Reconfigurable Terahertz Dipole Antenna with Integrated Graphene Sheets

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Reconfigurable Terahertz Dipole Antenna with Integrated Graphene Sheets

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***Abstract*-The tunability of graphene's surface conductivity attracts tremendous interests in electromagnetic applications. This proposing feature enables graphene one of the ideal materials for reconfigurable antenna designs. In this paper, a new dipole antenna with two integrated graphene sheets operating in terahertz frequency is proposed and its reconfiguration of radiation properties is investigated. The two graphene sheets are deposited at the feeding positions of the two dipole arms, which increases the tunable freedoms of the dipole antenna's impedance up to two degrees. The tunable two-degree freedom of the dipole antenna enables antenna's operating frequency reconfigurable in a wide frequency range from 0.65 to 1 THz, and total radiation efficiency change from 13% to 89% when graphene chemical potential is electrically tuned from 0 eV to 0.5 eV. At 1 THz frequency, the realistic gain can be tuned from 1.6 dB to -8.7 dB. The more than 10 dB difference of the realistic gain makes the dipole antenna switchable. The fancy reconfigurable properties of the dipole antenna can be applied for multi-functional wireless THz systems and beam-forming THz antenna arrays.**

I. INTRODUCTION

The advancement in wireless systems requires the integration of multiple radios into a confined space to maximize connectivity. Reconfigurable antennas are proposed to cover different wireless services that operate over a wide frequency range, and significantly satisfy the requirements of multi-functional wireless systems [1,2]. A reconfigurable antenna can achieve a tunable operating frequency, a reconfigurable radiation pattern, a reconfigurable polarization behavior, or a combination of any of these properties [1]. Conventional electrical reconfiguration techniques are mainly based on the use of switches, such as radio frequency micro-electromechanical systems (RF-MEMS) and p-i-n diodes or varactors, to connect and disconnect antenna parts as well as to redistribute the antenna currents [3-5].

In the sub-Terahertz and Terahertz (THz) frequency domain, the two-dimensional material graphene is introduced for tunable electromagnetic devices with specific advantages, such as modulators [6], absorbers [7,8]. Graphene is attracting increasing research interests on reconfigurable antennas because of its tunable surface conductivity and easy integration with other components in the THz frequency [9,10]. However, graphene based reconfigurable antennas suffer low total radiation efficiency, especially when graphene chemical potential is close to 0 eV [10,11]. In this paper, a new reconfigurable dipole antenna with graphene integrated is proposed. The investigation of the reconfigurable dipole antenna is not limited to its reconfiguration properties but also try to seek the potential applications of its low total efficiency.

II. DIPOLE ANTENNA WITH INTEGRATED GRAPHENE

A. Electromagnetic Properties of Graphene

The electromagnetic properties of a two-dimensional graphene sheet can be represented by its surface conductivity. Graphene surface conductivity consists of intraband and interband terms. In the terahertz and lower frequency bands, interband contribution to graphene's surface conductivity is negligible compared to the intraband contribution [8,12]. The Drude-like model of graphene's surface conductivity is

$$\sigma_s \approx \sigma_{s,intra} = \frac{\sigma_0}{1+j\omega\tau}\,. \qquad (1)$$

where

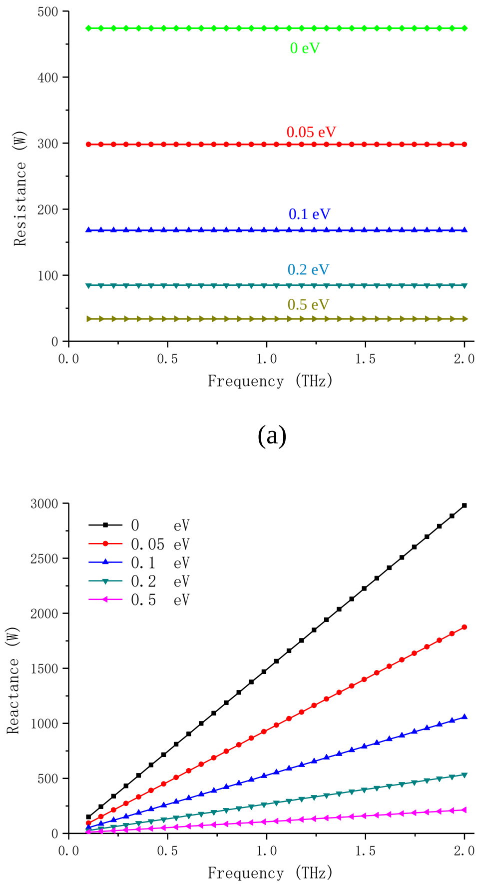
$$\sigma_0 = \frac{e^2\tau k_B T}{\pi\hbar^2}\left[\frac{\mu_c}{k_B T} + 2\ln(e^{-\frac{\mu_c}{k_B T}}+1)\right] \qquad (2)$$

is the direct-current (DC) conductivity, σ_s is graphene surface conductivity, $\sigma_{s,intra}$ is graphene intraband conductivity, e is the charge of an electron, $\tau = 1/(2\Gamma)$ is the phenomenological electron relaxation time, Γ is scattering rate, k_B is Boltzmann's constant, T is temperature in Kelvin, ω is angular frequency, $\hbar = h/2\pi$ is reduced Planck's constant, and μ_c is chemical potential.

The surface impedance of a graphene monolayer is related to its surface conductivity and has the relationship

$$Z_s = \frac{1}{\sigma_s} = R_s + jX_s \qquad (3)$$

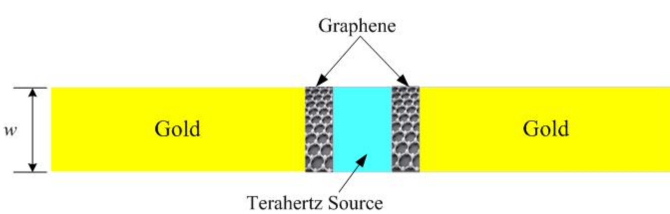
where Z_s is graphene surface impedance, j is the imaginary unit, R_s and X_s are resistance and reactance, the real and imaginary parts of surface impedance, respectively.



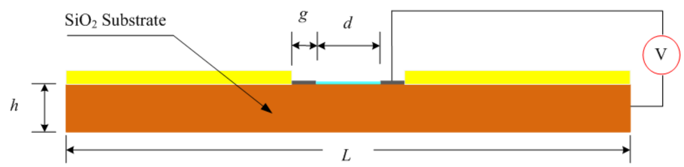
(b)

Figure 1. Graphene surface impedance versus frequency for different chemical potentials: (a) resistance; (b) reactance.

At room temperature, the frequency dependent surface impedances of a graphene monolayer are plotted in Fig.1 for different chemical potentials. The relaxation time is chosen as 0.5 ps. The surface resistance of graphene is almost frequency independent for every single chemical potential and reduces with increasing chemical potential; the surface reactance of graphene, however, increases monotonically with frequency for every single chemical potential, and decreases with increasing chemical potential at a fixed frequency. The frequency independent resistance of graphene shows frequency independent energy absorption.



(a)



(b)

Figure 2. Schematic diagram of dipole antenna with integrated graphene sheets: (a) top view; (b) side view.

B. Dipole Antenna with Integrated Graphene sheets

A dipole antenna consisting of two gold patches, two graphene sheets, and SiO_2 substrate is displayed in Fig. 2. Two Graphene sheets are symmetrically integrated between two gold patches and terahertz source. Gold patches and graphene sheets are deposited on SiO_2 substrate. Two DC-voltage sources are connected with two graphene sheets, respectively, and commonly connected with SiO_2 substrate. DC-voltage sources are used to apply voltages to two graphene sheets, and then tune surface impedances of two graphene sheets via changing their chemical potentials. The length and width of dipole antenna are L = 140 um and w = 10 um, respectively. Length of two graphene sheets is equal and g = 1.5 um. The gap width between two graphene sheets is d = 7 um. Thickness of substrate is h = 0.3 um.

For graphene sheet, the relaxation time is 0.5 ps, and temperature is 300K. Two different bias voltages can be applied to two graphene sheets, which makes tunability of the antenna radiation more flexible compared to one graphene sheet situation. The chemical potentials of two graphene sheets are denoted by μ_1 and μ_2, respectively, both of which vary from 0 eV to 0.5 eV. To show capability of tuning antenna radiation through integrated graphene sheets, 6 pairs of specific chemical potential values are chosen for the two graphene sheets. The reflection coefficients in dB versus frequency are plotted in Fig. 3 for 6 pairs of μ_1 and μ_2 values. It shows that resonant frequency of dipole antenna shifts from 0.65 THz to 1 THz by increasing the total chemical potentials of two graphene sheets, while the realistic gain is incrementally tuned from -6.8 dB to 1.6 dB and total radiation efficiency increased from 13.3% to 89.2% as shown in table I.

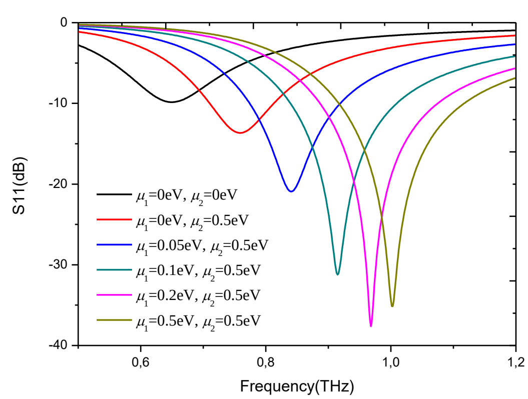


Figure 3. Reflection coefficients of the dipole antenna versus frequency for different chemical potentials of graphene.

TABLE I
RADIATION FEATURES OF DIPOLE ANTENNA FOR DIFFERENT GRAPHENE CHEMICAL POTENTIALS

Chemical potential μ_1(eV)	Chemical potential μ_2(eV)	Operating frequency (THz)	Total efficiency	Realistic Gain (dB)
0	0	0.65	13.3%	-6.76
0	0.5	0.76	27.5%	-3.57
0.05	0.5	0.84	47.0%	-1.20
0.1	0.5	0.91	67.5%	0.40
0.2	0.5	0.97	81.4%	1.25
0.5	0.5	1.00	89.2%	1.62

At 1 THz, the total efficiency and realistic gain of dipole antenna are 89.2% and 1.62 dB for graphene chemical potentials μ_1= μ_2 = 0.5 eV, respectively, and can be tuned down to 8% and -8.7 dB via changing graphene chemical potentials to μ_1= μ_2 = 0 eV. More than 10 dB realistic radiation gain difference is reached at the operating frequency 1 THz via supplying two different bias DC-voltages applied to graphene sheets.

III. CONCLUSION

Tunable property of graphene surface conductivity is implemented into THz dipole antenna design and makes the radiation features of the proposed dipole antenna reconfigurable. Through varying graphene chemical potential from 0 eV to 0.5 eV, the operating frequency of dipole antenna is tunable in the range from 0.65 to 1 THz, total radiation efficiency is tuned from 13.3% to 89.2%, and the realistic gain is changed from -6.8 dB to 1.6 dB. The lowest total radiation efficiency 13.3 % at resonant frequency 0.65 GHz is suffered mainly due to strong absorption of graphene at chemical potential 0 eV. At the fixed operating frequency 1 THz, the realistic radiation gain can be tuned from 1.6 dB to -8.7 dB, which makes dipole antenna switchable. The switchable feature can be applied for electrically controllable beam-forming antenna array.

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