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A broadband metamaterial absorber based on multi-layer graphene in the terahertz region

Pan Fu [a], Fei Liu [a,*], Guang Jun Ren [a,*], Fei Su [a], Dong Li [a], Jian Quan Yao [b]

[a] School of Electrical and Electronic Engineering, Tianjin Key Lab. of Film Electronic & Communication Devices, Engineering Research Center of Communication Devices and Technology, Ministry of Education, Tianjin University of Technology, Tianjin 300384, PR China

[b] College of Precision Instrument and Opto-electronics Engineering, Institute of Laser and Opto-electronics, Key Laboratory of Opto-electric Information Science and Technology, Ministry of Education, Tianjin University, Tianjin 300072, PR China

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ABSTRACT

A broadband metamaterial absorber, composed of the periodic graphene pattern on SiO_2 dielectric with the double layer graphene films inserted in it and all of them backed by metal plan, is proposed and investigated. The simulation results reveal that the wide absorption band can be flexibly tuned between the low-frequency band and the high-frequency band by adjusting graphene's Fermi level. The absorption can achieve 90% in 5.50–7.10 THz, with Fermi level of graphene is 0.3 eV, while in 6.98–9.10 THz with Fermi level 0.6 eV. Furthermore, the proposed structure can be switched from reflection (>81%) to absorption (>90%) over the whole operation band, when the Fermi level of graphene varies from 0 to 0.6 eV. Besides, the proposed absorber is insensitive to the polarization and can work over a wide range of incident angle. Compared with the previous broadband absorber, our graphene based wideband terahertz absorber can enable a wide application of high performance terahertz devices, including sensors, imaging devices and electro-optic switches.

1. Introduction

Metamaterial is an artificially engineered periodic array with many exotic electromagnetic properties, such as negative refractive index [1], asymmetric transmission [2], and cross polarization conversion [3]. All of the special properties make metamaterial become excellent candidates for electromagnetic wave absorbers [4–6]. Metamaterial absorbers (MAs) have been widely explored since the first theoretical and experimental demonstration presented by Landy et al. in 2008 [7]. After that, different sets of MA designs have been investigated in almost every technologically relevant spectral range including microwaves [8], terahertz [9], infrared [10,11], and optical wavelength [12]. However, most of the absorber work at single band, double band, even multi-band, in limited wavelength spectrum, and this restricted wavelength spectra limits many practical applications, such as solar energy harvesting [13] and sensing [14]. In order to adapt to the development of multifunctional terahertz devices, the broadband absorbers with tunable or switchable absorptivity behavior have important research value.

Due to ultra-high electronic mobility, highly confined plasmonic propagation and extremely low loss, graphene, a single layer carbon atom arranged in a honeycomb structure, has attracted considerable attention [15,16]. In addition, its sheet conductivity can be changed in a broad frequency range by means of static electric fields [17] or chemical doping [18], which enables fast electrical modulation and on-chip integration [19,20]. Currently, theoretical research of absorbers in regard to graphene gradually become the focus of study. For instance, the frequency-tunable metamaterial perfect absorbers based on graphene micro-ribbons [21,22], graphene nanodisk [23] as well as the combination graphene wire and gold cut wire [24] have been studied and explained. However, in the scope of our knowledge, these perfect graphene-based absorber has single or narrow band absorption, and their tunable range of reported is very limited, even some of these absorbers are polarization dependent, which hinders their potential applications.

In this paper, we focus on the THz band proposed a polarization independent wideband MA. Theoretical simulation results show that the absorption efficiency of the proposed structure can be as high as more than 90% over 3.60 THz (from 5.50 to 9.10 THz). Furthermore, by changing the Fermi level of the graphene films (the changes of graphene Fermi level in each layers are the same) the state of the proposed MA can be switched between reflection ($\mathrm{reflection} > 81\%$) and absorption ($\mathrm{absorption} > 90\%$) and the structure can achieve high switching

* Corresponding authors.
E-mail addresses: feiliu@tju.edu.cn (F. Liu), rgj1@163.com (G.J. Ren).

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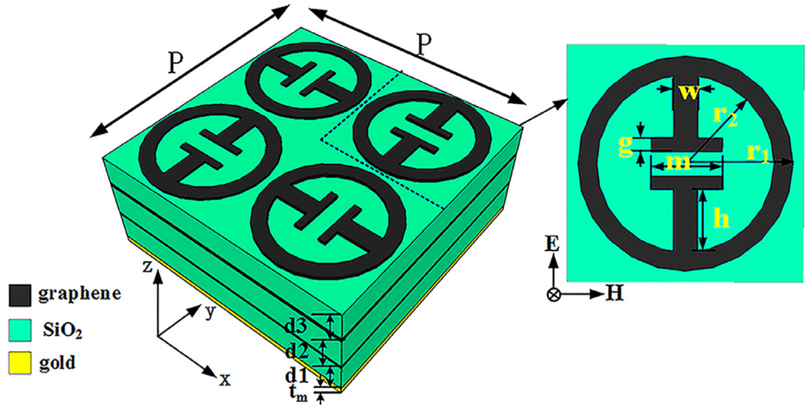

Fig. 1. Schematic of the proposed absorber. The geometrical parameters of the proposed structure are: $P = 5$ μm, $w = 0.3$ μm, $g = 0.15$ μm, $m = 0.8$ μm, $h = 0.4$ μm.

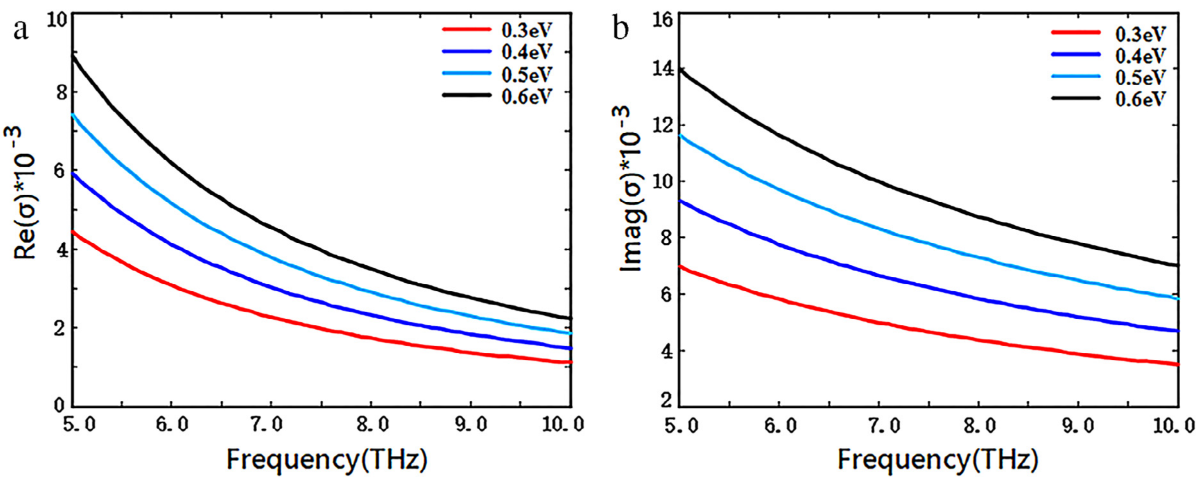

Fig. 2. Graphene conductivity (a) real part (b) imagine part at different Fermi level.

intensity (71%) while maintaining broad bandwidth (6.98–9.10 THz). Besides, the presented absorber also exhibits well performance to large incident angles of electromagnetic wave, which is desirable for many applications, especially for the application of solar energy conversion.

2. Structure of the tunable absorber

The structural schematic diagram of the absorber unit cell and the direction of incident wave are illustrated in Fig. 1. From top to bottom, there are a periodical graphene pattern, double-layer of graphene sheet (the two layers of graphene sheets are unpatterned graphene planes) sandwiched with silicon dioxide layer and the gold ground plane, tightly stacked to form the unit cell of the MA. In this structure, the top graphene-pattern consists of a graphene ring and two "T" shaped graphene bands. The outer radius r_1 and inter radius r_2 of the graphene ring are 1 μm and 0.6 μm respectively. This structure is periodic in two directions (x, y) with periodicity $P = 5$ μm. The dielectric layer SiO_2 with its relative electric permittivity of 2.25 [25] and the thickness of each layer are $d1 = 3$ μm, $d2 = 5$ μm, $d3 = 3$ μm. The ground plate is made of gold with a conductivity $\sigma_{gold} = 4.56 \times 10^7$ s/m, and the ground plane have a thickness t_m of 0.2 μm. The thickness of the gold layer used here is much larger than the typical skin depth in the terahertz band, therefore, the wave transmission is totally suppressed. We assume a plane wave normally impinges on the absorber structure and the incident electric field along the y-axis. In the numerical simulations, the graphene is modeled as an effective media with a thickness $t_g = 1$ nm [26].

In terahertz range, graphene's surface conductivity can be well described by the Drude model [27]:

$$\sigma_g = \frac{e^2 E_f}{\pi \hbar^2} \frac{\mathrm{i}}{w + \mathrm{i}\tau^{-1}}$$

where e, $\hbar$, w and τ are universal constants related to the charge of an electron, the reduced Planck constant, the radian frequency and carrier relaxation time, respectively, E_f is chemical potential (i.e. Fermi level E_f) of graphene. The real part and imagine part conductivity of graphene at different Fermi level are calculated in Fig. 2(a) and (b). It is obvious that the real and imaginary parts of the conductivity are related to the frequency when the Fermi level is fixed. Since the spectral shift of the resonance determined by the imaginary part of the conductivity, and the amplitude modulation of the resonance controlled by the real part [28–30], so the absorption can be adjusted by controlled the Fermi level via the applied voltage or chemical doping.

In this study, the numerical simulations are carried out by using the full-wave finite integration method (FIT). In the x and y directions the unit cell boundary conditions were applied, and open space boundary conditions were used in the z-direction. According to the theory of multiple reflection and interference of the incident electromagnetic field, the absorptivity $A(\omega)$ can be obtained by [31] $A(\omega) = 1 - R(\omega) - T(\omega)$, where $R(\omega)$ represents the reflection, $T(\omega)$ represents the transmission. Because of the existence of bottom continuous metallic film, the transmission is very close to zero, and the absorption can be expressed as $A(\omega) = 1 - R(\omega)$.