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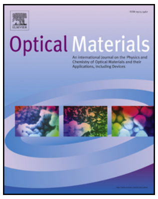

Magnetic field induced enhanced absorption using a gated graphene/1D photonic crystal hybrid structure: Quantum regime

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ABSTRACT

The terahertz (THz) absorption properties of a gated graphene monolayer placed on top of a one-dimensional photonic crystal is investigated in the presence of a perpendicular magnetostatic bias. The response of electrons to the magnetic field is inspected in the quantum regime, due to the low doping level of graphene grown on the C-terminated surface of silicon-carbide. It has been shown that there is the possibility of achieving enhanced absorption at low magnetic fields for certain states of circular polarization of light. Furthermore, adjusting the gate voltage of the graphene provides another method of tuning absorption in the proposed structure. Therefore, one can obtain enhanced absorption with the appropriate choices of magnetic and electric biases. We believe that these properties make our structure suitable for designing tunable graphene-based THz absorbers.

1. Introduction

The ability to interact strongly with light is a highly desirable property for a material to be used in many photonic applications such as photodetectors, sensors, photovoltaics and absorbers [1–3]. Electromagnetic wave absorbers in the terahertz range (0.1–10 THz) are particularly important for applications ranging from security to medicine [4,5]. Although some semiconductors such as silicon and gallium arsenide can be used for effective optical absorption in the visible wavelength region, low energy spectral regions (THz) currently lack suitable absorbent materials. Therefore, one of the researchers' challenges is to seek highly absorbent materials in these regions. Graphene, a gapless semiconductor with unique electrical and optical properties, can absorb photons of any energy which makes it an appropriate candidate for use in active optoelectronic devices [6–8]. The absorption of this one-atom-thick material is approximately 50 times greater than gallium arsenide with the same thickness. However, it is not sufficient to be used in optoelectronic applications [9]. Recently, different approaches have been suggested to improve graphene-light interactions. For example, integrating graphene with plasmonic nanostructures [10–12], or nanoparticles [13], multilayer Bragg mirrors [14], photonic crystals [15–19], Photonic quasicrystals [20], patterning doped graphene into a periodic nanodisk [21], etc [22,23]. Here, we utilize graphene grown on a one-dimensional photonic crystal (1DPC) to get enhanced absorption by allowing multiple passes through the monolayer graphene as compared with the absorption of bare graphene. In fact, the advantage of placing graphene on top of a layered structures is the presence of a defect mode within the photonic band gap of the structure, and, therefore the controlling through the flow of light in comparison with Refs. [24,25]. Our main goal is to study the possibility of creating a magneto-tunable enhanced absorption in the proposed structure. Thus, we apply the magnetostatic bias perpendicular to our proposed structure. The influence of varying gate voltage of graphene is also discussed. The outline of this work is organized as follows: The theoretical model and method are presented in Section 2. We use graphene in the quantum regime with the Landau levels (LLs) dependent Kubo conductivity model. In Section 3 the numerical results and discussions are analyzed. The conclusions are also summarized in Section 4. We found that our structure can act as a THz absorber for certain states of circular polarization through the appropriate adjustment of magnetic bias and gate voltage.

2. Theoretical modal and method

The considered structure in this paper has the form G/SiC $(A/B)^N$, where G, A and B represent monolayer graphene, Si and SiO_2, respectively (Fig. 1). Here, we consider the Faraday geometry in which the external magnetic field is perpendicular to the structure along the direction of propagation of light (z axis). N denotes the number of periods which is taken as 10. $d_G = 0.335$ nm is the thickness of the single

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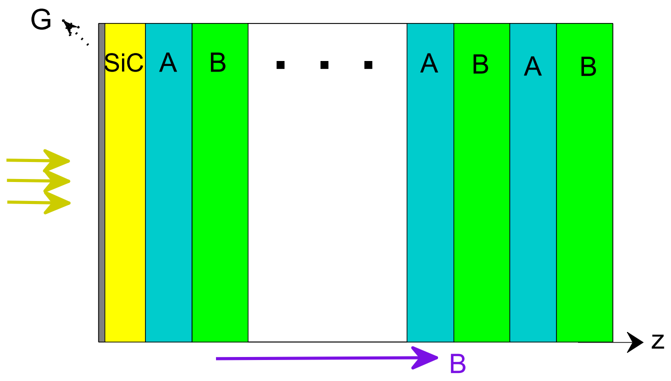

Fig. 1. Schematic Faraday geometry of the studied structure, where a monolayer graphene G is prepared on top of a 1DPC. The perpendicular external magnetic field is applied on the structure.

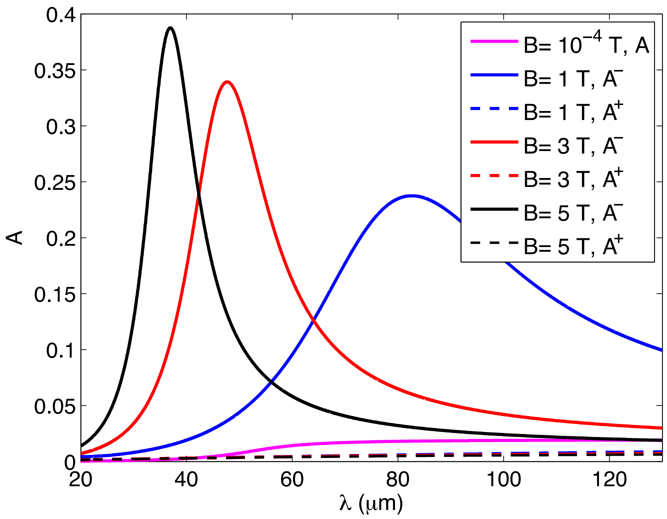

Fig. 2. Absorption of RCP (A^+) and LCP (A^-) light versus wavelength in the bare graphene for $V_g - V_{CNP} = -1.87.B\,(V)$ at B = 10^{-4}, 1, 3, and 5 T.

graphene layer and the other layers have quarter wavelength optical thicknesses with a central wavelength of $\lambda_0 = 70\,\mu m$. The relative permittivities, ε, of SiC, A and B are 12.25, 10.89 and 5.06, respectively [26,27]. In order to calculate the absorption spectra in the proposed structure, the 4 by 4 transfer matrix method is used [28]. According to this method, the total transfer matrix of the structure is as follows:

$$\mathfrak{I} = [D^{(0)}]^{-1}\,(S_G\,S_{SiC})\,(S_A\,S_B)^{10}\,D^{(0)}, \tag{1}$$

where the dynamic matrix in air, $D^{(0)}$, and the characteristic matrix in the jth layer, S_j, are given as

$$D^{(0)} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \end{bmatrix}, \tag{2}$$

$$S_j = \begin{bmatrix} \cos\left(\omega N_j^+ d_j/c\right) & -\frac{i}{N_j^+}\sin\left(\omega N_j^+ d_j/c\right) & 0 & 0 \\ -iN_j^+\sin\left(\omega N_j^+ d_j/c\right) & \cos\left(\omega N_j^+ d_j/c\right) & 0 & 0 \\ 0 & 0 & \cos\left(\omega N_j^- d_j/c\right) & -\frac{i}{N_j^-}\sin\left(\omega N_j^- d_j/c\right) \\ 0 & 0 & -i\,N_j^-\sin\left(\omega N_j^- d_j/c\right) & \cos\left(\omega N_j^- d_j/c\right) \end{bmatrix}$$
$$j = (A, B, G, SiC). \tag{3}$$

Here, $N_j^{\pm} = \sqrt{\varepsilon_{xx}{}^{j} \pm i\,\varepsilon_{xy}{}^{j}}$ show the refractive indexes in the jth layer in which indexes "+" and "-" correspond to the right-handed circularly polarized (RCP) light and left-handed circularly polarized (LCP) light, respectively. Also, ω, c and d_j represent the angular frequency of light, the light speed in the vacuum and the thickness of the jth layer, respectively. It should be noted that applying the perpendicular magnetic field, B, to the graphene makes it gyrotropic with an asymmetric relative permittivity tensor given as [29]:

$$\overleftrightarrow{\varepsilon_G} = \begin{pmatrix} \varepsilon_{xx} & \varepsilon_{xy} & 0 \\ -\varepsilon_{xy} & \varepsilon_{xx} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{pmatrix}. \tag{4}$$

Here, the matrix elements of permittivity are expressed as $\varepsilon_{xx} = 1 + \frac{i\,\sigma_0}{\omega\,\varepsilon_0\,d_G}$, $\varepsilon_{xy} = \frac{i\,\sigma_H}{\omega\,\varepsilon_0\,d_G}$, and $\varepsilon_{zz} = 1$, where ε_0 is the vacuum permittivity, and σ_0 and σ_H are, respectively, the longitudinal and Hall components of the graphene optical conductivity. In other words, graphene models as an anisotropic biased sheet in which the surface conductivity is a tensor [29,30] compared with conductivities in Refs. [31–33]. Since we consider the graphene layer grown on top of the C-terminated surface of SiC, due to the low doping level in graphene, the Fermi level crosses quantized LLs, and therefore, the quantum modal is used in describing the conductivity as follows [30]:

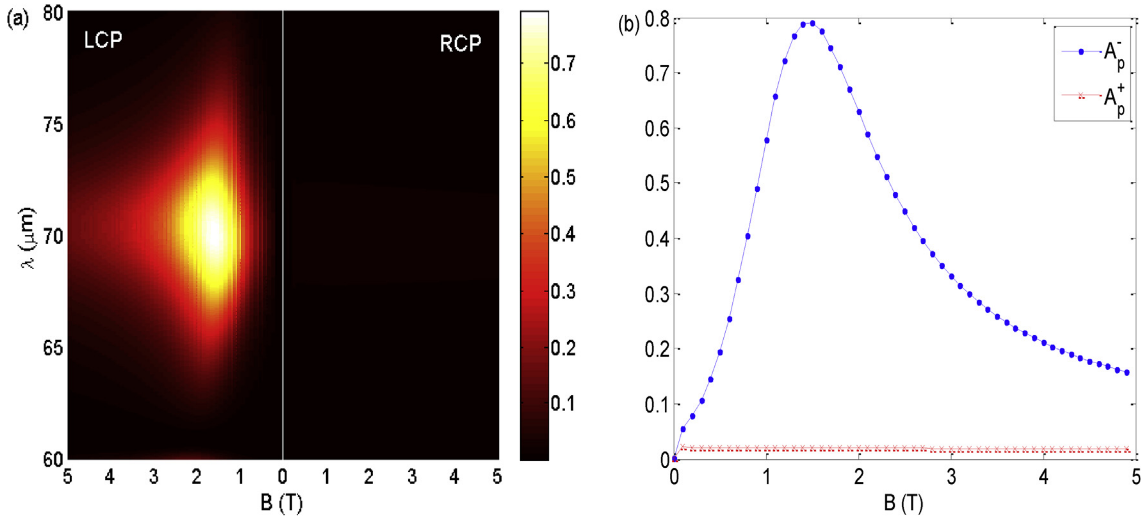

Fig. 3. (a) Absorption spectra of the proposed structure as a function of magnetic field for LCP (left panel) and RCP (right panel) light. (b) Absorption peak values (A_p) of LCP and RCP light versus magnetic field. The parameters are the same as those of Fig. 2.