. Surface conductivity of graphene has been calculated by Kubo's formula.

The surface conductivity expression of an infinite graphene sheet specified in equation (1), includes two parts, intraband as a first term and interband as a second term, intraband corresponds intraband electron-phonon scattering process and interband corresponds to interband electron transition [10]. Graphene conductivity in the infrared and visible range is determined by interband transitions while, for terahertz range it is controlled by intraband transition. The conductivity model is given by [11]

$$\sigma(i\omega, \square_c, T, \Gamma) = -j\frac{q_e^2\ (\omega+2i\Gamma)}{\pi\hbar^2}\ [\frac{q_e^2}{(\omega+2i\Gamma)^2}\int_0^\infty \xi(\frac{\partial f_d(\xi)}{\partial \xi} - \partial fd-\xi\partial\xi d\xi-0\infty fd-\xi-fd\xi\omega+2i\Gamma 2- 4\varepsilon h2\ d\xi\ )\ ] \qquad [1]$$

It is understood that the inductive nature of conductivity seen in fig. 1 and fig. 2 allows an infinite graphene sheet to support transverse magnetic (TM) surface waves also referred to as surface plasmon polariton (SPP), as the conductivity results from the plasmon-like behaviour of the electrons [12].

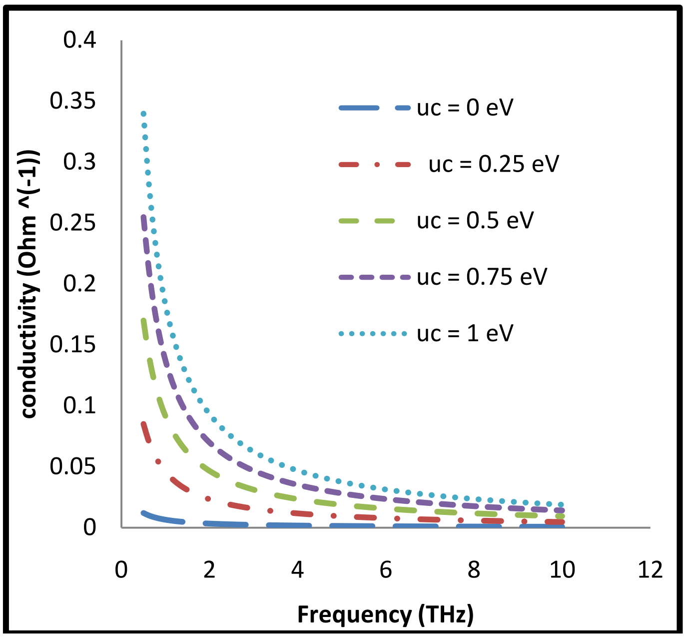

Fig.1 Real part of surface conductivity of graphene for different chemical potential.

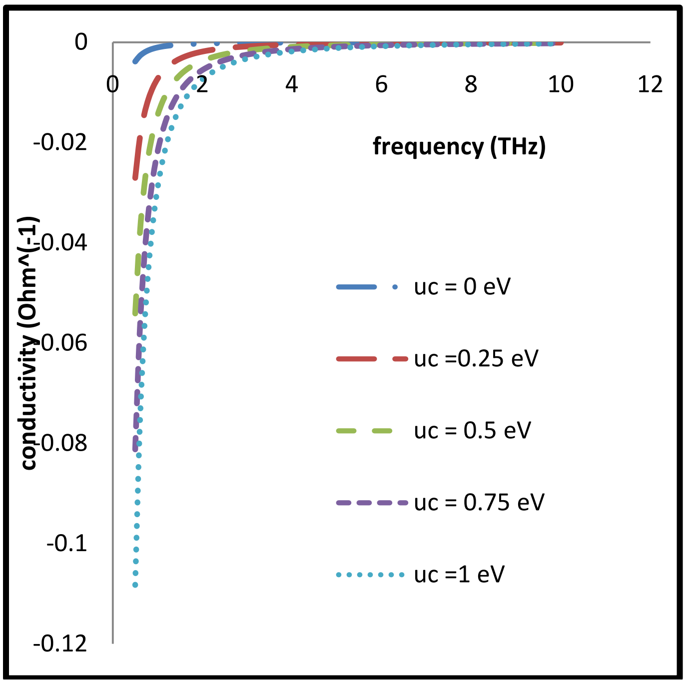

Fig.2 Imaginary part of surface conductivity of graphene for different chemical potential

Chemical voltage, □$_c$ is very important parameter for evaluating the performance of the terahertz antenna using graphene which explains the distribution of energy of electrons at which a quantum state is equally probable to be empty or filled. Material doping is used to tune surface plasmon polariton (SPP) of graphene. Further external bias is used to control material doping through V_{DC}. Therefore graphene conductivity σ or surface impedance (Zs = 1/σ) can be dynamically changed by V_{DC}. This behavior of graphene is utilized to design reconfigurable small size antennas.

II. II. Theory

The studied inset fed microstrip terahertz antenna consists of a rectangular patch arranged on a dielectric substrate of permittivity ($\varepsilon_r = 10$). A perfect ground plane is placed below the substrate and participate in the radiation of the path through the radiation of the field. The patch is made of graphene. To determine the width Wp of the patch antenna we use the following equation [13]

$$Wp = \frac{c}{2 f_r \sqrt{\frac{\varepsilon_r + 1}{2}}} \quad [2]$$

Where f_r is desired resonant frequency and c is the speed of light.
The effect of fringing fields acting of the outside of the radiating patch. The effective dielectric constant can be given by

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12*h}{W_p}\right)^{-1/2} \quad [3]$$

The length of the patch, L_p can be calculated as:

$$L_p = L_{eff} - (2*\Delta L) \quad [4]$$

where the effective length L_{eff} is calculated as

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon reff}} \quad [5]$$

where ΔL is the fields overflow. The length, width of the ground plane and width of the feed line are calculated as

$$Lg = L_p + (6*h) \quad [6]$$

$$Wg = Wp + (6*h) \quad [7]$$

$$Wf = h\left(\frac{Zc}{50\sqrt{\varepsilon_r}} - 2\right) \quad [8]$$

where Zc is intrinsic impedance of free space and value is 377 Ohm.

The position of the inset feed point where the input impedance is 50 ohm is calculated as:

$$Z_{in}(x) = \frac{1}{2(G_1 \pm G_{12})} \cos^2\left(\frac{\pi}{L_p} x\right) \quad [9]$$

where G_1 and G_{12} are given by

$$G_1 = \begin{cases} \frac{1}{90}\left(\frac{W_p}{\lambda_0}\right)^2 \; for\; W_p \ll \lambda_0 \\ \frac{1}{120}\left(\frac{W_p}{\lambda_0}\right) \; for\; W_p \ll \lambda_0 \end{cases} \quad [10]$$

$$G_{12} = \frac{1}{120\,\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{K_0 W_p}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0(K_0 L\sin\theta)\sin^3\theta\, d\theta \quad [11]$$

The calculated parameters are tabulated in table I and proposed design is shown in fig. 3.

Parameters	**Symbol**	Value
Resonant frequency	f_r	0.5 THz
Length of the Substrate	Ls	267.34 µm
Width of the Substrate	Ws	308.36 µm
Thickness of the Substrate	Ts	11.86 µm
Length of the Patch	Lp	196.18 µm
Width of the patch	Wp	237.2 µm
Length of the feed line	Lf	56 µm
Width of the feed line	Wf	39.49 µm
Notch gap	A	12 µm
Inset feed position	B	20 µm

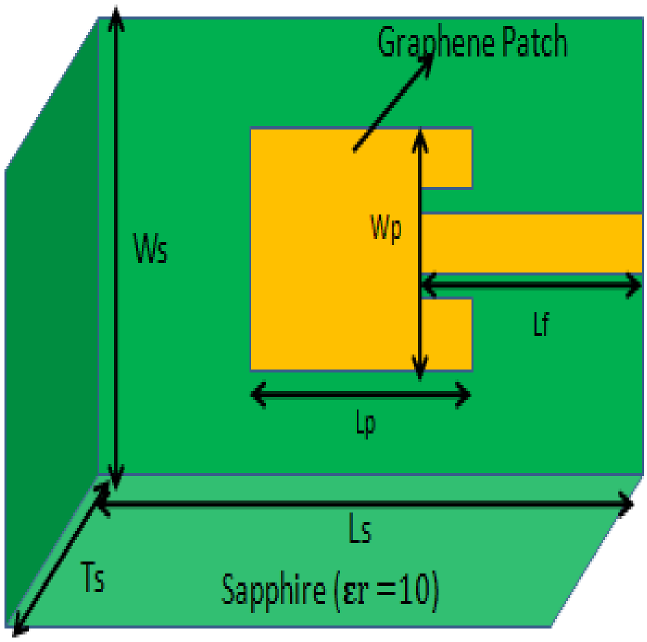

Fig. 3 Schematic of graphene inset fed microstrip terahertz antenna

III. V. Results Analysis:

The proposed graphene based terahertz antenna is designed in high frequency structure simulator (HFSS) and analyzed for various performance parameters such as return loss, radiation pattern, directivity and gain of the antenna. In first step we have modeled graphene properties and have applied them using MATLAB into the high frequency software for the design of graphene based terahertz antenna. MATLAB is used here to determine the data for frequency dependent conductivity as per the values of chemical voltage.

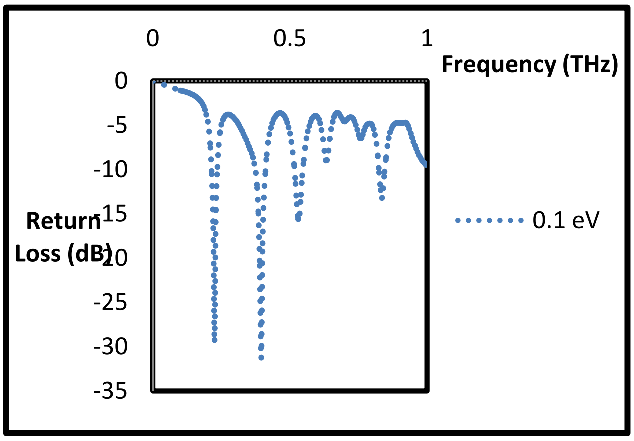

Fig. 4 Return loss plot at chemical voltage of 0.1 eV

We have found return loss of the proposed antenna for chemical voltage in range of 0.1 eV to 1.0 eV and as shown in fig 4 to fig. 13. From these results it is observed that resonant frequency shifts from 0.2 THz to 0.9 THz. which shows a good quality of frequency reconfiguration. Fig. 4 shows return loss plot at chemical voltage of 0.1 eV, which can be easily achieved by d.c electric bias. Return loss at 0.1 eV chemical voltage shows four resonant frequencies (considering -10 dB threshold), which can be suitable for multi resonant operations. In addition it gives minimum return loss of -30dB and -32 dB at around 0.2 THz and 0.4 THz respectively which is near to our designed and desired resonant frequency and can be further set by selecting proper chemical voltage.

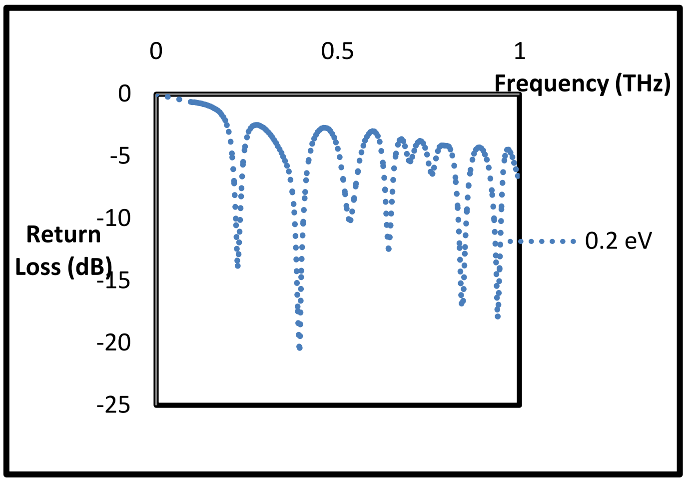

Fig. 5 Return loss plot at chemical voltage of 0.2 eV

Fig. 5 shows return loss plot at chemical voltage of 0.2 eV. It shows multi resonant operations and have six resonant frequencies for -10 dB threshold. Minimum value of the return loss is -21 dB at 0.4 THz. Frequency reconfiguration can be observed by operating the antenna at 0.2THz and 0.4 THz and frequency shift of 0.2 THz is noted in variation of chemical voltage.

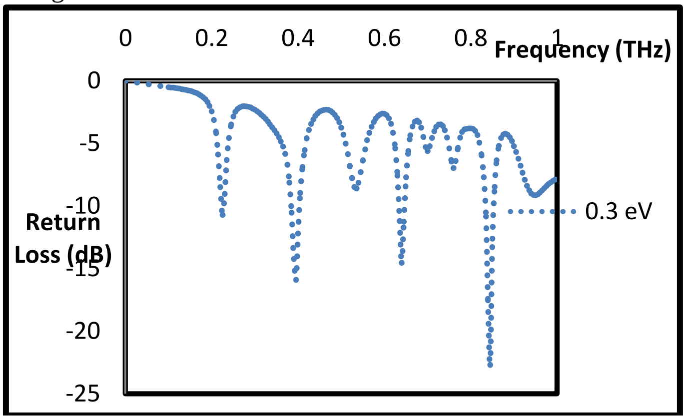

Fig. 6 Return loss plot at chemical voltage of 0.3 eV

Fig. 6 shows the return loss at chemical voltage of 0.3 THz and has four resonant conditions. Minimum value of return loss is -23 dB at 0.82 THz. Frequency reconfiguration can be easily observed from here.

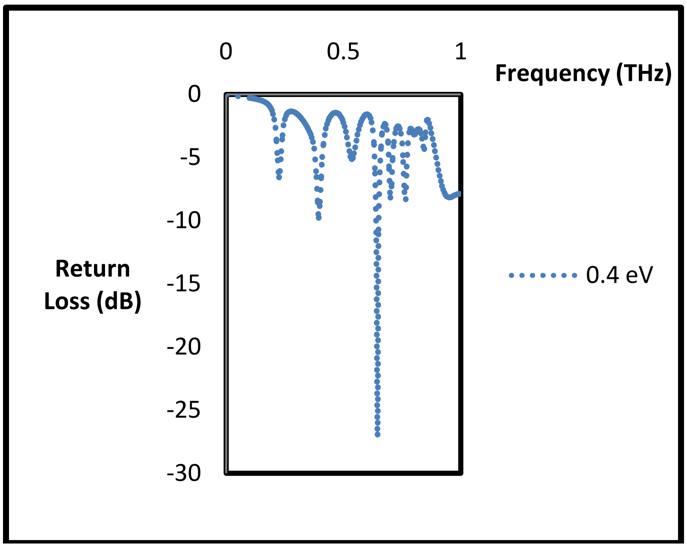

Fig. 7 Return loss plot at chemical voltage of 0.4eV

Fig. 7 shows return loss plot at chemical voltage of 0.4 eV. It shows two resonant conditions at 0.4 THz and 0.61 THz. Minimum return loss is -27 dB.

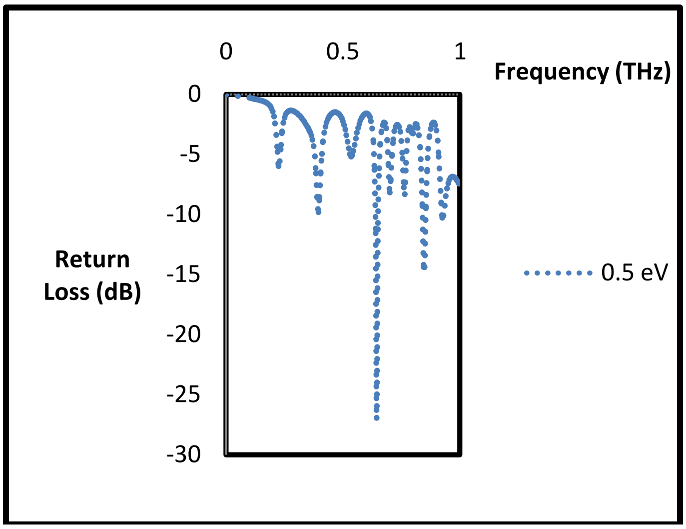

Fig. 8 Return loss plot at chemical voltage of 0.5eV

Fig. 8 shows return loss plot at chemical voltage of 0.5 eV. It also shows three resonant conditions at 0.41 THz, 0.51 THz and 0.81 THz. Minimum return loss is -27 dB at 0.51 THz.

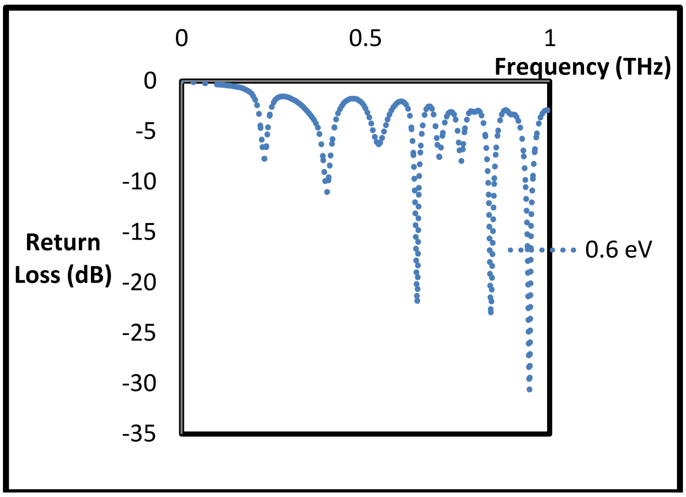

Fig. 9 Return loss plot at chemical voltage of 0.6 eV

Fig. 9 shows return loss at chemical voltage of 0.6 eV. There are four resonant conditions at 0.41 THz , 0.61 THz, 0.81 THz and 0.9 THz. Minimum return loss here is -32 dB.

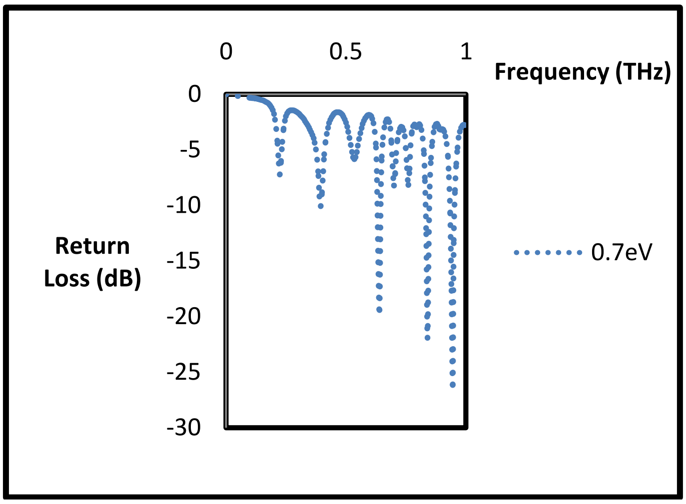

Fig. 10 Return loss plot at chemical voltage of 0.7eV

Fig 10 shows return loss plat at chemical voltage of 0.7 eV. There are also four resonant conditions.

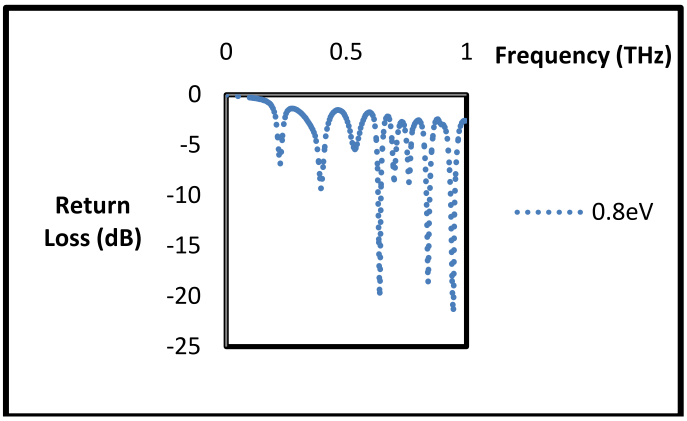

Fig. 11 Return loss plot at chemical voltage of 0.8 eV.

Fig. 11, 12 and 13 show return loss plots at chemical voltage of 0.8 , 0.9 and 1.0 eV respectively. Resonant conditions can be readily seen from the plots.

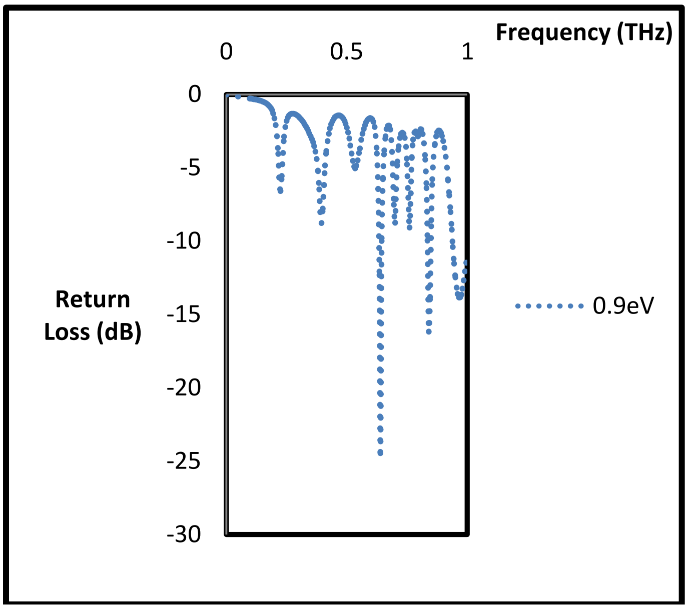

Fig. 12 Return loss plot at chemical voltage of 0.9 eV.

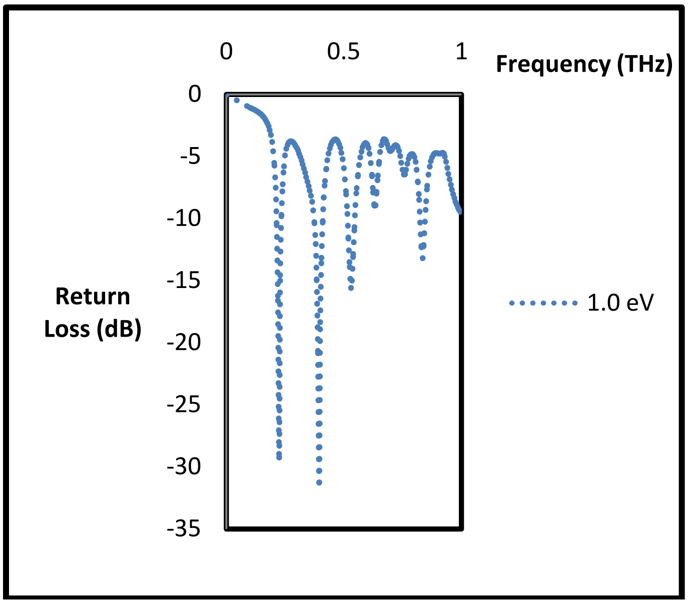

Fig. 13 Return loss plot at chemical voltage of 1.0 eV

From all the return loss plots it can be seen that frequency reconfiguration has been achieved. Resonant frequency can be changed dynamically by changing dc bias voltage and so chemical voltage. Resonant frequency may be changed from 0.21 THz to 0.91 THz and similar change may be observed from the return loss plots. Comparison of return loss plots for chemical voltage (0.1 to 0.5 eV) and chemical voltage (0.6 eV to 1.0 eV) are shown in fig. 14 and fig 15 respectively, from this also frequency reconfiguration may be easily observed.

Gain and directivity plots for the proposed THz antenna at chemical voltage of 0.6 eV, 0.7 eV and 0.8 eV are shown in fig. 17, 18, 19, 20, and 21 respectively. Maximum gain at 0.8 eV is 2.16 dB and maximum directivity at 0.6 eV is 7.8dB.

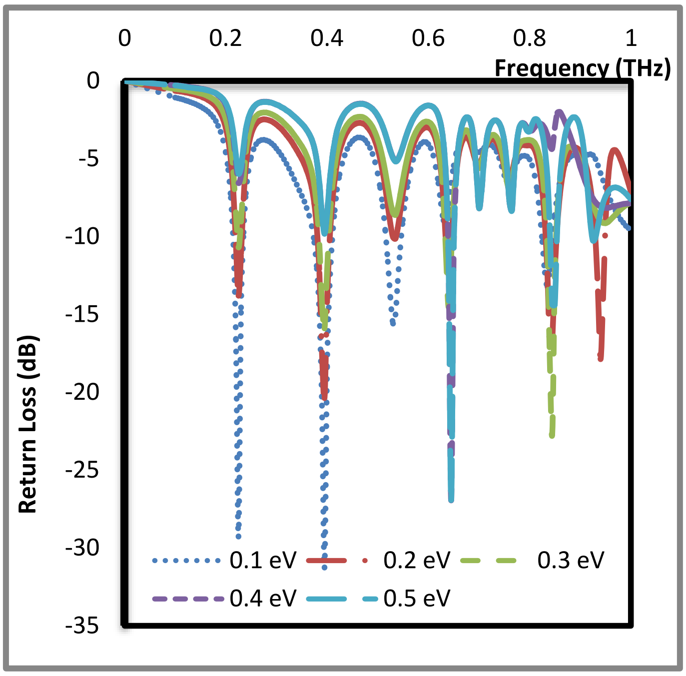

Fig. 14 Comparison of Return loss plots for various chemical voltages (0.1 eV to 0.5 eV).

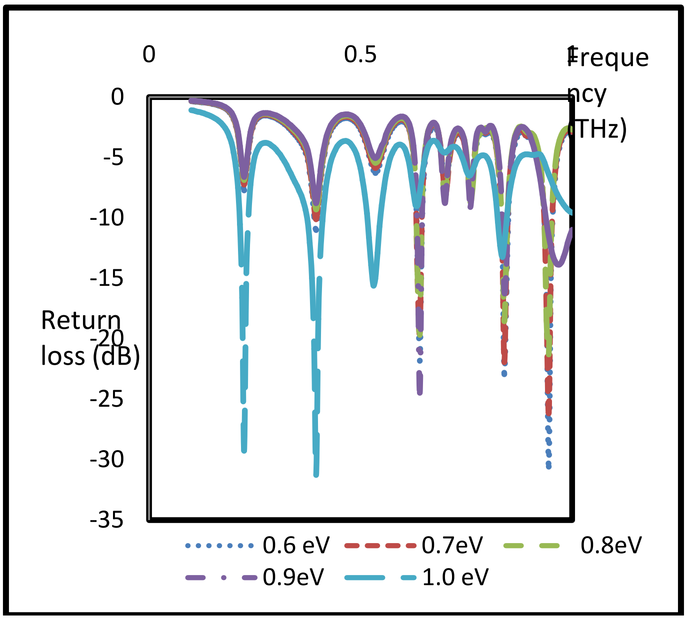

Fig. 15 Comparison of Return loss plots for various chemical voltages (0.6 eV to 1.0 eV)

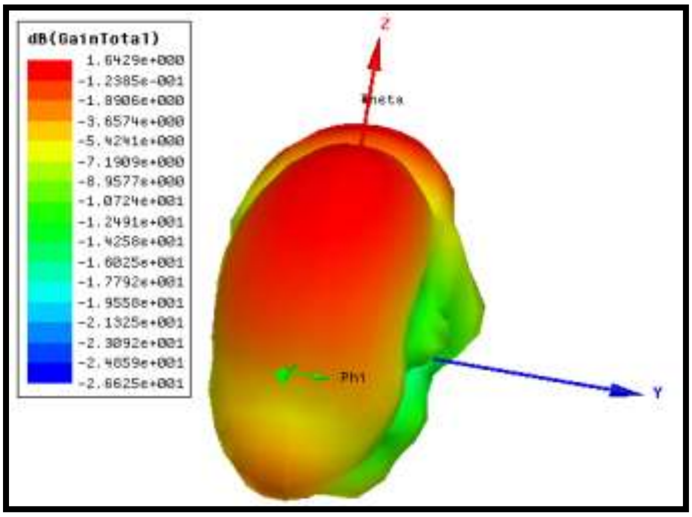

Fig. 16 Gain plot at chemical voltage of 0.6 eV

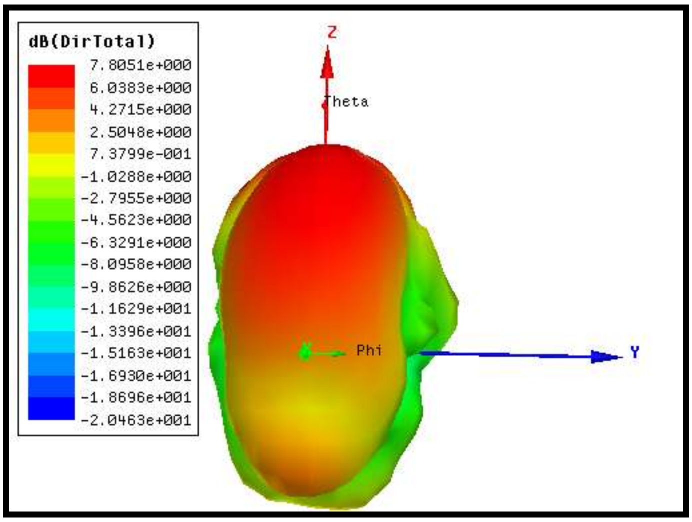

Fig. 16 Directivity plot at chemical voltage of 0.6 eV

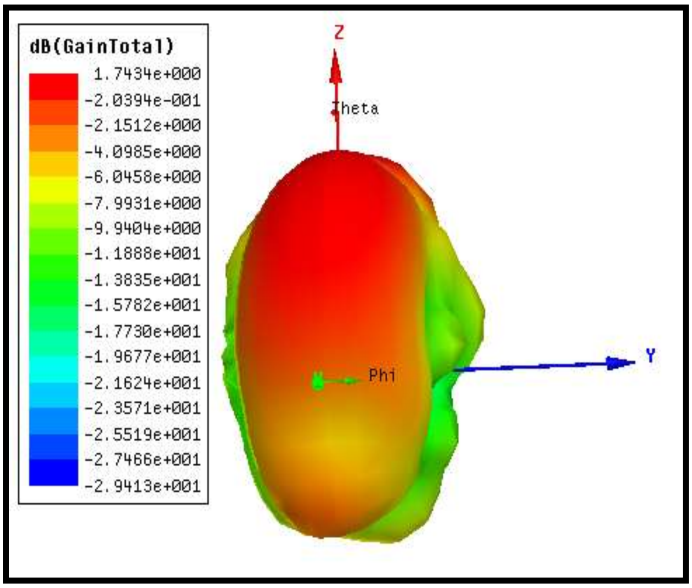

Fig. 18 Gain plot at chemical voltage of 0.7 eV

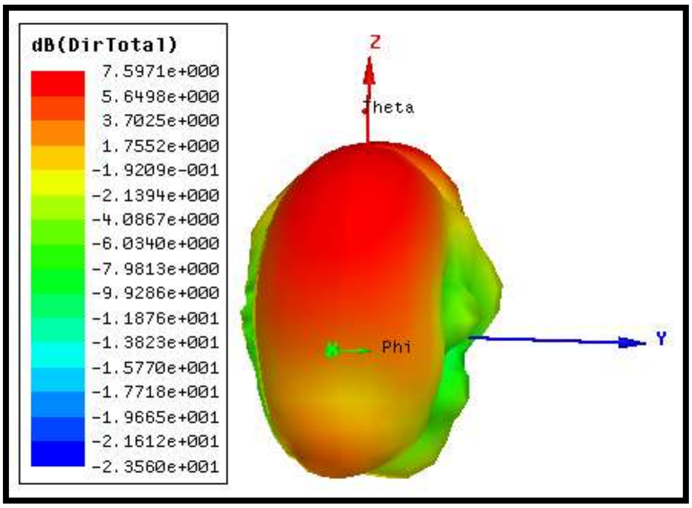

Fig. 19 Directivity plot at chemical voltage of 0.7 eV

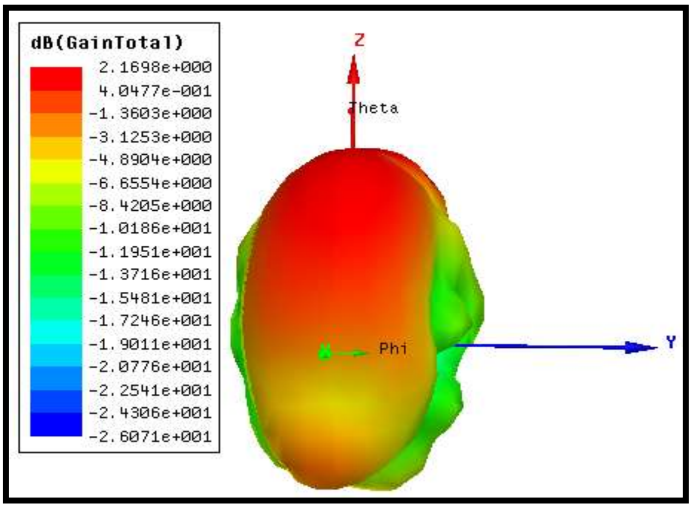

Fig. 20 Gain plot at chemical voltage of 0.8 eV

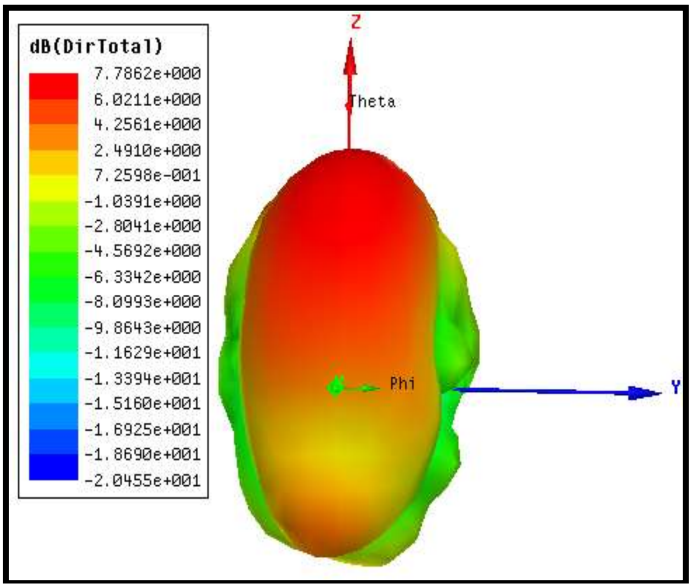

Fig. 21 Directivity plot at chemical voltage of 0.8 eV

IV. CONCLUSION

A small size terahertz microstrip antenna using graphene with tunable resonant frequency is proposed. Proposed antenna is analyzed for various parameters such return loss, directivity and reduced size. Reconfiguration of the proposed antenna is reported and verified by analyzing various return loss plots and their comparison considering chemical voltage from 0.1 to 1.0 eV. Minimum return loss of -32 dB is reported at 0.1 eV, 0.6 eV and 1.0 eV. Maximum value of the directivity reported is 7.8 dB. 3D Radiation pattern of the proposed is also shown at some selected chemical voltages. Proposed antenna has reduced size i.e. area and volume of the antenna are 0.082 mm^2 and 0.01 mm^3 respectively and at the same time performance is improved. Reduced size is very much suitable for future era applications such as wireless networks on chip (WNoC) and wireless nano sensor networks (WNSNs).

FUTURE SCOPE

Proposed design lacks in terms of gain of the proposed antenna, the maximum value is 2.16 dB, so there is scope to enhance the gain of the antenna. It may be achieved by some modifications in the design or material used in substrate or stack substrate.

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