Optics Communications 369 (2016) 65–71

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Design of separately tunable terahertz two-peak absorber based on graphene

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ARTICLE INFO

Article history:
Received 14 November 2015
Received in revised form
13 February 2016
Accepted 16 February 2016
Available online 23 February 2016

Keywords:
Terahertz (THz)
Separately tunable absorber
Two-peak
Graphene
Conductivity

ABSTRACT

A separately tunable terahertz (THz) two-peak absorber based on graphene is presented. From bottom to top, the absorber contains four layers, i.e., gold reflector, graphene patch array, polyimide and metal split-ring resonator (SRR) array layer. The controlling voltage is applied between the reflector and two separated surface electrodes to tune the Fermi level of graphene. As a result, these two absorption peaks can be separately tuned by the controlling voltages. The finite integral technique (FIT) is used to study the absorption theory and modulation mechanism. The simulation results show that the absorption of low-frequency and that of high-frequency are 95.5% and 90.0%, respectively. And the maximum modulation depths of them are about 49% and 71%, respectively. Moreover, the absorber is insensitive to polarization and still has good absorption at large angle. The separately tunable THz two-peak absorber offers a new way for the development of frequency selective detectors working in the range of microwave, THz and infrared.

1. Introduction

Recently, terahertz (THz) technology develops very fast and has potential application in many areas, such as biomedicine [1], security [2], identification of substance [3], and so on. Due to lack of high efficient THz source and high sensitive THz detector, many problems have to be settled practical applications [4–7] of THz technology. An effective method to improve the sensitivity of THz detector is to carry out frequency-selective detection, which can be realized by using tunable absorber in THz range.

In recently, tunable THz absorber has attracted much attention. A tunable THz absorber based on the microelectromechanical systems (MEMS) technology is proposed, but it has a very low modulation depth [8,9]. A vanadium dioxide based tunable THz absorber with good modulation is reported. But it is very sensitive to the temperature and required very strictly control the working temperature, which is limited in some special applications [10,11]. So, the tunable absorber based on new principle, new materials and with good performances is urgently needed at present.

With the development of materials science and technology, a new material, i, e., graphene, is invented and quickly applied in many domains. Generally, graphene is single-atom-thick planar sheer of sp^2-bonded carbon atoms that are densely packed in a honeycomb crystal lattice, which has unique electronic properties, such as high electron mobility and the lowest resistivity at room temperature [12,13]. Due to the tunable conductivity, graphene can work as a good candidate to fabricate the tunable absorber. In recent years, the research on tunable THz absorber based on graphene has attracted many attentions. Rodriguez [14] demonstrate a graphene-based absorber which shows an extraordinary modulation depth of 15% at 0.75 THz when the controlling voltages changes in the range of -10 V–20 V. Using multilayer of graphene-polymer, Amin [15] proposed a broadband absorber with a maximum bandwidth of 6.9 THz. Huang [16] constructs a tunable broadband absorber by using graphene patch array on the surface, and the bandwidth can be modulated by changing the conductivity of the graphene patch array. But it is difficult to apply controlling voltage in practical application. By introducing dual metal resonance rings, Innocenti [17] designed a graphene-based absorber, and got a maximum modulation depth of 18% at 2.8 THz when the applied voltages varies from -1 V to 1 V. However, the absorber is very sensitive to the polarization of THz wave.

This paper presents a two-peak separately tunable THz absorber based on graphene patch array on the metal reflector and SRR array on the surface. The absorption theory and modulation mechanism are studied using the finite integral technique (FIT).

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http://dx.doi.org/10.1016/j.optcom.2016.02.036
0030-4018/

2. Structural design

The unit cell of the tunable absorber is shown in Fig. 1, and it contains two long arm resonance absorbers (S_1) and two short arm resonance absorbers (S_2), which arranged as an array of $\left[\begin{matrix} S_1 & S_2 \\ S_2 & S_1 \end{matrix}\right]$. From bottom to top, the absorber consists of four layers, i.e., gold reflector, graphene patch array, polyimide spacer and metal split-ring resonator (SRR) array. The optimized structural parameters of the absorber are listed in Table 1.

The absorber is modeled in electromagnetic simulation software CST Microwave Studio 2011 which based on the finite integral technique (FIT). The periodic boundary condition is applied in x and y directions, and the open boundary condition is set in z direction. The thickness of gold reflector and SRR layer are 0.2 μm and their conductivity is $\sigma = 4.09 \times 10^7$ S/m. Polyimide spacer layer is modeled as loss polyimide with a complex dielectric constant $\varepsilon = 3.5 + 0.02i$ [18]. The surface conductivity of graphene depends on its Fermi-level E_F [19–21]. When its imaginary part of conductivity $\sigma_{g,i} > 0$, the graphene patch layer can be equivalent to an ultrathin "metal" layer which with a thickness of $t_g = 2$ nm. Under the condition of normal incidence, the absorption is expressed as $A = 1 - R - T$ (or $A = 1 - |S_{11}|^2 - |S_{21}|^2$), where R is the reflectivity, T is the transmittance (S_{11} is the reflection coefficient, S_{21} is the transmission coefficient). Due to the skin depth of THz wave on the gold film is less than 100 nm and the THz wave cannot penetrate the gold film, the transmittance is zero ($T = 0$). Thus, the absorption is simplified as $A = 1 - R$.

The simulated absorption curves of the resonance absorber S_1, S_2 and the two-peak tunable absorber D are all plotted in Fig. 2.

In Fig. 2, the low frequency absorption peak (black dash line) is produced by resonance absorber S_1 (in this simulation, the unit cell only contains S_1), the high frequency absorption peak (red dash line) is produced by the resonance absorber S_2 (in this simulation, the unit cell only contains S_2), and the green solid line is produced by the two-peak absorber D.

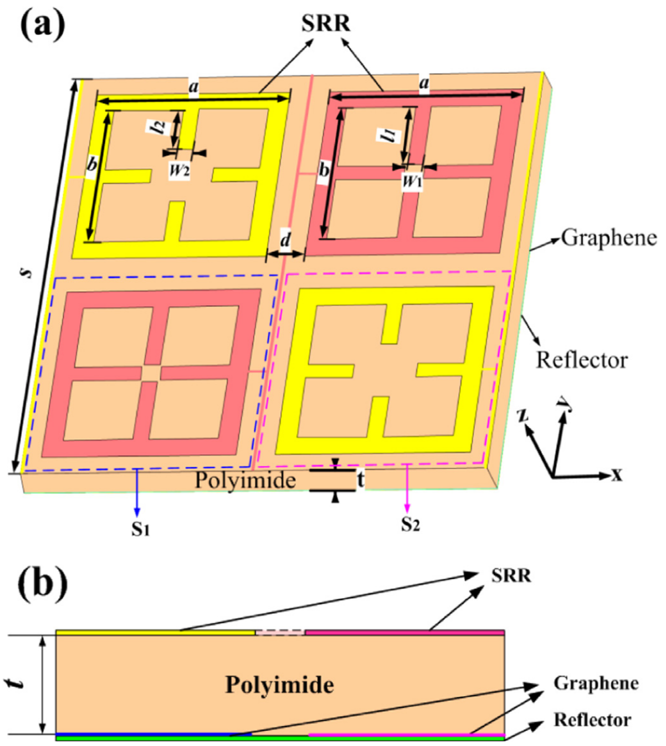

Fig. 1. Schematic of the unit cell of two-peak tunable absorber (a) and its central cross-section view (b).

Table 1
Structural parameters of two-peak tunable absorber (unit: μm).

S	a	b	l_1	W_1	l_2	W_2	t	d
240.0	100.0	80.0	33.2	8.0	25.4	8.0	6.9	20.0

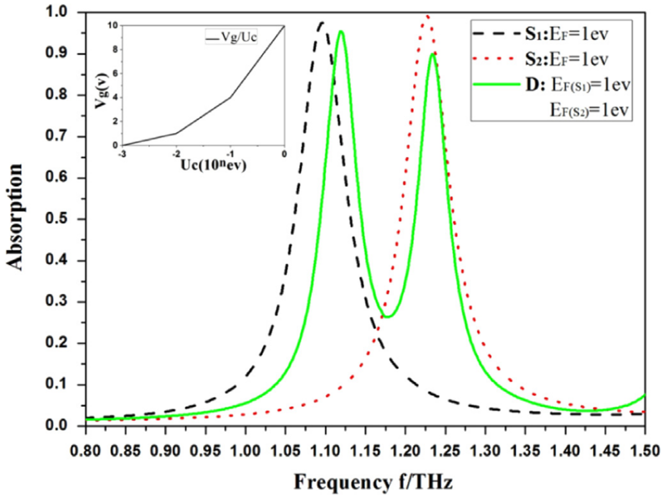

Fig. 2. Absorption curves of absorber S_1, S_2 and two-peak absorber D.

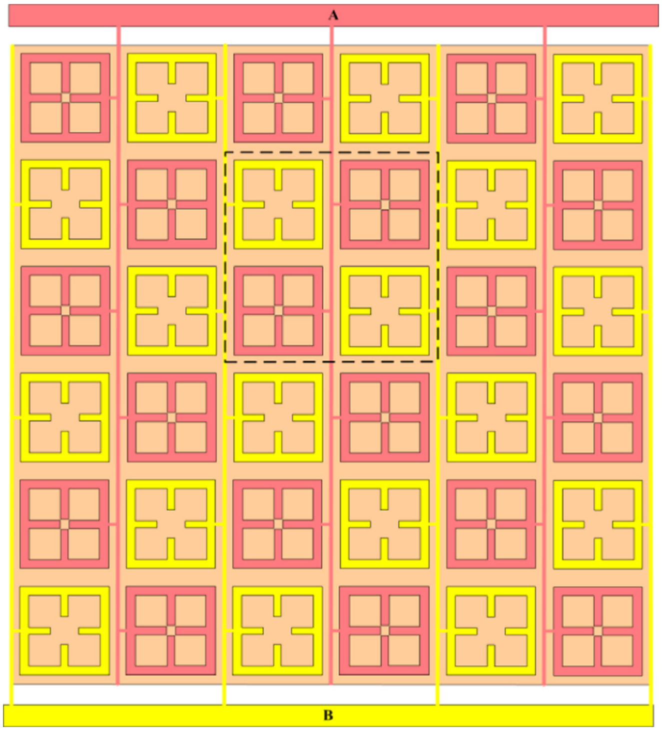

Fig. 3. The schematic of separately tunable two-peak THz absorber.

The array of two-peak tunable absorber is shown in Fig. 3. To achieve the modulation of low frequency resonance peak, the controlling voltage V_A is applied between the electrode A and the bottom metal reflector. Similarly, to modulate high frequency resonance absorption peak, the controlling voltage V_B should be applied between the electrode B and the bottom metal reflector. The absorption theory and modulation mechanism will be studied in the subsequent sections.