NUMERICAL CALCULATION OF ZEEMAN EFFECT AND LANDE-FACTOR IN NANOWIRE GATED QUANTUM DOTS

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ABSTRACT

A self-consistent solution of the Poisson-Schrodinger equations in gated quantum dot is performed using the control volume method to give the spin states of electrons and the Zeeman splitting energy. In this work, we have calculated the Landé g-factor in several orientations of the external magnetic field. We have also studied the influential related coefficients. Moreover, the variation of potential energy in nanowire quantum dot versus the variation of the voltage gates has been studied. The Results obtained by the present study were in good agreement with those of numerical and experimental methods.

KEYWORDS: Quantum dot, Nanowires , Coulomb blockaded, artificial atom, Single Electron Transistor.

1 INTRODUCTION

Recently there is increasing interest in spin quantum dot nanowire for in nanodevice applications [1]. Nanowires are grown from several methods (CVD, MBE, VLS...), the vapor-liquid solid system is high degree of controlling parameters such as position, diameter, length and composition [2].

Appearance of Zeeman energy splitting imposes the existence of an external magnetic field, because the electron undergoes the oscillation between the opposite spin states [3].

There is currently great interest in studying spin related phenomena in semiconductor quantum naowires with spin-orbit interaction (SO) [4]. Energy spectra of such dots as determined by transport spectroscopy bear distinct signatures of strong spin-orbit (SO) interaction which results from the structure inversion asymmetry (Rashba SO coupling [5]) or the bulk inversion asymmetry (Dresselhaus SO interaction [6]).

In nanowire quantum dots the effective g-factor was recently measured in electric dipole spin resonance (EDSR) experiments [7] for a two-electron spin-blocked configuration or by magnetotransport measurements on electron [8] and hole [9] quantum dots, Moreover, the mixing of the spin states by SO coupling determines an effective Landé factor (g factor) and its anisotropy [10] as a function of the magnetic field orientation.

In this work, we applied nanodevice model single quantum dot nanowire (InAs) as presented in reference [11] and which is defined by local gating. Five gates underneath the wire create the confinement potential and control the electron number on the dot [11]. Numerical calculation, we have resolved the Poisson-Schrödinger equations one dimensional, by fins volume method; we have studied the Zeeman splitting enrgy in semiconductor quantum dots nanowires and by several orientations of the magnetic field we have calculated the Landé g- factor. Also, we have studied the influential related coefficients. Moreover, the variation of potential energy in nanowire quantum dot versus the variation of the voltage gates has been studied.

2 MODEL STRUCTURE

Figure.1. shows the real model of the single quantum dot nanowire (InAs) as present in reference [11].Single quantum dot is coupled to the source and to the drain, and also it is coupled capacitively to one or more gates which let changes in the electrostatic potential [12] and there is five gates underneath the wire create the confinement potential and control the electron number on the dot.

Figure 01: Real model of the single electron transistor [11]

3 THEORY

We consider a single-electron quantum dot defined in nanowire described by one-dimensional Hamiltonian:

$$h = \frac{P^2}{2m^*} + V(r) + H_{SO} + \frac{1}{2} g\mu_B B.\sigma \qquad (1)$$

Where $P = -i\,\eta\nabla + e\mathrm{A}$ considering the symmetric gauge we obtained the following:

$$\mathrm{A} = B\,(z\sin\Phi, -z\cos\Phi\,, y\cos\Phi - x\sin\Phi) \qquad (2)$$

The confinement potential which we take in a separable form:

$$V(r) = V_L(x) + V(y,,z) + |e|\,.\,E.r \qquad (3)$$

Where E stands for the external electric field. We assume the electric field is applied on the direction (oz). In this work, we applied the magnitic field aligned in the xy plane with an angle Φ between B and the x axis, the Zeeman term stands for the following expression:

$$\frac{1}{2} g\,\mu_B B.\sigma = \frac{1}{2} g\,\mu_B B(\sigma_x\cos\Phi + \sigma_y\sin\Phi) \qquad (4)$$

Where H_{SO} describes Rashba Spin –orbit interaction which results from the structure inversion asymmetry. We account for Rashba SO coupling :

$$H_{SO} = \alpha_0 \frac{\partial V}{\partial r}\,.\,(\sigma \times K) = \alpha\ (\sigma_x k_y + \sigma_y k_x) \qquad (5)$$

Where $\alpha = \alpha_0 E_z$.

We have solved the Poisson equation one-dimensional by fins volume method, and we have calculated the electrostatic potential by Poisson-equation:

$$\nabla\left[\varepsilon_0\varepsilon_r(r)\,\nabla\,\Phi\,(r)\right] = -\rho(r) \qquad (6)$$

Where ε_0 is present the permittivity of the vacuum and the relative permitivity ε_r (InAs) is equal to 12.5, than the charge density is:

$$\rho(r) = e\,(N_d - N_a - n\,(r)\,) \qquad (7)$$

Where N_d , N_a are the donors and acceptors density respectively, the last term is the electrons density. In this work, we have used asymptotic solution (1D the x direction) for solved Schrödinger equation. Such a system is described by the Hamiltonian,

$$\begin{aligned} h_{1D} &= \frac{\eta^2 k_x^{\,2}}{2m^*} + V(x) - \alpha\,\sigma_y k_x \\ &\quad + \frac{1}{2} g\mu_B B(\,\sigma_x\cos\Phi + \sigma_y\sin\Phi) \end{aligned} \qquad (8)$$

Where $k_x = -i\dfrac{\partial}{\partial x}$.

A numerical method is based on the self-consistent procedure of the solution of the one dimentional Poisson-Schrodinger equations with a nonuniform mesh size in nanowire quantum dot, by fins volume method; we have studied spintronics of the electron in semiconductor quantum dots nanowires.

4 RESULTS AND DISCUSSIONS

Figure 2 present the distribution of the potential energy in the quantum dot we observed the electrons accumulated in the leads when the quantum well is high. When we have varied the voltage of the gate 3 (Vg3 = -1, -1.5, 0, 1, 1.5, 2 V), we have observed the depth of the quantum dot is increased becouse the energy decreases, in this states the electrons can be traverse the potential barrier by tunneling effect at energy decrease condition.

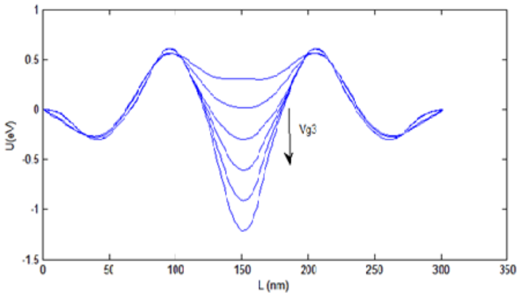

Figure 02: Variation of potential energy in nanowire device

A magnetic field parallel to the nanowire is applied (fig 3) we observed that when the magnetic field increases the energy level is doubled or it split. Due the spin the electron up and down and the difference between the levels is proportional with the magnetic field, so this consequence determines the Zeeman splitting effect.

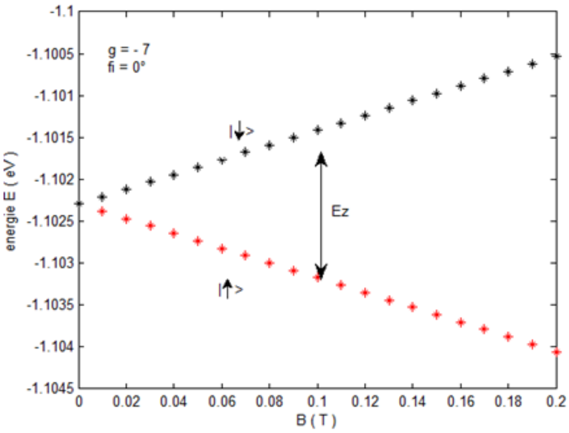

Figure 03: Single-electron energy in the quantum dot a function the magnetic field with radius R=55nm and SO interaction constant $\alpha = 25meVnm$

Figure 4 shows the extracted Zeeman energy for a single electron for different magnetic field, at $\Phi = 171^0$ the Zeeman energy increases linearly with magnetic field. When the direction of magnetic field is changed by $\Phi = 81^0$ a smaller Zeeman splitting is calculated.

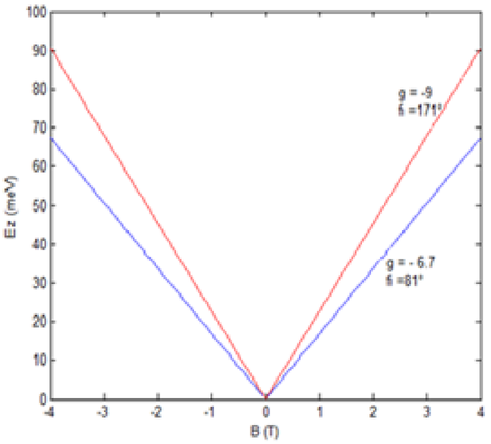

Figure 04: Variation of the Zeeman splitting a function the magnetic field in quantum dot

The effective g-factor have studied a function the orientation of the magnetic field B=3.5T (Fig.5) and the length of the dot is equal to 100 nm, we have only observed the amplitude of the oscillation is different with the variation of the SO interaction constant, and the shape of the oscillation as the same of the results was obtained in reference [9].

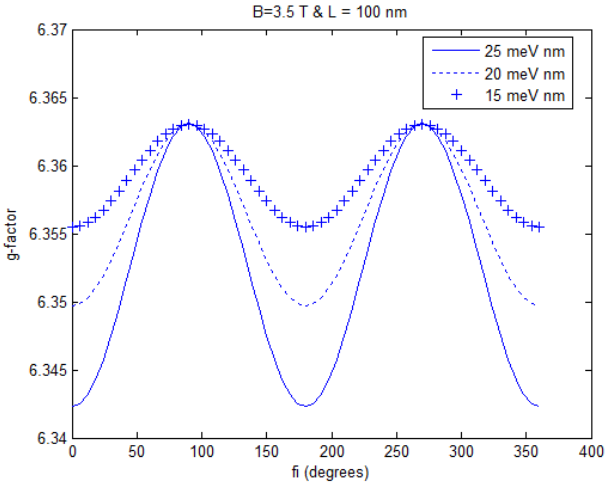

Figure 05: effective g-factor obtained for quantum dot nanowire with the variation of the interaction constant

For determined the influential related coefficient, we have also studied the Landé-g-factor by the polarization of the voltage gate 3, we have found the amplitude of the oscillation is increased also with decreases the voltage gate 3 and the size of the quantum dot (L=55nm).

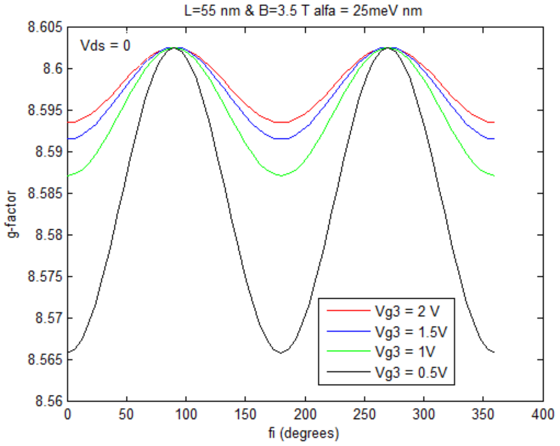

Figure 06:.Influence the polarization of the gate on effective g-factor

5 CONCLUSION

For determined the electronics proprieties in the real model of the nanowire single quantum dot, we have solved one-dimensional Poisson-Schrödinger equations by the fins volume method with applied the different orientation of the external magnetic field. In this paper, by variation of the magnetic field and the polarization of gate we have calculated the Zeeman splitting energy effect, the Landé g-factor in several orientations of the external magnetic field and the influential related coefficients. We have observed that the amplitude of the Lande-g factor is related with many coefficient lakes the dot size, the voltage polarization of the gate3, and to the SO coupling interaction constant.

Moreover, such method confirmed the Zeeman splitting energy effect.

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