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The role of laser field in the electron transport through serially coupled double-quantum dots

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Abstract. In this study, a mathematical model is developed to study the transport properties of a system consisting of serially coupled double-quantum dots embedded between two nonmagnetic leads in the presence of a laser field effect on double-quantum dots. To examine the device properties and develop a spin-dependent analytical formula for the occupancy numbers, related quantum dot energy levels and the molecular virtual levels, the treatment in this research is based on the time-independent Anderson–Newns model. These formulas are solved self-consistently to compute the tunneling current which is utilized to calculate the differential conductance "Our calculations focus on the strong regime". All the parameters that included in our calculations can be tuned experimentally. It is found that the electron transport through the system is enhanced as the frequency of the laser field increases, and the energy window is getting wider too. These results are very important to be applied to nano-devices, since the laser can be used as a tool to assist the transport of electrons through the system.

1 Introduction

The developments in the study of nanotechnology are opening a broad field, especially those depend on semiconductor quantum dots' electronic structure; in these structures, the electrons are confined in zero-dimensional systems [1–3]. Due to confinement, quantum dots have a few number of electronic shells, like atoms; in this case, the quantum dots are often called "artificial atoms" [4]. Over recent years, most theoretical and experimental studies have emphasized the electron transport through the double-quantum dot systems [5–8]. Due to the importance of the double-quantum dots (DQD) in the applications of physics and nanoscale devices, it has attracted the interest of many researchers [9–11]. The double-quantum dot (DQD) has been used in quantum computer technology [12, 13], as a noise detector [14]. Also, the DQD devices are exploited in optical spin manipulation [15]. In electron transport studies, environmental effects can be directly observed thanks to the geometry of quantum dots systems and the physical factors that can be changed in these systems. The component dots in double-quantum dot systems (DQDs) can be organized in series, parallel, or even in a T-shaped configuration [16–20].

The motivation of this study is to investigate the effect of the laser field on the electron transport process through two coupled quantum dots. The present study presents a mathematical model for electron transport via a device consisting of two serially coupled dots connected to two nonmagnetic leads. To investigate laser field effect, current and differential conductance are studied.

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2 The model calculation

In our present study, the double-quantum dots (DQDs) are serially linked and located between two nonmagnetic leads in a system, as shown in Fig. 1, that is theoretically modeled. $\mathbf{V}_{1L}$ represents the coupling interaction between the left lead and QD1, and $\mathbf{V}_{2R}$ is the coupling interaction between the right lead and QD2. $\mathbf{V}_{12}$ represents the coupling interaction between QD1 and QD2. Interactions between the double-quantum dots (DQDs), the right lead and the second quantum dot, and the left lead and the first quantum dot, as well as the effective spin exchange interaction between double-quantum dots J, the laser field parameters, and the bias voltage applied to the leads ($eV_{bias} = \mu_L - \mu_R$), are the parameters that taken into account in this study.

The system can be described in the current study by the following Hamiltonian:

$$H = H_{Leads} + H_{DQD} + H_{QD-QD} + H_{DQD-Lead}, \tag{1}$$

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