Superlattices and Microstructures 91 (2016) 391–400

Contents lists available at ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices

Effects of an in-plane magnetic field on the energy dispersion, spin texturing and conductance of double quantum wires

B. Gisi [a], Y. Karaaslan [a], S. Sakiroglu [b, *], E. Kasapoglu [c], H. Sari [c], I. Sokmen [b]

[a] Physics Department, Graduate School of Natural and Applied Sciences, Dokuz Eylül University, 35390 İzmir, Turkey
[b] Physics Department, Faculty of Science, Dokuz Eylül University, 35390 İzmir, Turkey
[c] Physics Department, Faculty of Science, Cumhuriyet University, 58140 Sivas, Turkey

ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form 21 December 2015
Accepted 22 December 2015
Available online 24 December 2015

Keywords:
Rashba and Dresselhaus coupling
In-plane magnetic field
Double quantum wire
Anharmonic potential

ABSTRACT

We investigate the electronic structure, spin and transport properties of double quantum wires formed by a symmetric, double quartic-well potential subjected to an in-plane magnetic field by taking into account Rashba and Dresselhaus spin-orbit couplings. The energy dispersion relation of the system is analyzed for different strengths of spin-orbit interactions, magnitude and direction of magnetic field. Our numerical results reveal that the existence of aforementioned parameters modifies strongly the energy band structure, introduces a wave vector dependence to energies and also leads to crossings and anticrossings between subbands. This complex structure of energy dispersion gives rise to the appearance of square-wave like oscillations in the conductance. The spin-orbit couplings, magnetic field, potential profile and Fermi energy of an electron significantly affect the depth and width of conductance steps. Moreover, we found that the competing effect between spin-orbit couplings and magnetic field leaves its marks on the spin texturing.

1. Introduction

Recent advances in fabrication of high-mobility low-dimensional semiconductor structures have prompted the large number of works in this area. The double low-dimensional semiconductor structures, such as double quantum wells, double quantum wires and double quantum dots, constituted by restricting the motion of charge carriers are attractive phenomenon in from various branches of physics to chemistry [1]. The one-dimensional double well potential is a well-known and topical problem in quantum mechanics [2]. This potential consisting of two valleys separated by the potential barrier is utilized to study the properties of numerous systems [3]. The study done by Bender et al. [4] for obtaining the energy eigenvalues of quantum anharmonic oscillator has been quite impressive that has been followed by a great number of works. The energy eigenvalues of double well anharmonic oscillator are investigated using perturbative or nonperturbative methods by many researchers. Banerjee et al. [5] obtained the eigenvalues of two-well oscillator by a nonperturbative method WKB. Hodgson et al. [6] performed an analytic procedure to calculate accurate wavefunctions and energy eigenvalues of a double minimum potential with almost degenerate levels. The effect of an external field onto the behavior of the lowest eigenvalues of the quantum double well anharmonic oscillator was surveyed by der Straeten et al. [7]. Also, Witwit [3] calculated energy levels of

* Corresponding author.
E-mail address: serpil.sakiroglu@deu.edu.tr (S. Sakiroglu).

http://dx.doi.org/10.1016/j.spmi.2015.12.032
0749-6036/

nonsymmetric double well potentials in one-, two- and three-dimensional systems for large values of the depth of the potential.

Furthermore, a great deal of theoretical [8,9] and experimental [10,11] work has been devoted to survey the electronic and transport properties of double quantum wires (QWs), consisting of two parallel long QWs coupled through a potential barrier allowing the tunneling of electrons between them. Shi et al. [12] investigated the magnetotransport properties of dual QWs for different heights of barrier in the presence of magnetic fields. Numerical results show that if the potential barrier is height enough, *i.e.* the coupling between the QWs is weak so they are approximately independent, the lower energy eigenvalues are closely bunched as a couple. Lyo and his collaborates [13,14] searched the energy spectrum, magnetization and magneto-transport properties for tunnel-coupled double QWs subjected to an external magnetic field. The electronic transport properties of double QWs by considering impurity, perpendicular magnetic field and correlated disorder were investigated by Korepov [15,16]. Gudmundsson et al. [17] analyzed the energy spectrum, electronic transport and probability density of electron waves of a double QW system containing a coupling element in the middle barrier between the two parallel QWs under the influence of magnetic field.

The study of spin-orbit (SO) interaction in quantum confined structures is important from the standpoint of their fundamental role in spintronic applications [18]. These devices are based on manipulating and controlling the spin orientation by utilizing SO interaction which arises from inversion asymmetry properties of low-dimensional systems. Structural inversion asymmetry induces Rashba SO interaction which can be tuned by changing the gate voltages [19] whereas bulk inversion asymmetry gives rise to Dresselhaus SO interaction which contribution can be altered by sample thickness or electron density [20]. Considerable amount of survey has been paid on the electronic, spin and transport properties of single QWs taking into account the effects of external magnetic fields and SO interactions [21–29].

Band structure behaviors, spin texture and transport properties of double QWs have attracted immense interest in respect of promising remarkable new devices, faster, smaller, and more powerful for the applications in quantum computing, spin-field effect transistors and spin filters [30,31]. It is therefore important to characterize electronic energy spectrum of double QWs in the presence of different external agents, in order to gain a better understanding of the conductance and spin-related properties. In this purpose Karaaslan et al. [32] investigated the effects of Rashba SO interaction on the electronic energy dispersion and conductance of double QW under the influence of perpendicular magnetic field. Recently some experimental techniques have been developed to control a coupling of spin to electric field [33,34]. According to the result of these experiments, an in-plane magnetic field is more appropriate to obtain a prominent spin resonance. SO interactions generate an effective in-plane magnetic field which gives rise to an drift-driven in-plane spin polarization, and the summation of an external magnetic field and SO induced effective magnetic field leads to observe surprising spin polarization [33,35]. In the light of these findings it is worth to investigate the effect of an in-plane magnetic field on the energy, spin texture and conductance of double QW considering the SO interaction. The organization of the paper is as follows: In Section 2 we briefly present the system and methodology used throughout our study. In Section 3 we discuss the numerical results while Section 4 summarizes our findings.

2. Theory and formalism

Semiconductor nanowires are powerful class of materials that through a controlled growth and organization can be produced in a wide range with a compositional and/or doping modulation [36]. Spatially separated two identical quasi-one-dimensional systems can be coupled by an additional lateral confinement to produce a double quantum wire structure [37]. Therefore, the confinement potential representing the local depletion of stacked two-dimensional gases contained in double-quantum-well heterostructures with controllable tunneling barrier thickness can be modeled by a double quartic-well confinement potential given as

$$V(y) = \frac{1}{4}\lambda\left(y^2 - \frac{\mu^2}{\lambda}\right)^2, \tag{1}$$

where μ and λ are positive, adjustable structural parameters controlling the height of the barrier between wells and the width of wells. In-plane magnetic field applied with an arbitrary orientation is chosen as $\mathbf{B} = B(\cos\phi\mathbf{e}_x + \sin\phi\mathbf{e}_y)$ where ϕ stands as an azimuthal angle. The wire orientation along $x-$ direction is shown in Fig. 1.

The solutions of Schrödinger's equation can be written as a product of plane waves propagating along the x axis and y dependent spinor part as follows:

$$\psi_{nk_x}(\mathbf{r}) = \frac{e^{ik_x x}}{\sqrt{L}}\begin{pmatrix}\varphi_{nk_x}(y,\uparrow)\\ \varphi_{nk_x}(y,\downarrow)\end{pmatrix}. \tag{2}$$

Here φ_{nk_x} is the spinor function. We use integer numbers $n = 1,2,3,\ldots$ to label different energy subbands and introduce a continuous wave number k_x. The finite-T frame formalism is used as a numerical trick, but results of actual calculations are for $T = 0$ case. $\sigma_a(a = x,y,z)$ being the corresponding Pauli matrix, we can calculate spin magnetization components,