A Tunable Antenna Based on Loaded Graphene Sheets for GHz Applications

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***Abstract*—A novel dipole antenna with graphene loaded on both ends is studied in this paper. It has an obvious tunable range by changing the loaded graphene surface impedance. Simulation results indicate that by changing the surface resistance of the graphene from 50 Ω/□ to 1000 Ω/□, the resonant frequency of the proposed antenna can be tuned from 7.8 GHz to 10.7 GHz Moreover, both the bandwidth performance and the radiation pattern still perform well while adjusting the graphene surface resistance. This antenna is designed for GHz applications and the results are useful for designing tunable graphene antennas and other devices working in GHz band.**

Keywords—tunable GHz antenna; loaded graphene;

I. INTRODUCTION

Graphene has been a hot topic since it was experimentally discovered about one decade ago. Many results about using graphene in THz devices have been reported so far [1] [2] [3]. Our group has also made some progress in designing tunable graphene devices in THz band，and we are also trying hard to design graphene devices in GHz band [4] [5] [6]. Nevertheless, it is still a challenge to use graphene to fabricate the tunable passive devices in GHz. It has two main reasons. For one thing, the surface conductivity σ of a thin layer graphene sheet can be expressed as

$$\sigma(\omega,\mu_c,\Gamma,T)=\frac{je^2(\omega-j\Gamma)}{\pi\hbar^2}\Big[\frac{1}{(\omega-j\Gamma)^2}\int_0^\infty \varepsilon\Big(\frac{\partial f_d(\varepsilon)}{\partial\varepsilon}-\frac{\partial f_d(-\varepsilon)}{\partial\varepsilon}\Big)d\varepsilon - \int_0^\infty \frac{f_d(-\varepsilon)-f_d(\varepsilon)}{(\omega-j\Gamma)^2-4(\varepsilon/\hbar^2)}d\varepsilon\Big], \tag{1}$$

where ω is the radian frequency, μ_c is the chemical potential, Γ is the phenomenological scattering rate, T is the temperature, and $f_d(\varepsilon)=1/(\exp((\varepsilon-\mu_c)/k_BT)+1)$ is the Fermi-Dirac distributions. The surface impedance ($1/\sigma$) and the conductivity of the graphene are much more frequency-sensitive in THz as this Kubo formula describes [7]. While in microwave band, graphene remains the surface impedance tunable property, but the inductance characteristic can be negligible, which greatly limits its applications in GHz antennas and other devices. For another, the traditional method to change the graphene surface impedance is adding electric field vertical to the graphene. In this case, a thin layer of isolation oxide should be introduced under the graphene. Actually, this manufacturing process introduced above will bring a lot of trouble to fabricate the antenna working in microwave.

Thankfully, a group proposes a new method to change the surface impedance of the graphene. They apply the bias voltage horizontal to the graphene and in that way the isolation oxide layer is no longer used. They also study it by experiment to show the dependence of surface impedance on the bias voltage [8]. In our previews work, we have also proposed a contact free characterization technique to obtain the surface impedance of graphene [9]. As a lot of paper reported, the typical values are from 100 Ω/□ to 1000 Ω/□. Moreover, few layer graphene is reported to have surface impedance as low as 10 Ω/□. Here we change the surface impedance from 50 Ω/□ to 1000 Ω/□ to study the performance of the proposed dipole antenna in our following simulations. These values can be tuned by changing the extern voltage applied on the graphene.

II. PROPOSED STRUCTURE AND SIMULATION

The structure of the proposed tunable antenna is shown in Fig. 1. We choose FR-4 (ε_r =4.3, loss tanδ = 0.025) as the substrate (green). The graphene sheets (black) are connected at the ends of the dipole antenna to extend its physical length. Respectively, at another side of the two graphene films, we also introduce two short pieces of metal, which are connected to the ground plane through two vias, for we can apply the DC voltage at the back of the substrate to bias the two graphene films. As for the zero bias voltage, we can introduce it though the feeding line. Thus, by adjusting the DC bias voltage, the surface impedance of the two graphene sheets can be controlled.

Here, we choose 50 Ω/□, 150 Ω/□, 250 Ω/□, 450 Ω/□, 650Ω/□, 1000Ω/□ to represent the change of the graphene surface impedance. All the return losses are summarized in Fig. 2. We can see from Fig. 2 that the resonant frequency of the proposed antenna is about 7.8GHz, when the surface impedance is 50 Ω/□. As the surface impedance becomes larger, the center frequency also tends to become larger. And the antenna has a resonant frequency of 10.7 GHz, when the surface impedance becomes 1000 Ω/□. It illustrates that our proposed antenna can have an obvious shift in resonant frequency when the surface resistance of the applied graphene changes.

This work was jointly supported by the National Science Foundation of China (61371031 & 61571395).

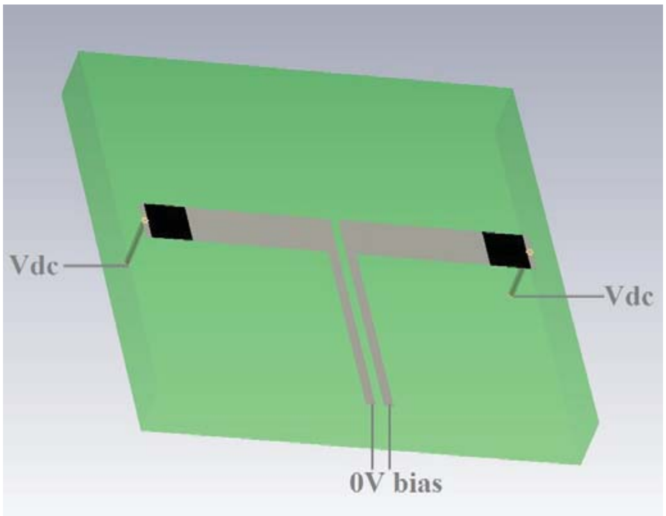

Fig. 1. Perspective view of the proposed tunable antenna structure.

From Fig. 2, we can also find the bandwidth performance of the antenna is still relatively wide although we introduce the lossy material (graphene) and change its surface impedance. What is more, Fig. 3 shows the radiation pattern and we can find both the main lobe gain and the side lobe suppression of the proposed graphene loaded antenna still perform well as the graphene surface impedance changed from 50 Ω/□ to 1000 Ω/□. In a word, the proposed antenna has an obvious tunable range and its radiation performance is not badly influenced by changing the graphene surface impedance.

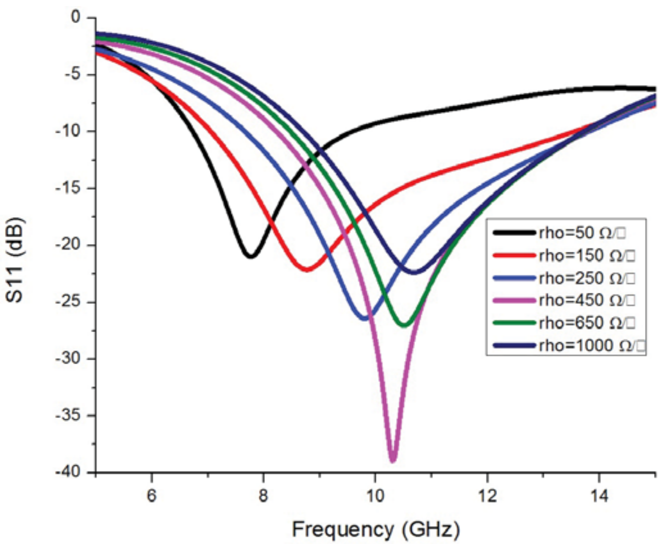

Fig. 2. Return loss of the proposed antenna with different graphene surface impedance.

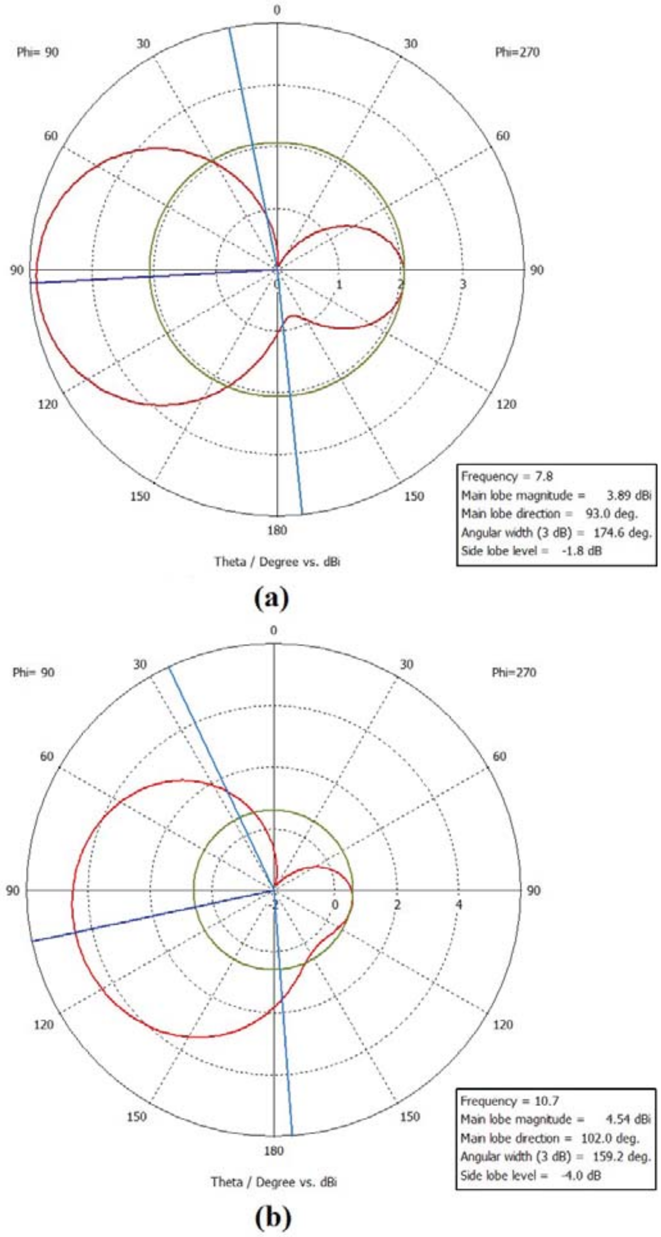

Fig. 3. The radiation pattern of the proposed antenna. (a) With 50 Ω/□ graphene sheets (black) loaded. (b) With 1000 Ω/□ graphene sheets loaded.

III. DISCUSSION

To illustrate the tunable property of the resonant frequency, we analyze the surface current of the proposed antenna shown in Fig. 4. From Fig. 4, we can find that the resistive graphene can also carry the radiation current and this current can be controlled by changing the surface resistance of the loaded graphene. In Fig. 4(a), the surface impedance of the graphene is 50 Ω/□, and we can see the surface current is

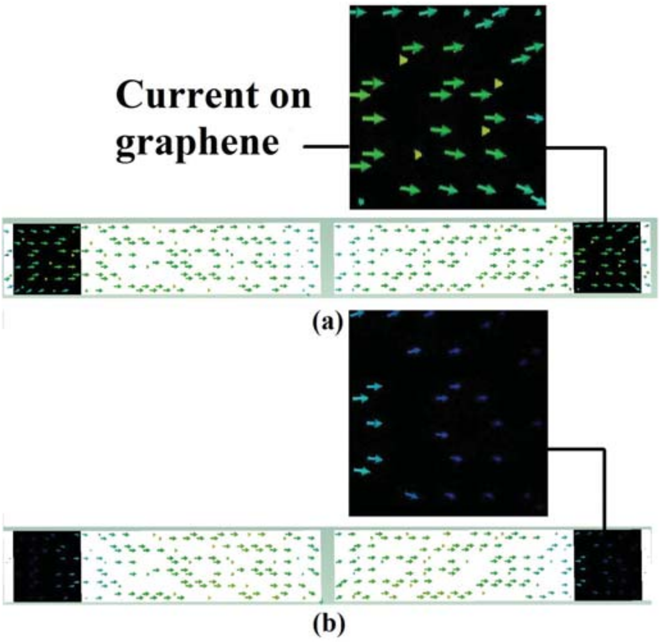

Fig. 4. The surface current on the main body of the proposed antenna. (a) With 50 Ω/□ graphene sheets (black) loaded. (b) With 1000 Ω/□ graphene sheets loaded.

obviously stronger than that on the 1000 Ω/□ graphene sheets shown in Fig. 4(b). Moreover, the introduced two vias and small metal connected to the ends of the dipole may influence the radiation of the antenna, we have already taken their effect into consideration in our simulation and it is also necessary for later experimental research.

While for the moving direction of the resonant frequency, it is easier to understand after showing the change of the surface current on the graphene. Compared to the surface current on the 1000 Ω/□ graphene sheets, when the graphene surface impedance of the graphene becomes smaller, it carries stronger current and thus the electric length of the dipole antenna is increased. For the resonant frequency of dipole antenna, it is mainly decided by the effective electric length, so it tends to become smaller and smaller as the graphene surface impedance changes from 1000 Ω/□ to 50 Ω/□. We can also suppose that as the surface impedance decreases to a certain degree, the resonant frequency will never become smaller, and the scattering property of the graphene is pretty close to that of metal.

IV. CONCLUSION

In this paper, we propose a novel tunable antenna which has graphene sheets loaded at both ends. This dipole is designed for GHz applications. It is found in simulation that the antenna has an about 2.9 GHz shift in the resonant frequency with graphene surface impedance changed from 50 Ω/□ to 1000 Ω/□. What is more, we explain this phenomenon by analyzing the scattering change and the surface current of the applied graphene. These results are helpful for designing other graphene tunable antennas and devices.

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