On The Effect of Chemical Potential on Mutual Coupling Between Graphene Patch Antennas At THz Band

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ABSTRACT

This paper investigates the effect of mutual coupling between two graphene patch antennas designed for THz systems. In particular, a reduction of more than 22 dB in the level of mutual coupling between the two antennas is obtained with the proper choice of the voltage applied to the graphene sheets. As a result, a wider bandwidth is obtained with a better reflection coefficient level.

Keywords: graphene; THz; graphene antenna

I. INTRODUCTION

Terahertz frequency (THz) band is defined roughly as that portion of the electromagnetic spectrum which extends from 0.1 THz to 10 THz and occupies an extremely large region of electromagnetic spectrum between the infrared and microwave bands. In the last few decades the researchers' interest in the THz region has raised for its technological potentials [1]; recent innovations in THz technologies find application in a wide variety of fields: radio-astronomy, THz imaging, remote sensing [2], secure communication links, THz radars, plasma diagnostic and sub millimeter-wave applications [3][4]. In this context, many different methods have been studied to control waves actively, such as plasmonic, photonic and electrical approaches. Nowadays, new devices and materials like graphene are on demand for THz technology and in particular for THz antennas. Graphene, the most intensively studied material, is a two-dimensional version of graphite that consists of a planar atomic layer of carbon atoms bonded in a hexagonal structure. This material has gained a lot of attention since 2004, when it was first deposited on dielectric substrates through graphite exfoliation [5]. Graphene can be obtained by means of diverse fabrication techniques, among which chemical vapour deposition (CVD) is one of the most promising for technological applications. The electronic and mechanical properties of CVD-grown graphene depend in large part on the characteristics of the grain boundaries. Graphene, owing to its ability to support plasmon polariton waves in the terahertz frequency range, enables the miniaturization and electrical tunability of antennas to allow wireless communications among Nano systems. In accordance to its conductivity, the propagation of Surface Plasmon Polariton (SPP) waves on doped graphene has been recently analytically studied and experimentally proven. SPP waves are confined EM waves coupled to the surface electric charges at the interface between a metal (in particular conditions) and a dielectric material. The propagation of SPP waves even on noble metals, which are considered the best plasmonic materials, exhibit large Ohmic losses and cannot be easily tuned. On the contrary, SPP waves on graphene have been observed at frequencies as low as in the Terahertz Band and these can be tuned by means of material doping: this property opens the way to tunable THz-antennas. In this work we focus our attention on patch graphene antennas. For any wireless application, patch antenna has to meet the requirements of high gain and low return loss. The gain of a patch antenna can be improved by increasing the number of antenna elements forming a linear or planar array. In this case, mutual coupling between patch antennas (arising from space waves of surface waves) becomes an important factor to consider, because it affects antenna parameters like terminal impedance and reflection coefficients and therefore the antenna array performance in terms of radiation characteristics (gain and directivity). In this paper we illustrate the effect of applied voltage at graphene layers on the mutual coupling between the two graphene patch antennas

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II. GRAPHENE CONDUCTIVITY

Thanks to its mono-atomic thickness, graphene can be accurately modeled as an infinitely thin surface of complex conductivity. The surface conductivity can be represented in a local form with the Drude-like intraband contribution. So, in the desired frequency range the Kubo formula for graphene conductivity can be written as [6]

$$\sigma^{-1} = (2\Gamma + j\omega)\frac{\pi\hbar^2}{q_e^2\, k_B\, T}\left[\frac{\mu_c}{k_B\, T} + 2\ln\left(1 + e^{-\frac{\mu_c}{k_B T}}\right)\right] \quad (1)$$

Where ω is the radian frequency, μ_c the chemical potential, Γ a phenomenological scattering rate assumed to be independent of energy, T the temperature, q_e the electron charge, and $\hbar$ the reduced Planck's constant. In our structure the voltage is applied to the sandwich-like structure obtained by superimposing two graphene sheets at a very small distance, separated by SiO_2 dielectric material, as shown in Fig.1.

The relation between the bias voltage and chemical potential can be written as :

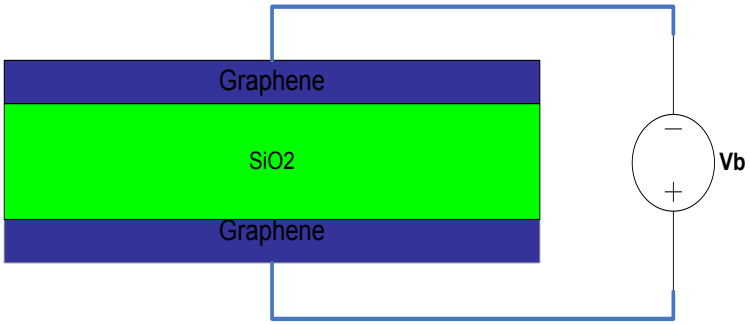

Fig.1. Voltage-controlled graphene sheets.

$$V_b = \left[\frac{q_e\, \mu_c^2\, h}{\pi\, \hbar^2 v_f^2\, \varepsilon_0\, \varepsilon_r}\right] \qquad (2)$$

Where V_b is the applied voltage on the graphene layer, h is the thickness of the substrate and $v_f \approx 1.0 * 10^6 m/s$; ε_0 and ε_r are the permittivity of vacuum and the relative permittivity of the dielectric respectively. From (2), the relationship between external voltage and chemical potential can be derived and is shown in Fig.2. The applied voltage increases when the chemical potential applied to the graphene increases.

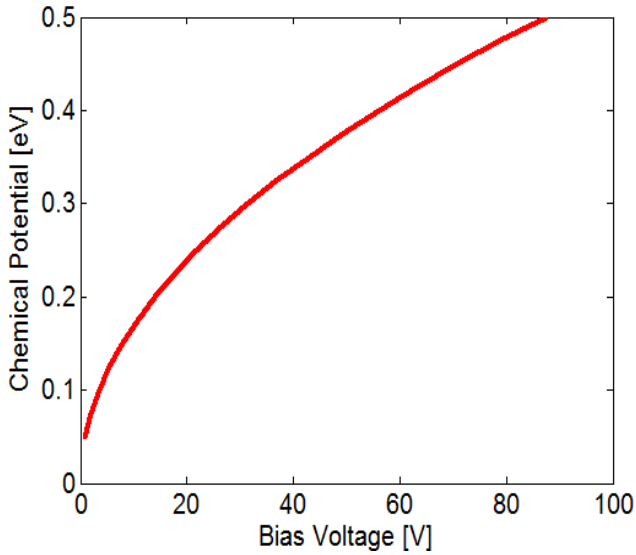

Fig.2. The relationship between applied voltage and chemical potential.

III. ANTENNA DESIGN AND RESULTS

In graphene, the electrons and holes are electrically induced by applying a positive or a negative voltage with respect to a reference electrode. Moreover, it has also recently been demonstrated that graphene can be efficiently used as a passive substrate with variable resistance, allowing the tuning of microwave devices in order to obtain the proper matching [7]. In this work, we present the effect of applied voltage on the mutual coupling between two graphene patch antennas. Mutual coupling between patch elements affects the radiation pattern and input impedances. The radiation from one element in the array induces currents on the other nearby elements and a further scattering contribution to the far field [8].

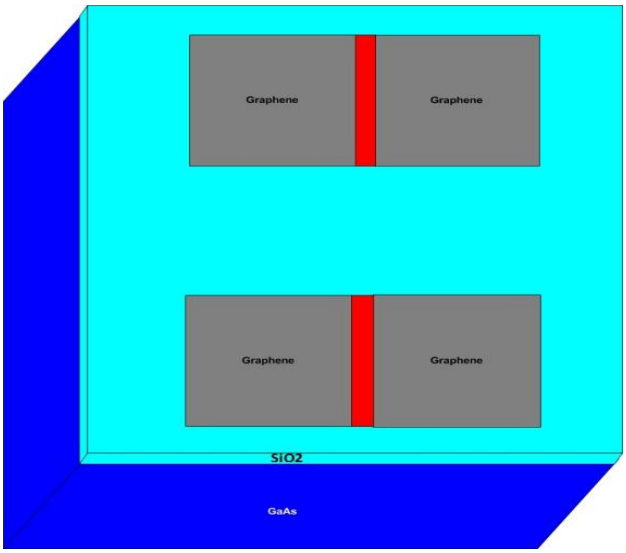

Fig.3. Antenna structure

Firstly we designed a simple dipole antenna consisting of two graphene layers, feeding a THz photo mixer which has an internal high impedance of about 10 kΩ and is placed above a GaAs-SiO_2 substrate as in Fig.3. The square substrate layer has a side length L=80 μm. On the top we have SiO_2 (h=1. 9 μm ,ε_r=3.8) and on the bottom GaAs (h=9 μm, tanδ=0.002 ε_r=12.9). The two dipole patch antennas with length 30 μm and width 15μm are located above the top of the dielectric structure. The simulation of this antenna is performed by the electromagnetic simulator FEKO [9]. Figure 4 shows the reflection coefficient (S11-solid line) and the mutual coupling coefficient (S21-dashed line), as a function of frequency for different values of the chemical potential, which in turn depends on the applied voltage. It is noticed that when the applied voltage is changed the resonance frequency changes (the antenna acts as a tunable antenna) and the mutual coupling decreases for decreasing values of the resonant frequency. For example, for μc=0.1 eV the resonance frequency is 1.5THz and the mutual coupling is -28dB, while for μc equal to 0.4 eV the resonance frequency is 2.7 THz and the mutual coupling increases to -21dB. So a significant improvement in isolation between elements can be obtained at low applied voltage on graphene layers. Figure 5 shows the gain at the resonant frequency as a function of chemical potential; we note that the gain decreases from 3.5dB at μc=0.05 eV (resonant frequency of 1 THz), to 1.2 dB for μc=0.3 eV (resonant frequency of 2.5THz).

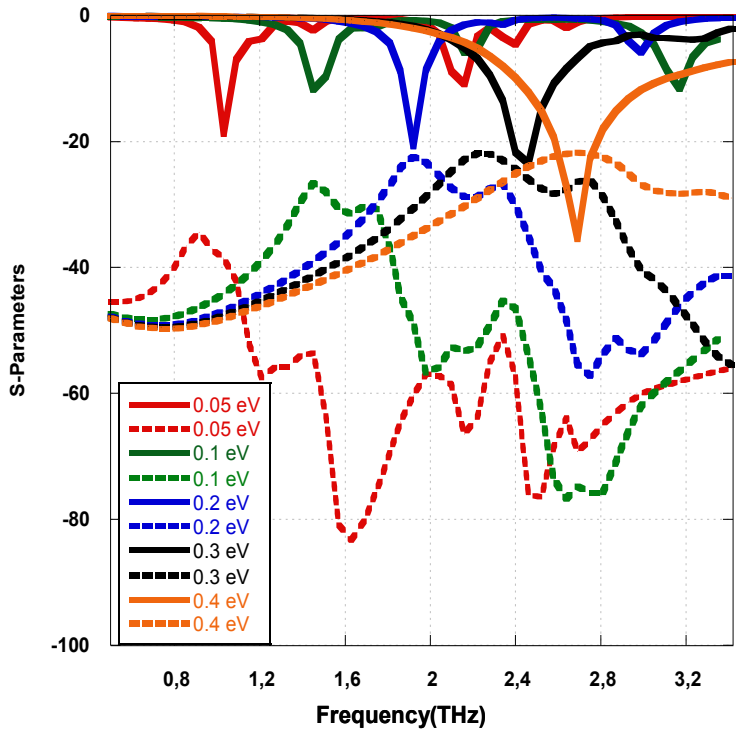

Fig.4. S-parameters

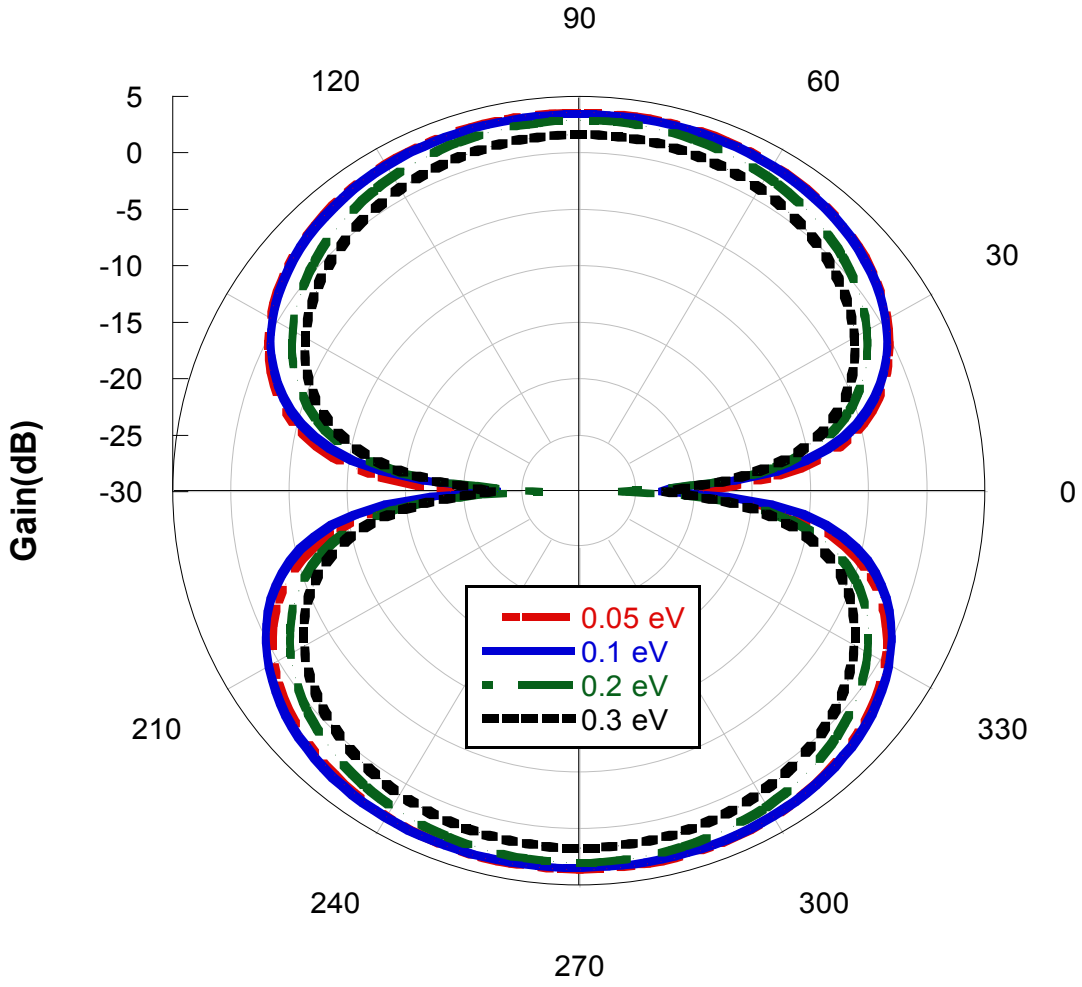

Fig.5. Gain

CONCLUSIONS

The use of graphene as a variable surface resistance was discussed in this paper with the aim of implementing a tunable patch THz antenna. In an array implementation, the mutual coupling between two patch antennas increases when the applied voltage on the graphene sheets is increased. By using a low voltage we can obtain a very good isolation between graphene patches.

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