Available online at www.sciencedirect.com
ScienceDirect
Superlattices and Microstructures 43 (2008) 537–541
Superlattices and Microstructures
www.elsevier.com/locate/superlattices

Transparency due to dipole–dipole interaction in photonic crystals doped with nanoparticles

Mahi R. Singh

Department of Physics and Astronomy, The University of Western Ontario, London, Canada N6A 3K7

Available online 20 August 2007

Abstract

In this paper, we have studied the two-photon absorption process in photonic crystals doped with four-level nanoparticles. It is considered that all the levels of the particles are interacting with the photonic crystal. The decay linewidths of all the four levels are included in the calculations of two-photon absorption process. The effect of the dipole–dipole interaction has also been included in the formulation. Numerical simulations have been performed for the two-photon absorption spectrum on an isotropic photonic crystal. It is found that the system switches between the transparent and the nontransparent states due to the dipole–dipole interaction. The phenomenon of switching depends on the linewidths of these states.
© 2007 Elsevier Ltd. All rights reserved.

Keywords: Photonic crystals; Nanoparticles; Transparency; Two-photon absorption; Nonlinear optics

1. Introduction

There is a considerable interest in studying the nonlinear phenomena in quantum optics, atomic gases and nanostructures [1–3]. The nonlinear effects play an important role in optical switching and quantum computation. We have also investigated the nonlinear phenomena such as solitons, electromagnetically induced transparency, the Stark effect and dark states in photonic crystals doped with multi-level nanostructures [4]. The aim of the present paper is to study the nonlinear phenomenon of the two-level absorption spectrum (TPAS) in photonic crystals doped with four-level nanoparticles. The effect of the dipole–dipole interaction (DDI) between the nanoparticles has also been investigated. Recently, the effect of the DDI has been included in the study of quantum coherence and interference phenomena in photonic crystals [5]. In this

E-mail address: msingh@uwo.ca.

0749-6036/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.spmi.2007.07.014

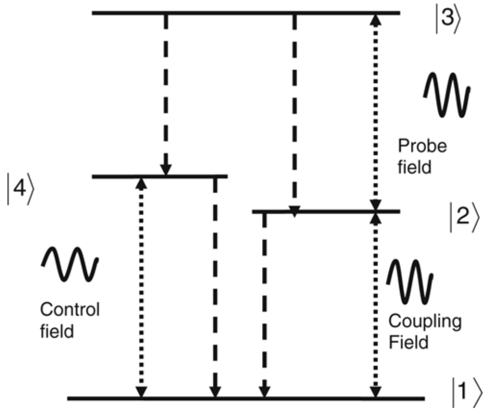

Fig. 1. A schematic diagram of a four-level nanoparticle.

paper, we have performed numerical simulations on the TPAS using the density matrix method. The decay linewidths due to the coupling between the nanoparticles and photonic crystals have been included. It is found that the system switches between the transparent and nontransparent states due to the DDI. This switching phenomenon depends on the decay linewidths of four-level nanoparticles. The present calculation can be applied with some modification to study the ultra fast optical switching and quantum entanglement. The ultra fast switching using bandgap tailoring has also been studied in photonic crystals [6,7]. Optical switching is an essential component of integrated photonic circuits.

2. Theory

We consider that the photonic crystal has an energy gap between energies ε_v and ε_c where ε_v is the maximum energy of the lower band and ε_c is the minimum energy of the upper band. The crystal is doped with an ensemble of four-level nanoparticles in the Vee-type configuration. The four levels of the nanoparticles are denoted by $|1\rangle$, $|2\rangle$, $|3\rangle$ and $|4\rangle$ (see Fig. 1). We consider that the nanoparticles are interacting with the photonic crystal which acts as a reservoir. Due to this interaction, level $|2\rangle$ decays to level $|1\rangle$, level $|3\rangle$ decays to the levels $|2\rangle$ and $|4\rangle$ and level $|4\rangle$ decays to level $|1\rangle$ (see dotted lines in Fig. 1). The decay interaction Hamiltonian can be written as:

$$\begin{aligned} H_{\text{int}} = &-\int_C \frac{\mathrm{d}\varepsilon_k}{2\pi}\sqrt{\gamma}[Z_2(\varepsilon_k)\,p(\varepsilon_k)\,\sigma_{21}^{+}\mathrm{e}^{-\mathrm{i}(\varepsilon_{21}-\varepsilon_k)t/\hbar} + Z_4(\varepsilon_k)\,p(\varepsilon_k)\,\sigma_{41}^{+}\mathrm{e}^{-\mathrm{i}(\varepsilon_{41}-\varepsilon_k)t/\hbar}] \\ &-\int_C \frac{\mathrm{d}\varepsilon_k}{2\pi}\sqrt{\gamma}[Z_3(\varepsilon_k)\,p(\varepsilon_k)\,\sigma_{34}^{+}\mathrm{e}^{-\mathrm{i}(\varepsilon_{34}-\varepsilon_k)t/\hbar} \\ &+ Z_5(\varepsilon_k)\,p(\varepsilon_k)\,\sigma_{32}^{+}\mathrm{e}^{-\mathrm{i}(\varepsilon_{32}-\varepsilon_k)t/\hbar}] + \text{c.c.} \end{aligned} \tag{1}$$

where $\sigma_{ij}^{+} = |i\rangle\langle j|$ and $\sigma_{ij}^{-} = |j\rangle\langle i|$. The resonance energy for the transition $|i\rangle \leftrightarrow |j\rangle$ is denoted by ε_{ji}. Here ε_k is the band structure energy of the photonic crystal. γ_i is an energy constant [4] and c.c. stands for the complex conjugate. The integration contour C consists of two intervals: $-\infty < \varepsilon \leq \varepsilon_v$ and $\varepsilon_c \leq \varepsilon < \infty$. The operators $p(\varepsilon_k)$ and $p^{\dagger}(\varepsilon_k)$ denote the annihilation and the creation, respectively. $Z_i(\varepsilon_k)$ is called the formfactor which is obtained in Ref. [4]. The nanoparticles are interacting via the DDI which is written as [8]

Download English Version:

https://daneshyari.com/en/article/1554881

Download Persian Version:

https://daneshyari.com/article/1554881

Daneshyari.com