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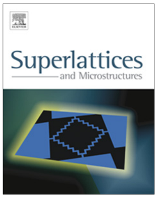

Optical bistability in triple quantum dot molecules in weak tunneling regime

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ABSTRACT

We investigated the optical bistability of a triple quantum dot molecule under coherent excitation and considering the spontaneous exciton decay and pure dephasing as two decoherence channels. By manipulating the laser detuning, electric field, and tunneling coupling, the threshold value and the hysteresis cycle width of OB can easily be controlled. Our scheme opens the possibility to control OB with electric gates, which are very useful in building all-optical switches and logic-gate devices for optical computing and quantum information processing.

1. Introduction

Over the last few years, phenomena based on quantum coherence have attracted attention of many researchers in coherent media [1–18]. One of the interesting phenomena, the optical bistability (OB) in multilevel atoms confined in an optical ring cavity, has been the subject of many recent studies because of its potential wide applications in all-optical switches, memories, transistors, and logic circuits [19]. Studies show that there are many different mechanisms [20–30] to control OB such as the phase fluctuation, the squeezed state field, the spontaneously generated coherence, and so on.

On the other hand, the OB behaviors in semiconductor quantum wells and quantum dots (QDs) have also been extensively studied recently. For instance, Joshi and Xiao [31] reported the bistable behavior in a three-level semiconductor quantum well that interacts with a strong driving

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electromagnetic field under two-photon resonant condition, and the results show that the threshold for switching to upper branch of the bistable curve can be reduced due to the presence of quantum interference. Li [32] analyzed the OB behavior in a four-subband quantum well system driven coherently by the control and probe fields inside the unidirectional ring cavity. He found that the energy splitting of the two upper excited states the coupling strength of the tunneling, the Fano-type interference, the driving field intensity as well as the frequency detuning can affect the OB behavior dramatically, which can be used to manipulate efficiently the bistable threshold intensity and the hysteresis loop. More recently, two schemes [33,34] for realizing the OB in quantum dot molecules (QDMs) have also been proposed.

In this work, we investigate the optical bistability in triple quantum dot molecules (TQDMs) inside an optical ring cavity. It is found that the optical bistability can be easily controlled via adjusting properly the corresponding parameters of the system. Our work is mainly based on the Refs. [20–34], however, our scheme is different from those works. First, we are interested in showing the controllability of the OB behavior via tunnelling-induced interference in a quantum dot nanostructure, which is much more practical than its gaseous counterpart [20–30] due to its flexible design and the wide adjustable parameters. Second, a few works have discussed OB behaviors in quantum dots [33,34] focusing on the strong tunneling regime. Unlike those works, we will mainly discuss the OB behavior in weak tunneling regime. Third, we consider two decoherence mechanisms here: the spontaneous decay of excitonic states and the pure dephasing.

2. The model and dynamic equations

We consider a four-level quantum dot molecule system [18] as shown in Fig. 1. Such a quantum dot molecule can be fabricated using self-assembled dot growth technology. With applied gate voltage, conductionband levels get into resonance, increasing their coupling, while valence-band levels become even more off-resonance, resulting in effective decoupling of those levels. As shown in Fig. 1(a), in the absence of a gate voltage, the conduction-band electron levels are out of resonance and the electron tunneling between the QDs is very weak. Contrast, in the presence of a gate voltage, the conduction-band electron levels come close to resonance and the electron tunneling between the QDs is greatly, as shown in Fig. 1(b). In such system, the tunneling can be controlled by placing a gate electrode between the neighboring dots. And in the latter case the hole tunneling can be neglected because of the more off-resonant valence-band energy levels. Thus we can give the schematic of the level configuration of a TQD system, as shown in Fig. 1(c). A probe laser field E (frequency ω) is introduced by the usual dipole interaction, which couples the ground state $|0\rangle$ with the exciton state $|1\rangle$. Under the tunneling couplings T_a and T_b, the electron can tunnel from QD1 to the QD2, and from QD2 to QD3. And we denote these indirect excitons as state $|2\rangle$ and state $|3\rangle$, respectively. Under the rotating-wave approximation, the Hamiltonian of this system is given as follow

$$H = \sum_{j=0}^{3} \hbar\omega_j |j\rangle\langle j| + [(T_a|2\rangle\langle 1| + T_b|3\rangle\langle 2| + \hbar\Omega \exp(i\omega t)|0\rangle\langle 1|) + H.c.], \tag{1}$$

where $H.c.$ means Hermitian conjugation, $\hbar\omega_j$ is the energy of state $|j\rangle, T_a$ and T_b are the tunneling strength, $\Omega = \mu_{01}E/2\hbar$ is the one-half Rabi frequency for the probe laser field, here μ_{01} is the dipole momentum matrix element and E is the electric field amplitude.

The system dynamics is described by Liouville–von Neumman–Lindblad equation, the density-matrix equations of motion in dipole and rotating-wave approximations for this system can be written as follows