Optik 127 (2016) 8857–8863

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Multipoint control of optical bistability in a defect slab doped with single-layer of graphene nanostructure

Gh. Solookinejad, M. Panahi, E. Ahmadi Sangachin, Seyyed Hossein Asadpour*

Department of Physics, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran

ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form 26 May 2016
Accepted 28 June 2016

PACS:
42.50,-p
42.65.pc

Keywords:
Optical bistability
Group velocity
Graphene nanostructure

ABSTRACT

In this study, we investigated the optical bistability (OB) properties of transmitted weak probe light from a defect dielectric medium doped by four-level graphene nanostructure. By using the transform matrix and density matrix methods, we explore the features of transmitted light versus incident light for studying the OB behaviors in a defect slab. Our numerical results show that the threshold of OB in multipoint of incident light can be easily manipulated by some controllable parameters such as Rabi-frequencies of applied fields and optical thickness of the slab. Moreover, we find that the group velocity of transmitted pulse from the defect slab can be adjusted by tuning the optical thickness of the slab. We hope that our study may be suitable for the future all-optical based devices in Nano sizes.

1. Introduction

Controlling light by light due to its potential application in all-optical sensors, all-optical memories and all-optical transistor have been discussed by many research groups in quantum and nonlinear optics [1–12]. One the most interesting phenomena which has potential application for developing all-optical systems are optical bistability and multistability. The experimental and theoretical investigation of OB in two, three and four-level atomic systems in an optical ring cavity has been discussed by many research groups [13–22]. For example, Joshi et al. experimentally studied the optical bistable behavior in an optical ring cavity filled with a collection of three-level rubidium atoms, interacting with two collinearly propagating laser beams. Sheng et al. [14] experimentally observed OM in an optical ring cavity containing three level Λ-type Doppler-broadened rubidium atoms. The realization of OB and OM in semiconductor quantum wells (SQWs) and quantum dots (SQDs) have also been reported by many groups [23–30]. For example, Joshi and Xiao [23] studied the OB behavior in a unidirectional ring cavity containing three-level Ladder type SQWs. In fact, SQWs and SQDs are candidate as a two-dimensional (2D) electron gas. They have properties similar to atomic systems such as the discrete levels, but with the advantages of high nonlinear optical coefficients and large electric dipole moments, due to the small effective electron mass. They are interested due to wide applications for building the future all-optical systems and devices [31–40].

Graphene because of its potential usages in nanoelectronics and condense matter physics due to its unusual electronic properties and unique optical properties has been interested recently. Graphene is a single-atom thick allotrope of carbon with unusual two-dimensional (2D) Dirac like electronic excitations [41–43], which can be controlled effectively by external electromagnetic fields [44]. The tunability of the charge carrier density and conductivity by the bias voltage make graphene

* Corresponding author.
E-mail address: S.Hosein.Asadpour@gmail.com (S.H. Asadpour).

http://dx.doi.org/10.1016/j.ijleo.2016.06.104
0030-4026/

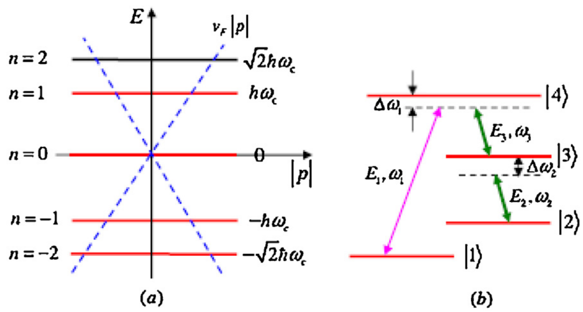

Fig. 1. (a) LLs near the K point superimposed on the electronic energy dispersion without a magnetic field $E = \pm v_F|p|$. The magnetic field condenses the original states in the Dirac cone into discrete energies. The LLs in graphene are unequally spaced: $\propto \sqrt{B}$. (b) Energy level diagram and optical transitions in graphene interacting with two continuous-wave control fields 1 and 2 and a weak pulsed probe field p. The states $|1\rangle$, $|2\rangle$, $|3\rangle$ and $|4\rangle$ correspond to the LLs with energy quantum numbers n = −2, −1, 0, 1, respectively. Graphene monolayer is a one-atom-thick monolayer of carbon atoms arranged in a hexagonal lattice, which we will treat as a perfect two-dimensional (2D) crystal structure in the x-y plane.

operates in both THz and optical frequency ranges. Belyanin and his coworkers [45–48], studied more linear and nonlinear optical properties of graphene system under strong magnetic field. Experimental and theoretical Investigations of optical solitons have also been analyzed in graphene [49–57]. Investigation of matched infrared solitons pairs based on FWM in a monolayer of graphene system has been presented in Ref. [52].

In this work, we will analyze the OB features of transmitted light from defect slab medium doped with a single-layer of graphene nanostructure by using the transform matrix and density matrix methods. We will demonstrate the impact of some controllable parameters such as optical thickness and Rabi-frequencies of applied fields on OB evolution of weak probe light through defect slab.

2. Model and equation

2.1. Pulse propagation in a dielectric medium

By using the transfer-matrix method, the reflection and transmission coefficients of the incident mono-chromatic wave with frequency ω_p in a dielectric slab can be expressed as [58]:

$$r(\omega_p) = \frac{-(i/2)(1/\sqrt{\varepsilon(\omega_p)} - \sqrt{\varepsilon})\sin(kd)}{\cos(kd) - (i/2)(1/\sqrt{\varepsilon(\omega_p)} + \sqrt{\varepsilon(\omega_p)})\sin(kd)}, \tag{1}$$

$$\mathrm{t}(\omega_p) = \frac{1}{\cos(kd) - (i/2)(1/\sqrt{\varepsilon(\omega_p)} + \sqrt{\varepsilon(\omega_p)})\sin(kd)}, \tag{2}$$

For the defect dielectric slab, the dielectric function can be divided into two parts;

$$\varepsilon(\omega_p) = \varepsilon_b + \chi(\omega_p) \tag{3}$$

where $\varepsilon_b = 1$ is the background dielectric constant and $\chi(\omega_p)$ is the susceptibility produced by the doped four-level graphene system. From Eqs. (1)–(3), we can realize that the reflection and transmission coefficients depend on the thickness of the slab and the susceptibility of the doped graphene system. In a resonance condition, the thickness of the slab is employed as $\mathrm{d} = \left(4\sqrt{\varepsilon_b}\lambda_0/2m\right)$, whereas, for the off-resonance condition, it is considered as $d = \left(4\sqrt{\varepsilon_b}\lambda_0/(2m+1)\right)$. Here, m is an integer number, and in the following numerical calculations is chosen as m = 300. Note that the other values also are available.

To investigating the OB behavior of the slab, one can use the relation between transmitted intensity U_t and the incident intensity U_{in} which is defined as follow:

$$U_{in} = U_t/T \tag{4}$$

In the next section, we explain the level structure of single-layer graphene system under strong magnetic field which we use as a defect layer in slab medium.

2.2. Single-layer of graphene system

The level structure of the doped graphene system under a strong magnetic field is presented in Fig. 1.

A monolayer of graphene system is a one-atom-thick monolayer of carbon atoms arranged in a hexagonal lattice. The chosen transitions between Landau levels (LLs) can be dipole allowed when we use the peculiar selection rules for electrons in graphene i.e., $\Delta|n| = \pm 1$ (n is the energy quantum number). Some nonlinear optical features of this system have been discussed in Refs. [49–52,56,57]. By using an external magnetic field in the range 0.01-10T, one can anticipate that the