Metal-graphene metamaterial for wide band absorber

Renbin Zhong, Yan Liu, Yiqing Wang, Long Yang, Anchen Ma and Shenggang Liu

Terahertz Research Centre, School of Electronics Science and Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054, China

Abstract: By construction metal-graphene metamaterial with simple gold strips parallel or side-by-side arranged on a monolayer graphene as molecular cells, multi-band and ultra-broad band absorber can be achieved at mid-infrared frequencies. The extremely absorption bandwidth up to 11.8THz can be obtained, the intensity exceeds 90% at the absorption peak. Independently tunable multi-band and ultra-wide band absorber is also explored by stacking molecular cells with two or three layers. The results will benefit the integrated micro-structure research with flexible tunability, and the multilayer structure has potential applications in tunable filtering, sensing, cloaking objects and other multispectral devices.

Keywords: Metal-graphene metamaterial; Absorber;Dynamical tunability

Introduction

Recent investigations on Metamaterial-based absorbers (MMA) are most suffer from narrow bandwidth or flexible tunability[1-6]. How to achieve independently tunability on graphene-based absorbers with excellent absorptivity and ultra-wide bandwidth still remains a challenge.

The traditional MMA is usually composed of three layers: a layer of periodically-arranged metallic patterns such as the concentric rings, the metal cut wires and the metal split ring resonators, a dielectric interlayer and a metallic ground plane. Multiple resonators can be obtained with different geometrical dimensions, so that the optical properties of metamaterials based on metallic structures cannot be changed anymore once the structure is defined.

To realize the dynamically tunable resonant properties, some actively controlled elements, such as semiconductors, liquid crystals, and liquid metals are applied in these metamaterials devices. This report proposes a kind of absorber with independently dynamical tunable resonant properties, which composed of multiple metal-graphene layers, and there is a thin dielectric film between two metal-graphene layers to function as the insulating spacer, a gold block at the bottom serving as the metallic ground plane, as depicted in Fig. 1(a). Each metal-graphene layer consists of periodically arranged gold strips and a monolayer of graphene. The metallic pads on each graphene layer serve as the electrodes along with the gold substrate to applying a gate voltage on it, and with different gate voltage independently Fermi energy level of the graphene can be realized.

Ruesults

A plane wave polarized parallel to the *x*-direction (*p*-polarized) is used as the normal incident light. For one metal-graphene layer structured absorber, the spectrums with several absorption peak can be obtained according to the number of the gold strips. Investigations demonstrate that the resonances of the single-layer absorber are insensitive to the incident angle.

For the double-layers absorber, the strips on the top graphene layer is set to be shorter than that on the bottom graphene layer, for the unite cell with only one gold strip on each layer, the geometric parameters are l_1=2.4μm and l_2=3.2μm, as shown in fig.1(b),The absorption spectrum with various Fermi energy level of the bottom graphene layer is simulated. When the Fermi energy of the top graphene layer level keep stable at 0.15eV, and that on the bottom graphene increasing from 0.15-0.6 eV, we can find that the lower-order resonance moves towards higher frequencies while the higher-order resonance frequency keeps unchanged, independently tunable properties is realized.

To better understand the resonance mechanism of the multilayer absorber structure, the inset two pictures depict the electric field distributions |E| with E_{f1}= E_{f2}=0.15eV at the corresponding resonance frequencies. At the low-order resonance f_1 (28.7THz), the electric field concentrates almost entirely around the edges and ends of the longer gold strip. Thus, the proposed absorber shows the resonance characteristics in accordance with the longer gold strip. The shorter gold strip is strongly excited at the high-order resonance f_2 (39.7THz), while the excitation of the longer gold strip is relatively weak. Hence the absorber mainly exhibits the resonance characteristics of the shorter gold strip.

More absorption peaks can be realized by stacking multilayer metasurfaces. Fig.1(c) shows a three layers metasurfaces absorber with three absorb peaks, by adding gold strips on different layer as shown in Fig. 1(d) an absorber with four absorb peaks and independently frequencies tenability is realized.

Furthermore, ultra-wide band absorber can be realized with side-by-side arrangement of gold strips in the molecular cells, as shown in Fig.2(a), the bandwidth can be expanded by the combination of close resonances. By changing the length of gold strip or applying different Fermi energy levels on different layers, an average peak absorption of 88.5% can be achieved in a wide bandwidth from 27.5THz to 38.4THz.

The bandwidth can be broadened even further by stacking one more metal-graphene layer which indicates introducing more resonators, as shown in Fig. 2(b). By designing the lowest- or highest-order resonant frequency, the wideband can be adjusted as shown by the series solid curves with various strip length *l4* from 3.15 μm to 3.25 μm. The bandwidth exceeding 80% absorption is about 7.5 THz, and the average peak absorption is 88.5%. By modifying the second-or third-order resonances, the flatness of the absorption wideband can be optimized with fixed bandwidth, as shown by the green dashed and blue ball curves. For a triple-layered structure, the average peak absorption is 84.7% from 27.5 THz to 38.4 THz with a minimum of 60%, as shown by the purple dashed curve.

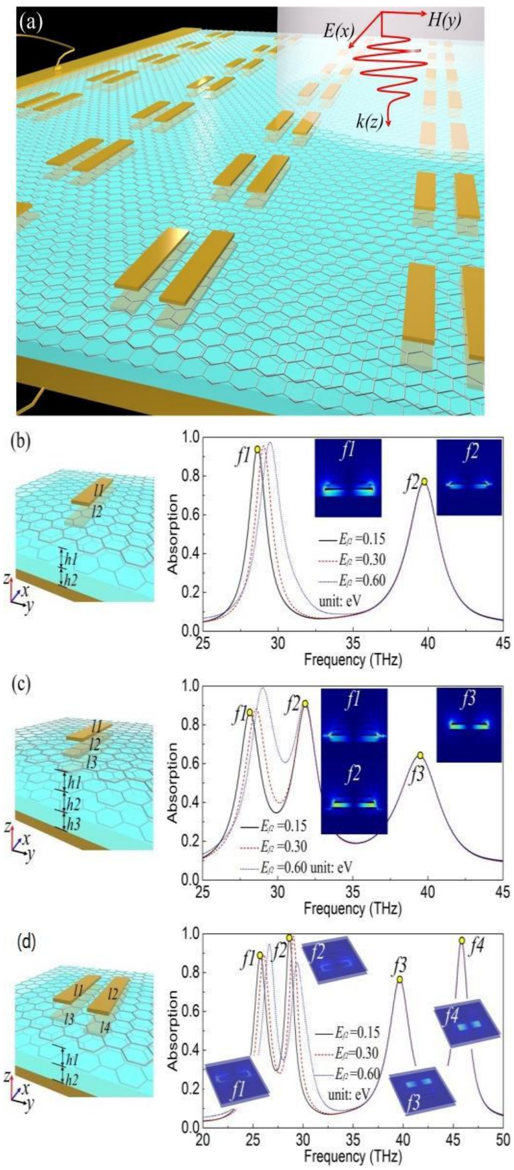

Fig.1 (a) Schematic of the absorber and the incident light polarization configuration; The simulated absorption spectra with various Fermi energy level and the amplitude of electric field |E| at the absorption peaks with the Fermi energy of graphene is fixed as 0.15 eV for the proposed absorber with (b) Double layers structure, (c) Three layers structure, and (d) Double layers structure with multiple strips. (e) The absorption spectrum as a function of frequency for double metal-graphene layers ultra-wide band absorbers with various Fermi energy levels or different gold strips' length.

Summary

This report presents a series of dynamically and independently tunable absorbers based on the combination of simple metal stipes on multilayer metal-graphene metamaterials, numerically investigated are carried at mid-infrared frequencies. Apart from adding the gold strips in each unit cell, the number of the absorption peaks can also be increased by stacking multiple metal-graphene layers. Further investigations demonstrate that the resonances of the single-layer absorber are insensitive to the incident angle. For the multiple metal-graphene layer structure, the location of the absorption bands can be tuned independently by adjusting the Fermi energy level of the graphene in each layer. The bandwidth of the broadband absorbers exceeding 80% absorption is up to 7.5 THz with the average peak absorption of 88.5%. For a triple-layered structure, the average peak absorption is 84.7% from 27.5 THz to 38.4 THz with a minimum of 60%, and the absorber with dual wideband is achieved by designing two quite different sets of gold strips length in top and bottom layer. Benefitting from these attractive properties, the proposed absorber may have potential applications in tunable filtering, sensing, cloaking objects and other multispectral devices.

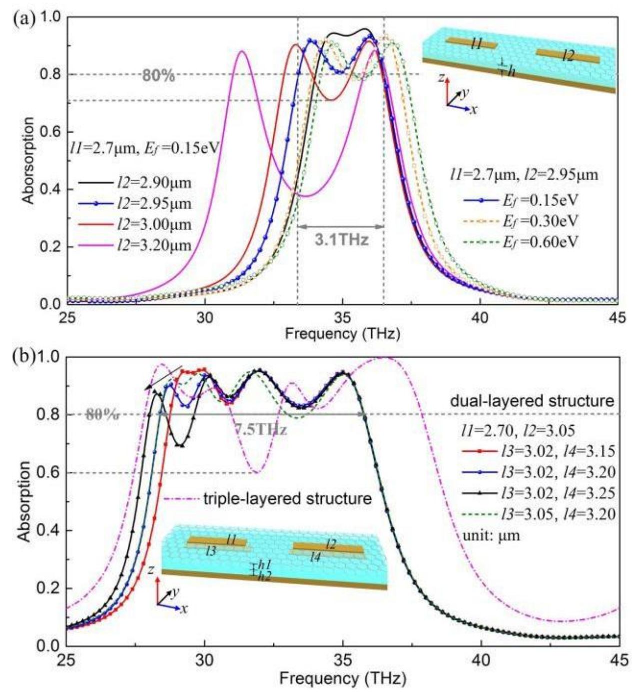

Fig.2. The absorption spectrum as a function of frequency for (a) single metal-graphene layer and (b) double metal-graphene layers ultra-wide band absorbers with various Fermi energy levels or different gold strips' length.

Acknowledgment

This work is supported by the National Key Research and Development Program of China 2018YFF01013001 and 2017YFA0701000, the Natural Science Foundation of China 61701084, 61505022.

Reference

[1]. J. Zhu, Z. Ma and W. Sun, "Ultra-broadband terahertz metamaterial absorber," *Appl. Phys. Lett*. vol.105, pp.4773-4779, 2014.

[2]. R. Parvaz and H.Karami, "Far-infrared multi-resonant graphene-based metamaterial absorber," *Opt. Commun.* , vol.396, pp. 267-274, 2017.

[3]. R Zhong, H Ding, Y Liu, S Liu. "A kind of compact ultra-broad bandpass planar terahertz filter". *Science China Information Science*. 61 (6):069401 (2018).

[4]. M. Kenney, J. Grant and Y. D. Shah "Octave-spanning broadband absorption of terahertz light using metasurface fractal-cross absorbers," *ACS Photonics*, vol.**4**, pp. 2604–2612, 2017.

[5]. R. Xu and Y. S. Lin, "Characterizations of reconfigurable infrared metamaterial absorbers," *Opt. Lett.*, vol.43, pp.4783-4786, 2018.