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A dual-band THz absorber based on graphene sheet and ribbons

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ABSTRACT

A dual-band graphene absorber is proposed and investigated in this paper. The absorber consists of the gold substrate, the graphene sheet sandwiched by dielectric layers and the array of graphene ribbon placed on the top. The two absorption peaks of the dual-band are 99.8% at 4.95 THz and 99.6% at 9.2 THz, respectively. Due to the characteristic of tunable surface conductivity of graphene, the absorption can be controlled by adjusting the chemical potential of graphene. We also investigate the dependence of the absorption curve of the proposed absorber on the structure parameters. In addition, the structure of the absorber is very simple and it can be manufactured by chemical vapor deposition (CVD).

1. Introduction

Metamaterial absorber can realize near-unity absorption in high frequency regime. The majority of perfect metamaterial absorber is composed of metamaterial layers and dielectric substrate. The metamaterial layers are fabricated into a variety of shapes to obtain prefect absorption by corrosion, carving and deposition. The perfect metamaterial absorber shows a great prospect in optical detection and sensing [1], thermal applications [2,3] and sub-wavelength optical devices [4].

Recently, graphene absorber has attracted much attention in the applications of all-optical and optoelectronic devices. Graphene is a two-dimensional layer of carbon atoms arranged in a honeycomb lattice [5,6]. It is appropriate to be applied in terahertz prefect absorber due to the natural advantage of high absorption reaching about 2.3% in the visible region [7,8]. Graphene also has many extraordinary electrical and optical properties, such as the high optical transparency and the ultrafast electronic transport properties [9]. Moreover, since the surface conductivity of graphene can be tuned by changing the chemical potential, the graphene absorber can work at a plurality of frequencies. This unique characteristic can expand the applied scope of prefect absorber. Graphene absorbers have been hot-spot and many studies have been published with various structures of absorbers, such as the graphene nanoslits [10], the graphene micro-ribbons [11] and graphene sheet. Nonetheless, most of them are single-band prefect absorber and the multiband prefect absorber is much desired.

Yao et al. have proposed a dual-band perfect absorber, composed of a graphene elliptical nanodisk array and a metal substrate spaced by a thin SiO2 dielectric layer [12]. Su et al. have proposed an ultra-thin terahertz metamaterial absorber based on graphene/MgF2 multilayer stacking unit cells arrayed on an Au film plane [13]. They theoretically demonstrate the dual-band total absorption effect of the proposed absorber. Zhang et al. have designed a dual-band absorber formed by combining two cross-shaped metallic resonators of different sizes within a super-unit-cell arranged in mirror symmetry [14]. The proposed absorber displays two perfect absorption peaks in the terahertz band. However, these absorbers are very complex and the manufacturing of absorbers are very difficult.

In this paper, we propose and investigate a terahertz dual-band graphene perfect absorber with tunable absorption. The proposed absorber can obtain the absorption over 99.6% at 4.95 THz and 9.2 THz and the absorption peaks can be tuned by adjusting the chemical potential. Furthermore, the structure of this graphene absorber is simple and easy to be fabricated by current manufacturing technique, providing a feasible route to achieve perfect absorption.

2. Structure and principles

The schematic of the dual-band graphene absorber is shown in Fig. 1. A graphene sheet sandwiched between two dielectric layers with different thicknesses is plated on a golden substrate. A

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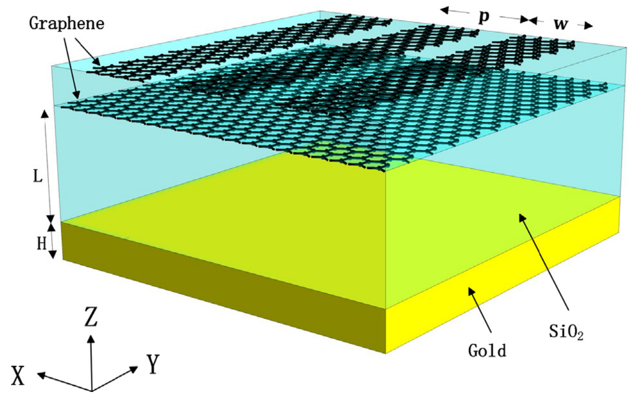

Fig. 1. The schematic of the dual-band graphene absorber.

periodic array of graphene ribbon is placed on the top of absorber. The period of graphene ribbon array is p and the width of graphene ribbon is ω. The thicknesses of two dielectric layers and gold substrate are D, L and H, respectively. The boundary conditions along x-direction and y-direction are the periodic boundary conditions. The permittivity of SiO_2 dielectric layer is $\varepsilon = 2.09$.

In our simulation, the volumetric permittivity approach is used to analyze the characteristic of dual-band absorber. The surface conductivity of graphene contains two parts, including intraband and interband parts ($\sigma_g = \sigma_{intra} + \sigma_{inter}$) [15,16]. They could be obtained from the Kubo formula [17].

Graphene is an anisotropic material with the tangential component of permittivity $\varepsilon_g = 1 - i\sigma_g/\omega_0\varepsilon_0\Delta$ and the normal component of permittivity is 2.5 [18]. The thickness of the graphene is Δ = 1 nm.

The permittivity of gold can be defined by the Drude Model and it can be expressed as:

$$\varepsilon_{Au} = 9 - \omega_p^2/(\omega_0^2 + i\omega_0\gamma), \quad (1)$$

where the plasma frequency $\omega_p = 4.35\pi \times 10^{15}\ s^{-1}$ and the collision frequency $\gamma = 3.1916\pi \times 10^{13}\ s^{-1}$ [19]. Gold is a perfect reflection material in the infrared region and the thickness of gold layer is chosen as H = 1 μm to ensure no incident wave can penetrate the absorber.

3. Simulation and discussion

In our work, the commercial software COMSOL Multiphysics is used to analyze the characteristics of the dual-band absorber. The tangential permittivity of graphene as functions of free-space frequency from 4 THz to 11 THz, with the chemical potential varying from 0.5 eV to 0.7 eV is plotted in Fig. 2. The real (imaginary) part of the permittivity increases (decreases) as the frequency increases with the fixed chemical potential. When the chemical potential increases, the real part of conductivity decreases while the imaginary part stays nearly unchanged.

The parameters of absorber are defined as: $p = 1.94$ μm, $\omega = 1.5$ μm, $D = 0.3$ μm and $L = 3.6$ μm. Unless otherwise noted, the chemical potential of the graphene ribbon and sheet is 0.6 eV. The absorption spectrum of the dual-band absorber is shown in the Fig. 3. The absorption peak of low frequency (APLF) is 99.8% at 4.95 THz and the absorption peak of high frequency (APHF) is 99.6% at 9.2 THz. When the incident wave enters the absorber, part of the wave is absorbed by graphene or excites the surface plasmons polaritons (SPPs) propagating as evanescent wave and others are reflected back. The insets in the Fig. 3 show the distribution of electric field of absorber at 4.95 THz and 9.2 THz, respectively. It can be obtained that the field intensity of SPPs excited at the edge of graphene ribbon is very strong and the SPPs excited on the graphene sheet and ribbon are coupled with each other. The electric field mainly concentrates on the edge of graphene ribbon at 4.95 THz. The distribution of electric field wraps the graphene sheet at 9.2 THz and more SPPs are excited on the graphene sheet.

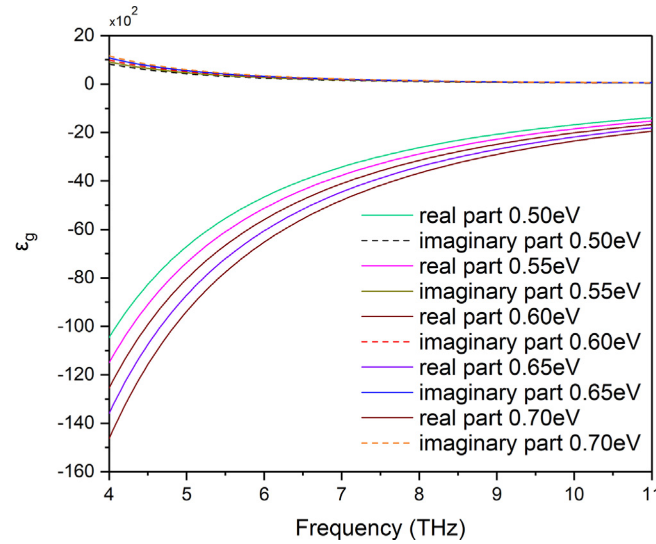

Fig. 2. The tangential permittivity of graphene as functions of free-space frequency with the changing chemical potentials.

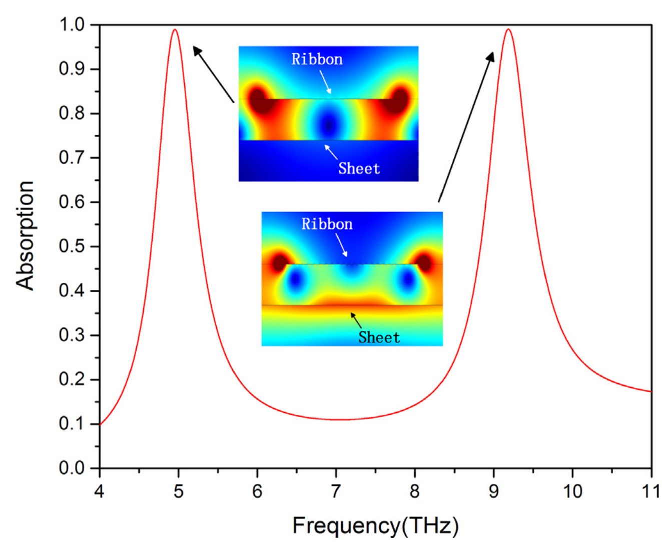

Fig. 3. The master drawing shows the absorption spectrum of the dual-band absorber. The insets at the top and bottom show the distribution of electric field of absorber at 4.95 THz and 9.2 THz, respectively.

By analyzing the simulation results of the dual-band absorber without graphene sheet or array of ribbon, the mechanism of the two absorption peaks can be illuminated. The absorber curves are shown in Fig. 4. The absorption peak of the dual-band absorber without the graphene sheet is at 5.7 THz. However, the absorption peak of the dual-band absorber without the array of ribbons is very weak at 10.9 THz. When the graphene sheet and array of ribbons are put together, the two absorption peaks have blueshift and the absorptivity tremendously increases. At low frequency, while the array of graphene ribbons revealing a great absorption is combined with graphene sheet, the fields on sheet and ribbons