Multi-layered Graphene Based Optically Tunable Terahertz Absorber

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***Abstract*—we present a broadband tunable terahertz (THz) absorber, which consists of cross-shaped multi-layered graphene (MLG) resonators. The proposed absorber possesses almost perfect absorption over the range 0.4-0.8 THz and can be easily fabricated. Dynamical tuning of absorption band is achieved by external optical pumping of modest intensity. This multi-layered graphene-based absorber has high potential for various THz applications**

I. INTRODUCTION

GRAPHENE metamaterial devices particularly absorbers have become recently in the focus of research attention, especially in the THz frequency range [1-4]. In comparison with conventional THz absorbers, graphene-based ones possess tuning capability of absorption characteristics in terms of resonant frequency and absorption value due to the graphene unique and adjustable electronic transport properties. Moreover, graphene can interact with radiation in millimeter, infrared and visible range of wavelengths, so using this material the possibility of THz radiation control by optical pumping can be achieved. However, most of existing graphene THz absorbers usually have low and narrowband absorption in the THz frequency range due to the limits concerning weak light-matter interaction in graphene monolayer and its resonant nature. To realize high wideband absorption, multi-resonance and multi-layering approaches are utilized, which are difficult in practical implementation [5]. Therefore, development of a tunable near-perfect broadband THz absorber which can be easily manufactured is an important task.

In this work, we propose an optically tunable wideband THz absorber based on multi-layered structured graphene (about 80 layers) that achieves almost perfect absorption over 0.4-0.8 THz and can be easily fabricated.

II. RESULTS

The designed unit cell of multi-layered graphene-based absorber metasurface is shown in Fig. 1. The structure consists of cross-shaped MLG resonators, 0.5 μm thick aluminum bottom film (with conductivity $\sigma=3.56\times10^7$ S/m) and 80 μm thick dielectric (with permittivity $\varepsilon=2.1$) spacer between them (made from TPX material which is near-fully transparent in the THz frequency range). The boundary conditions are selected to be periodical along x- and y-axis, and the THz radiation propagates along z-axis from the graphene-coated side. THz wave reflects from the aluminum film, so it interacts with graphene two times: it increases the efficiency of the device and makes it work in the reflection (absorption) mode. The parameters of the device are controlled by applying continuous-wave (CW) external optical pumping with wavelength of 980 nm and intensity in range from 0 to 10 mW/mm^2, which significantly changes the THz complex conductivity of multi-layered graphene.

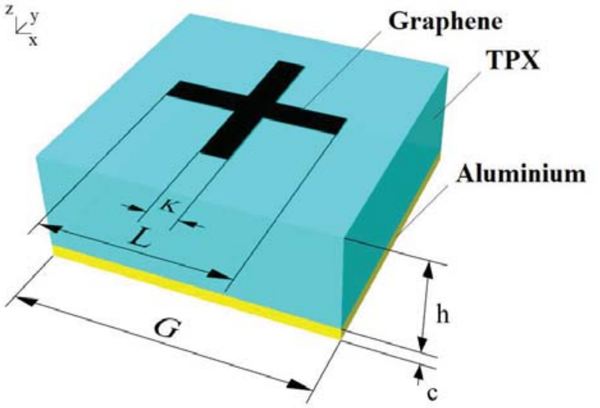

Fig. 1. Unit cell geometry of the proposed optically tunable absorber based on multi-layered graphene metasurface. The geometrical dimensions are the next: K=20 μm, L=175 μm, G=200 μm, h=80 μm, and c=0.5 μm.

To obtain absorption characteristics of the proposed THz device (Fig. 3), we performed numerical simulations based on finite element method (FEM) using CST Microwave Studio suite. The MLG was defined as infinitely thin film with experimentally obtained conductivity spectra in the 0.3-1.0 THz frequency range (Fig. 2) [6]. The MLG sample was fabricated by chemical vapor deposition (CVD) method in quartz furnace. The optoelectronic properties of this sample were studied by pulsed terahertz time-domain spectroscopy (THz-TDS) method in transmission mode using thin-film approximation (when the wavelength of THz radiation is much more than thickness of MLG) for the different infrared optical pumping intensities. The measurements were performed at room temperature under normal conditions.

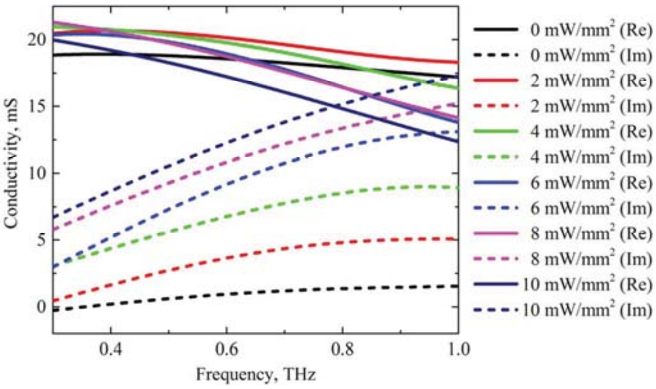

Fig. 2. Real and imaginary part of MLG conductivity vs frequency under optical pumping (980 nm) of different intensities.

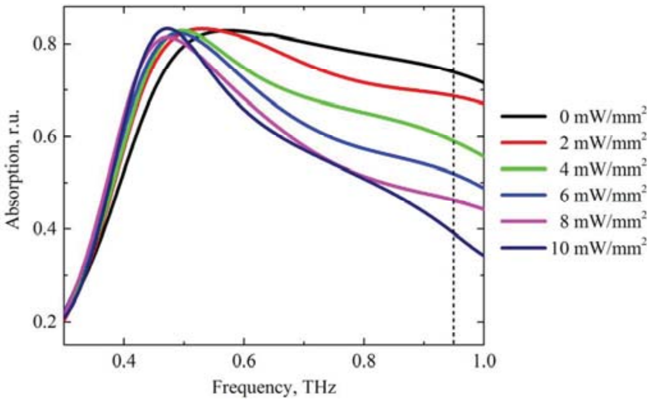

Fig. 3. Absorption spectra of MLG-based THz absorber under different optical pumping intensities.

As it can be seen from Fig. 2, the external optical pumping significantly changes the imaginary part of complex conductivity of MLG. At the same time, there is a tendency to saturation of changes in the spectrum of imaginary part of conductivity. The real part of the complex conductivity varies in a limited range of values.

The absorption spectra of designed device are shown in Fig. 3. As depicted in this figure, there is a significant influence of external optical pumping (980 nm) of modest intensity over absorption spectrum from 0.3 THz to 1 THz. Vertical dashed line in Fig. 3 represents the 0.95 THz frequency point, for which the dependency of absorption coefficient on optical pumping intensity is shown in Fig. 4.

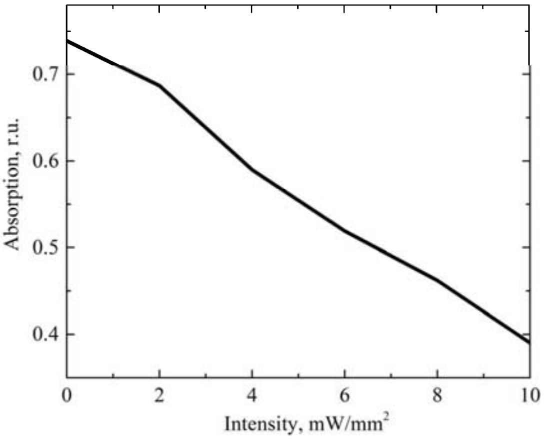

Fig. 4. Absorption coefficient of MLG-based THz absorber at 0.95 THz vs optical pumping intensity.

Fig. 3 shows that the proposed structure works in broadband mode, and the degree of tunability depends on the frequency of THz radiation. At 0.5-1.0 THz, as the intensity of the optical pumping increases, the absorption of the structure decreases. The greatest amplitude of absorption tuning is observed at frequencies near 0.9-1.0 THz. In Fig. 4 it is shown that at 0.95 THz the absorption coefficient of MLG-based absorber near-linearly depends on the intensity of infrared optical pumping and varies from 0.74 to 0.39 r.u. It also should be mentioned that at some frequency points (0.3 and 0.5 THz) the absorption coefficient almost does not depend on the pumping intensity. The position of such frequency points depends on the geometry of the metasurface unit cell.

III. SUMMARY

In summary, we have designed and numerically simulated an optically tunable broadband near-perfect THz absorber based on multi-layered graphene metasurface. Despite the ordered structure of the surface, this device operates in broadband mode. The ultrafast electronic properties of graphene allow to realize high-speed modulation of amplitude of THz wave which interacts with absorber. The usage of optical pumping method avoids the application of an electrode system and makes the absorber to work in all-optical mode. Moreover, the usage of optical pumping allows to achieve the working frequency of the device, unattainable in the electronic control circuit. Graphene is resistant to atmospheric influences and easily can be manufactured. It was shown that the efficiency of the absorption modulation depends on the frequency of THz radiation, while the absorption spectra of the structure are determined by its geometric parameters. Relatively weak optical pumping source can be used to control the absorber state. The proposed absorber can be used in many promising THz applications such as biosensing, imaging and wireless communications (in transparency windows of the atmosphere).

IV. ACKNOWLEDGMENTS

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