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Far-infrared multi-resonant graphene-based metamaterial absorber

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ABSTRACT

Recent developments in metamaterial designs have opened up the possibility of absorption in the terahertz frequency range. In this paper, a multi-resonant absorber is presented in which the resonance frequencies are theoretically organized by doping graphene ribbons with a ring-shaped gold on each ribbon per unit cell. This action allows the free electrons to flow on a piece of graphene surface to produce several absorption peaks in the far-infrared spectrum. Besides, in order to adjust the absorber to respond at different and wide frequency spectra, the absorption peaks can be managed by manipulating the gate voltage and dielectric thickness. This periodic structure also consists of a dielectric substrate of silicon dioxide and a metal slab at its back to ensure the zero transmission. Moreover, the equivalent circuit and transmission line model are derived based on the reflected fields and vector-fitting method to facilitate analysis of the proposed design and evaluation of the full-wave simulation results. At the end, the sensitivity of the absorption against oblique incidence is studied for both TE and TM polarizations.

1. Introduction

Since Pendry et al. explained that some periodically placed metallic wires and split ring resonators (SRRs) can yield negative effective permittivity and permeability, respectively, there has been a large amount of research in the metamaterial applications [1,2]. At the beginnings, metamaterials were just supposed to be only left-handed materials (LHM), but now metamaterials own much broader definition than LHM. The concept of metamaterial has been blended with the ability to control electromagnetic waves. This artificial material has been developed to bend electromagnetic waves for making a superlens due to its negative refractive index by Smith by the year 2005. In 2006, Pendry et al. accomplished in the realization of invisible cloaking by proposing transformation optics in microwave frequencies [3,4].

Since then, metamaterial design has been developed to meet a vast diversity of applications and created an intense interest among the researchers. For this purpose, two-dimensional materials emerged as advantageous and applicable matters for their exceptional features. Recently, graphene a 2D material in which carbon atoms constitute a honeycomb lattice with one atomic thickness, fulfills numerous demands in electronics, plasmonics and photonics, due to its flexibility, adaptability, and multi-functionality. This anisotropic material possesses a great strength and a high thermal and electrical conductivity in a wide frequency spectrum due to its large electron mobility [5,6]. On the other hand, graphene has attracted much attention for its extraordinary electrical, thermal, mechanical and optical properties [7,8]. In the far-infrared detectors, graphene plays a significant role to achieve a broadband absorption and ultrafast response [9]. Furthermore, possession of particular plasmonic properties, graphene has attracted intense attention in the research community in studying plasmonic waveguides. Graphene sheet can be managed to have a great conductivity amount due to its high electron mobility. The electron mobility of this platform can be adjusted either by chemical doping or gate voltage to produce desired conductivity in the frequency region of interest. Another advantage of using graphene in plasmonics is its compressed surface plasmon wavelength so that it smoothes the path for designing ultra-compact electronic and plasmonic devices [10]. This platform is also applied for fabricating terahertz absorbers.

THz absorbers play an important role in emitters, sensors, photodetectors and photovoltaic [11]. Since Landy et al. explained how their novel method of designing metamaterial absorber would be extended from microwave to THz and visible light [12], designing THz absorbers has drawn numerous attentions. This work inspired many researchers to develop metamaterial absorbers frequency range response to THz regime [13], Mid-Infrared [14], Near-infrared [15] and visible spectrum [16]. Although graphene is described and verified experimentally as a wide spectrum absorber ranging from visible to infrared and microwave when exposed to the excitation wave power greater than 80 μm [17], destructive interference is the condition based on which our proposed absorber works. Graphene absorption is the process in which graphene is engaged autonomously whereas destructive interference is the process in which reflected waves counteract each other to

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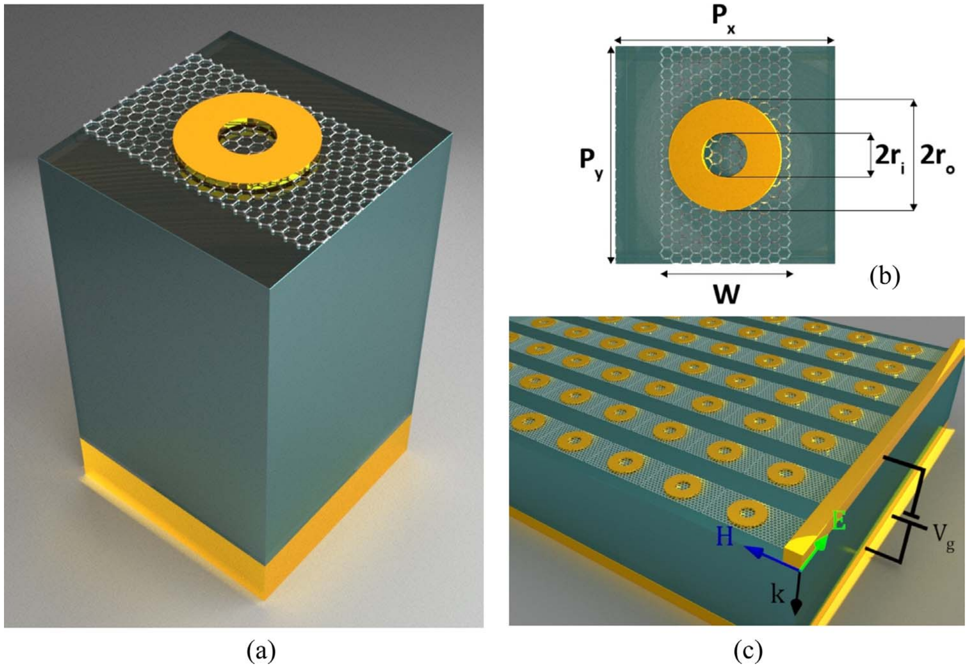

Fig. 1. The layout of the interest. (a) Perspective of the unit cell which is composed of a backed metal slab, a dielectric substrate, a Graphene sheet and a metallic ring. (b) The dimensions of the design. (c) The periodic integration of several unit cells.

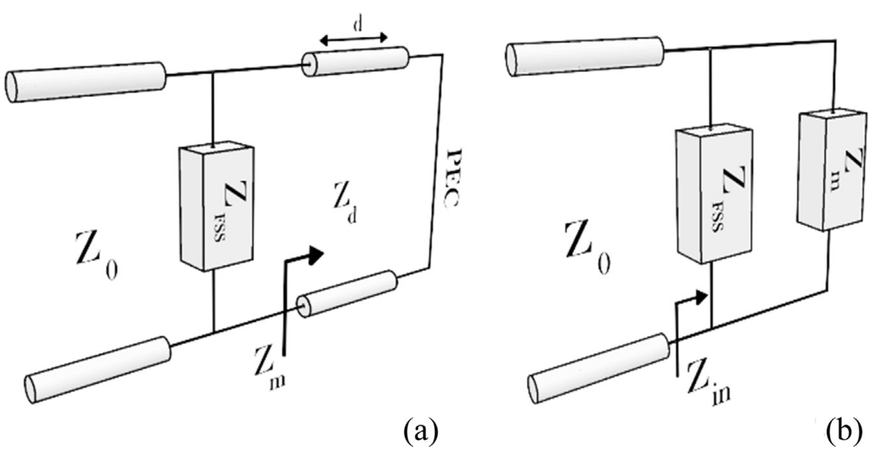

Fig. 2. The transmission line model and input impedance of an absorber.

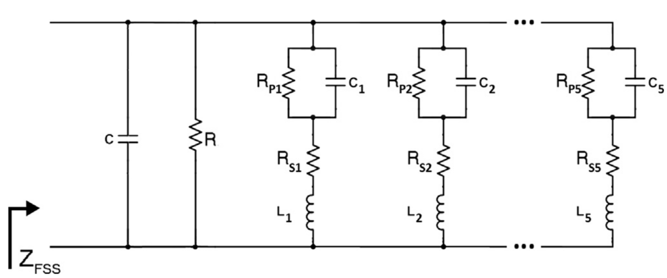

Fig. 3. The schematic of Z_FSS equivalent circuit.

produce absorption near unity. In this paper, a theoretically organized metamaterial absorber with novel characteristics is presented. One of these characteristics is having several absorption peaks in the THz spectrum and another one is the possibility to tune and sweep the frequency region of the efficient response to a higher and broader spectrum by graphene gate-voltage manipulation. The resonance produced by this structure is due to positioning a metallic ring on graphene. The idea of locating metal on graphene was first used by Cai et al. in order to enhance light absorption [18]. Another novelty and innovation made in this paper is proposing a correspondent and accurate equivalent circuit model based on vector-fitting method. By employing this method, one can directly add the specified lumped components to spice simulation program and simply analyze it in association with a large integrated circuit. The equivalent circuit extraction method not only can be used for the complicated structures comprising graphene, but also one can extend it to other types of 2D materials possessing exceptional and interesting properties such as topological insulators [19] and black phosphorus [20].

Now, first of all, the graphene properties in Section 2, and then the structure layout parameters for optimal responses are studied and the equivalent circuit model is revealed in Section 3. Then the absorption results are presented in Section 4. In this section, it is also demonstrated that this absorber works based on scattering cancellation caused by destructive interference where the impedance match between the absorber and free space is achieved [21–23].