THz Nano-Array Antenna Based On a Monolayer Reflector Graphene Surface

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ABSTRACT

Nano antennas recently became popular due to their ability to localize incident electromagnetic fields in sub-wavelength volumes. In this paper, a beam antenna is proposed for THz application, which is based on a switchable high-impedance surface (HIS) using a single-layer graphene. The use of graphene as reflection surface to enhancement the reflection power of the Nano antennas' system due to its unique electronic and optical properties which lead to a complex surface conductivity at THz frequencies. We report the configuration of a graphene patch array antenna based on grapheme surface deposited by Sio2/Si substrate.

Keywords: graphene; THz; graphene antenna

I. INTRODUCTION

Terahertz frequency (THz) band is coarsely defined as a portion of the electromagnetic spectrum which extends from 0.1 THz to 10 THz and occupies an extremely large region of the electromagnetic spectrum between the infrared and microwave bands, has attracted increasing attention in the last few decades for its technological potential [1]. Nowadays, new materials are on demand for THz technology especially THz antenna like graphene. Graphene, the most intensively studied material, a flat mono atomic layer of carbon atoms densely packed in a two-dimensional honeycomb lattice, has recently attracted the attention of the research community due to its novel mechanical, thermal, chemical, electronic and optical properties [2, 3, 4, 5]. Graphene is considered as a natural high impedance surface (HIS) due to its high resistivity in an ultra -wideband and can easily reach the THz band. The propagation features above the grapheme surface are defined by its conductivity that depends on other parameters such as the selected substrate and the applied voltage. Graphene also possesses fascinating properties including massless Dirac electronic structure, high mobility, extraordinary high thermal conductivity and strength which give it the possibility to be a good choice for THz applications .Graphene offers a new approach to THz communications thanks to its ability to support the propagation of Surface-Plasmon Polariton (SPP) waves in the terahertz frequency band [5]. Indeed, a graphene RF plasmonic antenna with lateral dimensions of just a few micrometers is predicted to resonate in the terahertz band [6] at a frequency up to two orders of magnitude lower [7] and with higher radiation efficiency with respect to typical THz metallic antennas [8-9]. In this contribution, a new beam antenna is designed based on the switchable graphene high-impedance surface (HIS) for THz application. We deal with the design of a single graphene patch antenna in the THz band, representing the main block in TX/ RX system for THz communication. Then by placing four graphene patches on a substrate with a graphene surface we achieve the tunability of the antenna parameters like: resonance frequency and radiation pattern.

II. ANTENNA DESIGN

In general, from an electrical point of view, graphene is a zero-gap semiconductor, or semi-metal, whose complex conductivity nature allows the propagation of plasmonic modes at THz frequencies. This conductivity of graphene is highly frequency-dependent, and can have completed different behavior e.g. at microwave and THz. The surface conductivity of an infinite graphene film can be calculated by means of the Kubo formalism[10]. Within the random-phase approximation, 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

$$\sigma^{-1} = (2\Gamma + j\omega) g(\mu_c, T) \qquad (1)$$

Where $g(\mu_c, T)$ is the real function independent of frequency given by:

$$g(\mu_c, T) = \frac{\pi\hbar^2}{q_e^2 k_B T}\left[\frac{\mu_c}{k_B T} + 2\ln\left(1 + e^{-\frac{\mu_c}{k_B T}}\right)\right]^{-1} \qquad (2)$$

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. The relation between the bias voltage and chemical potential can be calculated by [10]:

$$\mathrm{E} = \frac{\mathrm{e}}{\pi\hbar^2\varepsilon_0 v_f}\int_0^\infty \varepsilon\left(f_d(\varepsilon) - f_d(\varepsilon + 2\mu_c)\right)d\varepsilon \qquad (3)$$

Where

$$f_d(\varepsilon) = \left(e^{\frac{(\varepsilon-\mu_c)}{k_B T}} + 1\right)^{-1}$$

is the Fermi-Dirac distribution, ε is energy, and k_B is Boltzmann's constant. The resonant frequency of the graphene antenna can be dynamically tuned with the application of an electrostatic voltage. In Fig. 1, we report the configuration of a single graphene THz patch antenna(a=12 μm) over a 100 nm layer thickness of Al_2O_3 insulating film (εr = 9, $\tan\delta$ = 0.01) whose length is 20 μm, which provides a suitable method to control the graphene complex conductivity via electrostatic field effect [11]. Then by placing four symmetric graphene patches on a graphene monolayer deposited on 150 μm x 150 μm Si/SiO2, where the SiO2 layer has a thickness of 300 nm.

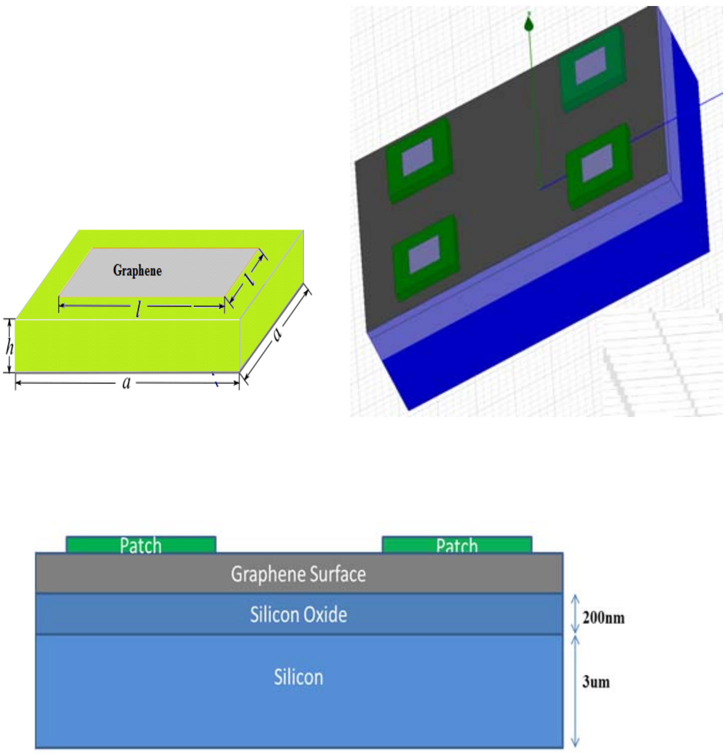

Fig.1. Geometry of the antenna layout

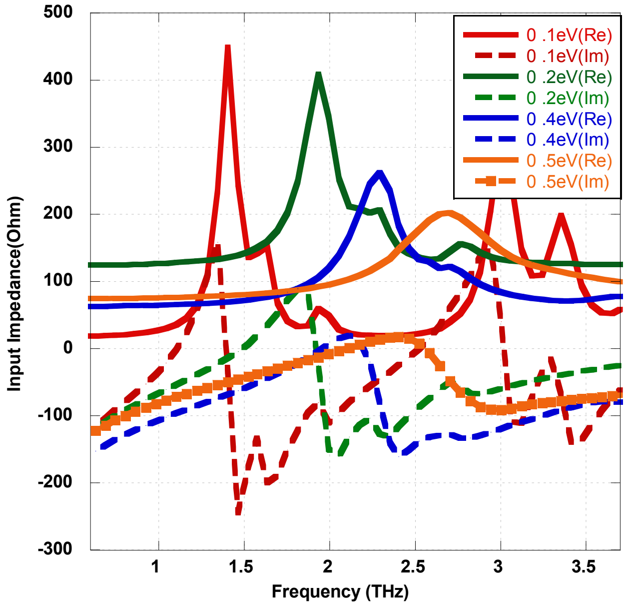

Fig.2. Input impedance at different bias voltages

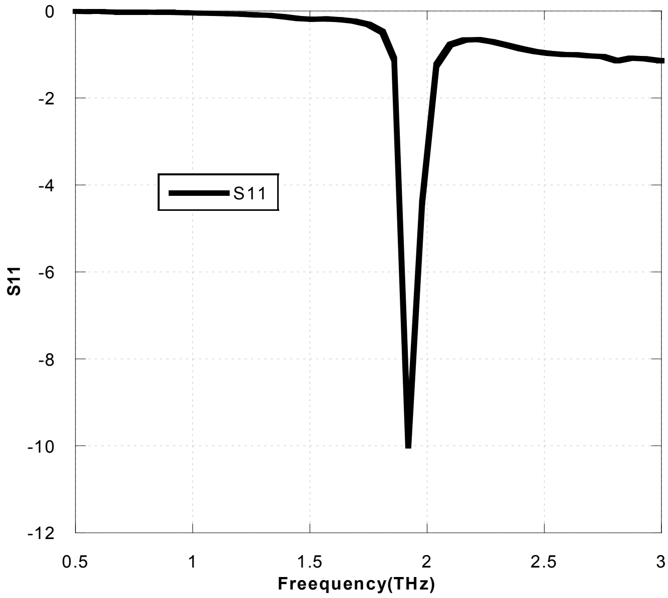

Fig.3. The return loss of single graphene patch

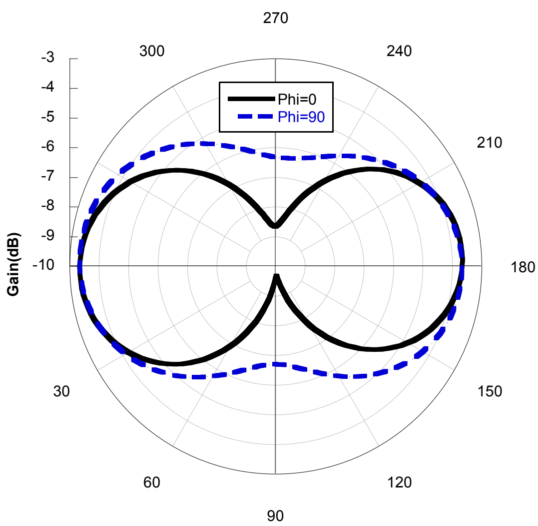

Fig.4. Gain of single graphene patch

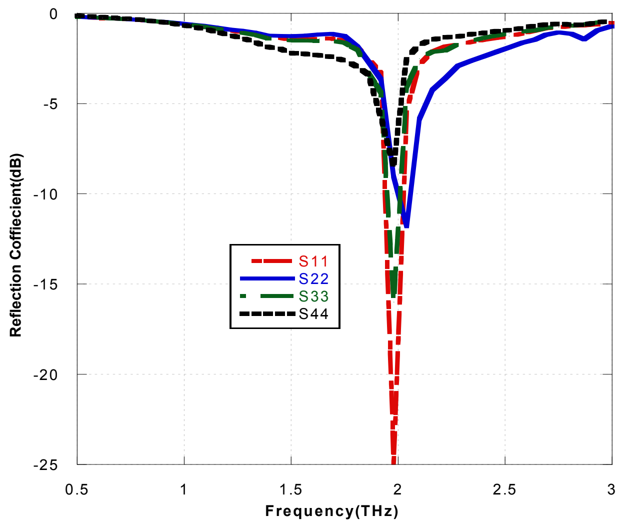

Fig.5. Return loss of the array nano- antenna

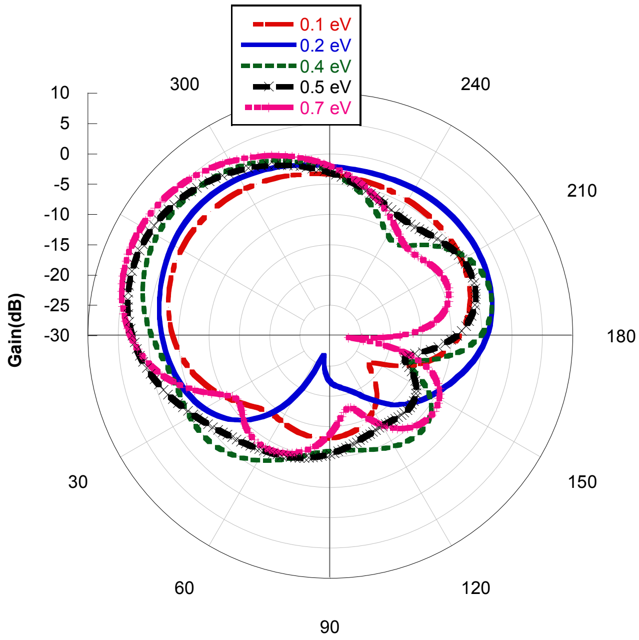

Fig.6. The Gain for values of μc for the graphene surface layer.

III. RESULTS AND DISCUSSION

The antenna design has been simulated using FEKO [12]. Firstly we started with the single graphene patch antenna. The resonance frequency can be changed due to the change of the D.C bias voltage at the graphene layer and thus the chemical potential μ_c due to tunability of the graphene surface resistance as indicated by equation (2) and (3). When the applied voltage on the graphene layer is increased, the chemical potential is increased also depending on the relation between the bias voltage and the chemical potential of graphene, but the real part of the impedance of graphene becomes lower. This leads to a change in the conductivity of the layer as shown in Fig. 2, which shows the real and imaginary parts of the antenna's impedance. From Fig.3 and 4 we can see that the antenna has a good return loss at roughly 1.9 THz at μ_c equal to 0.2 eV, but on the other hand the gain is still low, the maximum peak gain being about -3.5dB. In other words around half of the power is lost. If a graphene layer is added as a variable impedance section between the air and Si/SiO2, the reflection of the antenna can be improved. So, we designed an array configuration from four symmetric graphene patch elements and fixed them on a graphene surface deposited on Si/SiO2 . The main property of an antenna array that must be addressed here is radiation enhancement. Given that the coupling among the array elements is negligible, doubling the number of elements in a linear or planar array fed in phase doubles the directivity of the array. Figure 5 shows that the reflection coefficient roughly has the same resonance frequency as 1.9 THz with -10dB at the same applied voltage with $\mu_c = 0.2$ eV. The radiation pattern properties of the antenna model is shown in Fig. 6, which the gain increases by increasing the applied voltage on the graphene surface with a suitable efficiency . So, we can conclude that planar single patch antenna radiates equally on both sides as in Fig.4,while this symmetry can be broken by the presence of a graphene surface on one side as in Fig.6; this difference is due to changing current distribution on the antenna's surface. In this case, the antenna radiates most of its power into one side with more directivity. So a graphene layer is added between the air and the SiO2/Si substrate to act as a matching section. This matching section improves the radiation properties of the antenna .

CONCLUSION

It has been shown that graphene is a promising material for the realization of miniaturized resonant THz antennas. The use of graphene for realizing tunable graphene-based reflective layer, operating at THz is presented. We analyze a graphene-based Nano patch array antenna at THz band. Starting from design a single graphene patch element to the full array which is based on a graphene surface to control and improve the radiation properties of the antenna. The effects of a reconfigurable graphene reflective surface are introduced depending on the change in applied voltage. The results show that by increasing the applied voltage of the graphene surface, the gain is increased , which has a peak value larger than 6 dB.

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