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Dual-band absorption characteristics of one-dimensional photonic crystal with graphene-based defect

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ABSTRACT

In this article, the dual-band absorption characteristics of one-dimensional photonic crystals with graphene-based defect were theoretically analyzed and numerically simulated using the transfer matrix method. The dependence of dual-band absorption characteristics of the one-dimensional photonic crystal with graphene-based defect on period number of the structure behind the graphene layer, graphene layers, dielectric thickness of defect layer and the incident angle was obtained. Simulation results show that the absorptions with the lights whose wavelength are 699 nm and 1000 nm approximately enhance with the increasing of the layers of graphene. The absorption peaks increase with the decreasing of the dielectric thickness of defect layer and move toward the shorter wavelength. In the transverse electric (TE) mode, the absorption peaks can be regularly tuned by varying the incident angle. The results provide the theoretical basis for the study of graphene absorbers.

1. Introduction

As a type of gapless semiconductor, graphene consists of two dimensional (2D) honeycomb structures with monolayer of carbon atom thickness [1–3], and was widely used in physics, chemistry, materials science and other fields. Because of a variety of peculiar optical, mechanical and electronic properties like having zero band gap, high mobility at normal temperature and special optical absorption properties [3–7], graphene attracts more and more attention. This property makes graphene an alternative for optoelectronic devices such as transparent electrodes and optical display materials [8,9].

In recent years, the research and application of graphene are increasing rapidly all over the world. Graphene is considered to be a promising material for realization of ultra-fast optoelectronic devices, and may lead to materials revolution in many fields [10,11]. Hashemi et al. [12] numerically propose to utilize patterned metallic nanostructures to increase light absorption in single-layer graphene. Their simulation results show that excitation of surface Plasmon resonances in the metallic nanostructures significantly enhance the local electromagnetic field near the graphene layer, therefore, leading to a dramatic enhancement of the absorption in the graphene layer itself. Vincenti et al. [13] achieve a perfect, narrow-band absorption in an asymmetric one-dimensional photonic crystal (1DPC) with a monolayer graphene defect. Due to the large third-order nonlinearity of graphene and field localization in the defect layer, they demonstrate the possibility to achieve controllable and saturable absorption for the pump frequency. Liu et al. [14] theoretically investigate the optical absorption of graphene layers prepared on top of a one-dimensional photonic crystal with a spacer layer, they obtain the dependence of absorption characteristics of graphene on a 1DPC on graphene layers, the distance between the graphene and the 1DPC, electromagnetic mode and the incident angle.

A single layer of graphene may absorb as much as 2.3% of the incident light in a wide range of frequencies, which is a unique consequence of its conical electronic band structure [2,15]. Graphene layers have a significant effect on the absorption. Currently, the study of dual-band and multi-band absorption is less. In this paper, dual-band absorption can be realized by engineering an asymmetric 1DPC with a graphene defect. The dual-band absorption characteristics of one-dimensional photonic crystals with graphene-based defect were theoretically analyzed and numerically simulated using the transfer matrix method. The dependence of dual-band absorption characteristics on period number of the structure behind the graphene layer, graphene layers, dielectric thickness of defect layer, and the incident angle was obtained. Simulation results show that the absorptions with the lights whose

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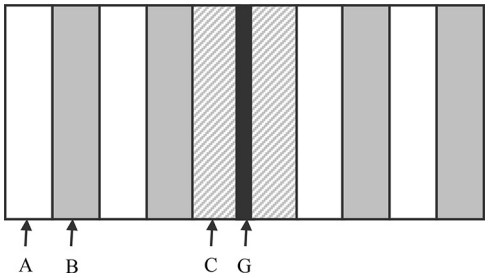

Fig. 1. Schematic of a 1DPC structure with a monolayer graphene defect layer.

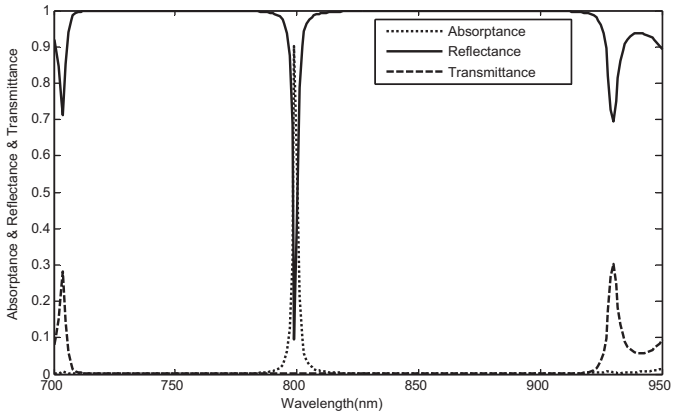

Fig. 2. Absorptance (dotted line), reflectance (full line) and transmittance (imaginary line) of 1DPC with a monolayer graphene defect at normal angle.

wavelength are 699 nm and 1000 nm approximately are enhanced with the increasing of the layers of graphene. The absorption peaks increase with the decreasing of the dielectric thickness of defect layer and move toward the shorter wavelength. In the TE mode, the absorption peak can be regularly tuned by varying the incident angle. In this paper, the 1DPC engineered saves raw material to a certain degree, and the preparation process is simpler due to the smaller total thickness and is convenient for application in a variety of absorbers. In addition, the number and position of absorption peaks can be adjusted by changing the dielectric thickness and defective media. This paper provides the theoretical basis for the study of graphene absorbers, and the designing concept for its application.

2. Theory basis

Due to its simplicity and straightforwardness, the transfer matrix method (TMM) [16–20] has been served in the calculation. The reflectance (R) and transmission (T) of the structure are calculated using TMM, respectively. It is well-known to obtain the absorption of the structure using [21–24]:

$$A = 1 - R - T \tag{1}$$

In this paper, the structure $(AB)^N CGC(AB)^M$ of the 1DPC with a graphene defect is theoretically investigated, as is shown schematically in Fig. 1, where, N and M are the number of periods of the 1DPC before and after the inclusion of graphene in the defect layer, respectively, $N = 3$, $M = 7$. The parameters used in the calculation are the permittivity [25] $\varepsilon_a = 15$, the refraction index [26] $n_b = 1.46$ for the antimony selenide Sb_2Se_3 and silicon dioxide SiO_2, the thicknesses of the SiO_2 and Sb_2Se_3 layers $d_a = 0.1\lambda_0$ and $d_b = 0.1\lambda_0$, $\lambda_0 = 694$ nm, the refraction index of graphene layers stacked in the natural graphite order [26,27] $ng = n + iC_1\left(\lambda/n\right)$, where $n = 3.0$, $C_1 = 5.446\ \mu m^{-1}$, the thickness of the graphene monolayer [26] $dg = 0.335$ nm, respectively. A and C are the same medium, $d_c = 0.085\lambda_0$. The simulation study is conducted in the TE mode.

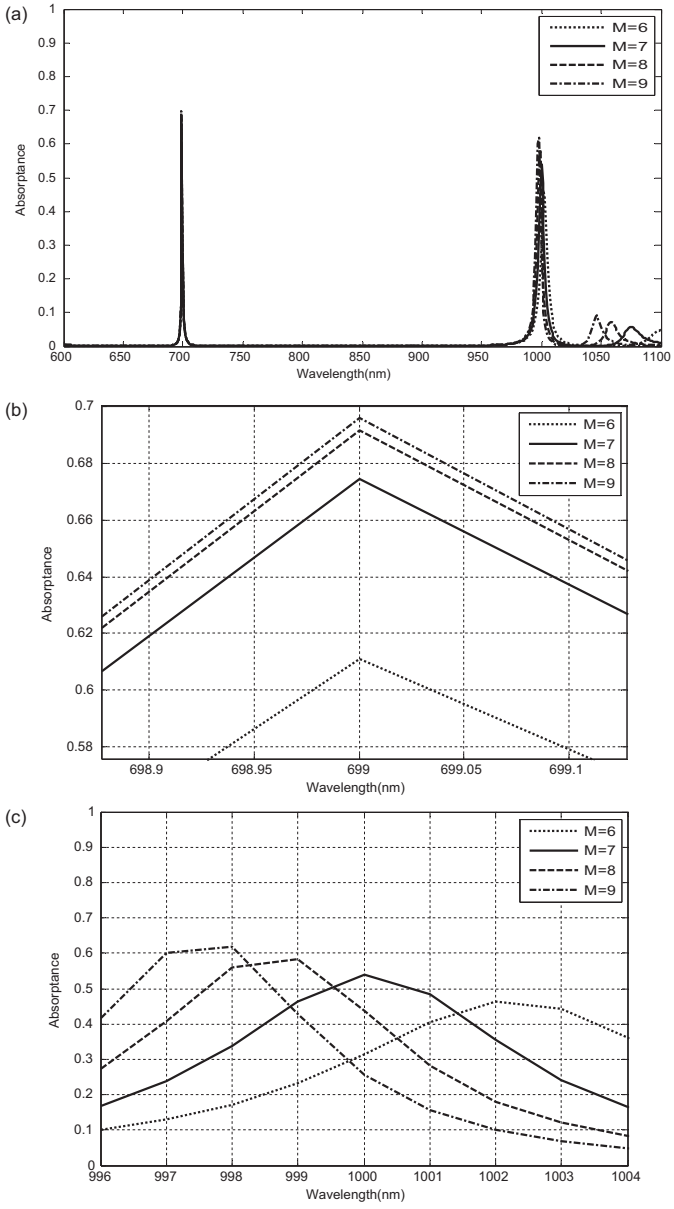

Fig. 3. (a) Absorptance as a function of wavelength for different period numbers. (b) At 699 nm, absorptance as a function of wavelength for different period numbers. (c) Around 1000 nm, absorptance as a function of wavelength for different period numbers.

3. Numerical results and analysis

In order to prove the validity of the program, an asymmetric 1DPC with a monolayer graphene defect is simulated, with the analogous structure parameters chosen in [13]. The asymmetric 1DPC is composed of two mirrors: the top mirror consists of six periods of Ta_2O_5 and SiO_2, while the bottom mirror is composed of 15 periods of the same materials, thus forming a $\lambda/2$ SiO_2 defect layer. The thickness of Ta_2O_5 and SiO_2 layers are 96 nm and 133 nm, respectively. The results are in agreement with works by means of a commercial tool based on the finite element method in [13] shown in Fig. 2. Consequently, it is proved that the calculation method in this paper is correct.