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Photon Assisted Tunneling in Strong Microwave Cavity within Double Quantum Dots in Semiconducting Nanotubes

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ABSTRACT We have studied strong microwave cavity within quantum dots in semiconductor carbon nanotubes. In carbon nanotubes the graphene related material with strong spin orbit coupling due to curvature of the carbon plane was found. We have considered detection of photon assisted tunneling involving spin flips and intervalley transitions. It was based on the time dependent configuration interaction approach for system of several carriers within tight binding approach. It was found that for system in which the charge transport was blocked by the Pauli blockade the Landau-Zener-Stueckelberg pattern contained separated lines corresponding to the spin or valley flips accompanied the electron hopping. We have considered unipolar quantum dots confining holes or electrons for systems in which phonon induced charge transition from the ground state to the excited state was allowed or blocked by the Pauli exclusion principle. It was found that the Landau-Zener-Stuecklberg pattern was reproduced informer case and non-degenerate triplet like spin valley polarized state was observed. The Landau-Zener-Stueckelberg interference pattern was utilized for the study of the dephasing process in double quantum dots including the spin coherence as well as for sensitive residual radiation defectors, charge and spin pumping. The phonon assisted and Landau-Zener-Stueckelberg interference was found in quantum dots for semiconducting carbon nanotubes. The nanotube was suspended above the electrostatic gates and produced a double quantum dot confining potential. The obtained results were found in good agreement with previously obtained results.

KEYWORDS Microwave, Semiconductor Carbon Nanotube, Intervalley Transition, Spin Flip, Quantum Dot, Electron Hopping, Photon.

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INTRODUCTION

Kouwenhoven et al. [1], Safford et al. [2] and Bick et al. [3] studied the tunneling in quantum dots in microwave fields when the Fermi level electrons passed through the higher energy confined levels during absorption of energy from radiation field. Shang et al. [4], Peffa et al.

[5] and Gaudreau et al. [6] presented the procedure of fast spin flips based on the Landau-Zener-Stueckelberg interference. Shevchenko et al. [7] and Mavalankar et al. [8] studied the dephasing process for these patterns in double quantum dots. The hopping parameters contained the spin-orbit interaction which arised from the curvature of the graphene plane were studied by several investigators [9-14]. Oskia and Szafran [15] showed that both the folding of the graphene plane into the tube and the bend of the tube were taken into account and included Peirls phase accounted for the interaction of the orbital magnetic moments with the external magnetic field. Osika and Szafran[16] presented that eigen-state of Hamiltonian were the creation and annihilation operators of the electron-electron interaction matrix elements. Aharonovich et al. [17], Senellart et al. [18] and Zhou et al. [19] studied that quantum dots were regarded as the best solid state quantum light emitter. The works on quantum dots in the field of quantum science and technology were carried out with InGaAs quantum dots obtained through Stranski-Krastanow growth method, which were invented. Kuhlmann et al. [20] and Lodahl et al. [21] presented the modified material quality to reduce charge noise by integrating quantum dots in photonic structures [22-25] by tailoring the quantum dot properties through external electric, magnetic and elastic fields [26] and by implementing advanced excitation schemes [27]. Mittelestadt et al. [28] and Singh [29] developed theoretical model and computational methods were used to interpret the observed optical properties of quantum dots.

METHOD

We have modeled a semiconducting carbon nanotube and chiral vector. We have considered both a straight nanotube and bent with radius. The nanotube suspended above the electrostatic gates which produced a double quantum dot confining potential given by

$$W_{QD}(z) = V_1 e^{\frac{-(z+z_s)^2}{d^2}} + V_2 e^{\frac{-(z-z_s)^2}{d^2}}$$

Where d is the quantum dot width, z_s is the shift of the dots from $z = 0$, V_1 and V_2 are the potential of the left and right quantum dots. The calculation of single electron states in the tight binding approximation with p_z orbitals and Hamiltonian is expressed as

$$H = \sum_{(i,j,\sigma,\sigma')} \left(c_{i\sigma}^{\dagger} t_{ij}^{\sigma\sigma^1} c_{j\sigma'} + H.c. \right)$$

$$+ \sum_{i,\sigma,\sigma'} c_{i\sigma}^{\dagger} \left(w_{QD}(r_i) \delta_{\sigma\sigma'} + \frac{g_L \mu_b}{2} \sigma^{\sigma\sigma'} . B \right) c_{i\sigma'}$$

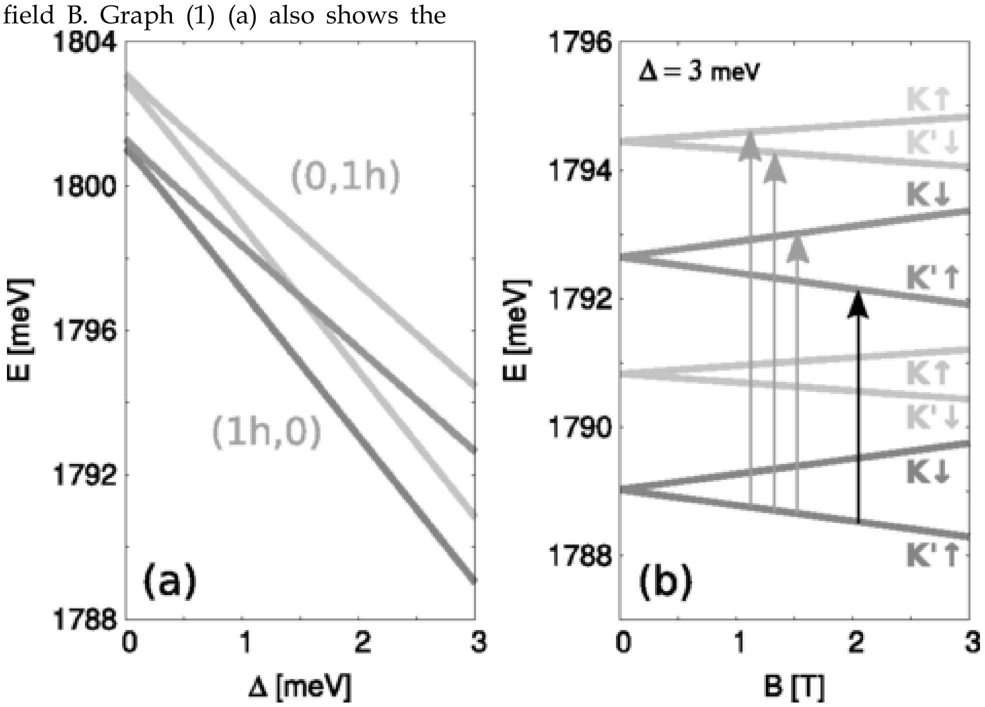
Where $c_{i\sigma}^{\dagger}\left(c_{i\sigma}\right)$ is the particle creation or annihilation operator at ion *i* with spin σ, $t_{ij}^{\sigma\sigma'}$ is the spin dependent hopping parameter, $\delta_{\sigma\sigma'}$ is the Kronecker delta, $g_L = 2$ is the Lande factor, μ_b is the Bohr magneton and σ is the vector of Pauli matrices. The hopping parameters $t_{ij}^{\sigma\sigma;}$ contained the spin orbit interaction which arised from the curvature of the graphene plane. The $t_{ij}^{\sigma\sigma'}$ included the Peierls phase which accounted for the interaction of the orbital magnetic moments with the external magnetic field. We have calculated the eigen-states by utilizing the configuration interaction method. The eigen problem of the Hamiltonian by solved by the equation given below.

$$H_{CI} = \sum_{a} \in_a g_a^{\dagger} g_a + \frac{1}{2} \sum_{abcd} v_{ab,cd} g_a^{\dagger} g_b^{\dagger} g_c g_d .$$

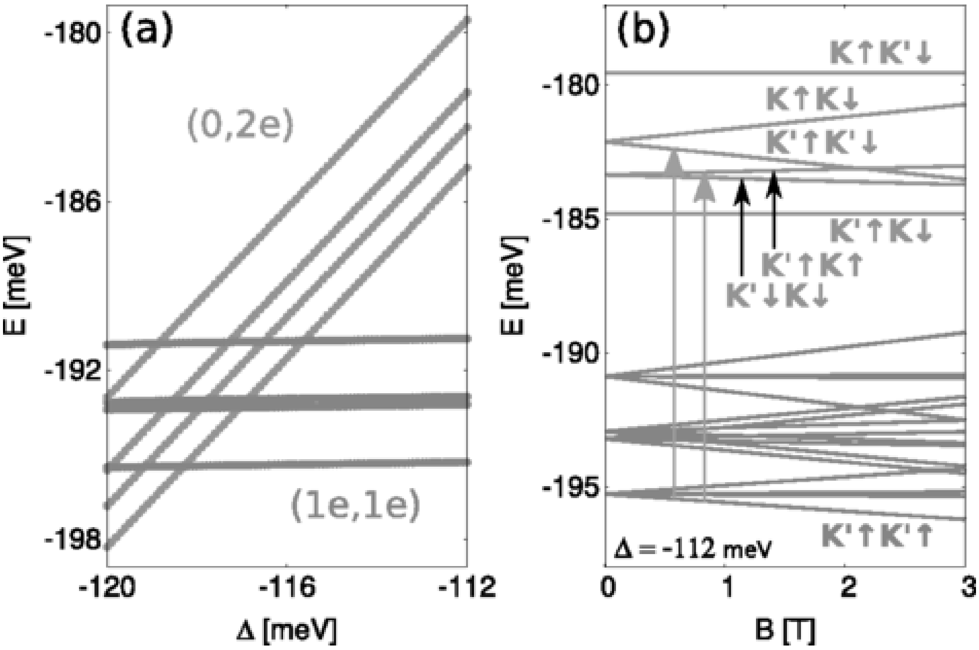
Where $\in_a$ is the energy of the *a*th eigen-state of Hamiltonian H, $g_a^{\dagger}$ and g_a are the creation and annihilation operators of the electron into *a*th state. $V_{ab,cd}$ are electron-electron interaction matrix elements. We have considered two electrons at the bottom of the conduction band and included the eight lowest conduction band orbitals in the configuration interaction basis. The dynamics of the system driven by an external *ac* electric field was simulated by solving the time dependent Schrodinger equation.

RESULTS AND DISCUSSION

We have presented the effect of strong microwave cavity within double quantum dots in semiconducting nanowires. A atomistic tight binding approach and the time dependent configuration interaction method were applied to describe the systems of a few confined electrons and holes. Graph (1) show the single hole lowest energy levels of the system as a function of the potential difference between the dots. It was found that the levels of the $(1h,0)$ and $(0,1h)$ branch are degenerate at potential difference $\Delta = 0$. The tunneling coupling between the dots were used in simulation of the Landau-Zener-Stueckelber interference. It was found that for positive value of Δ the $(1h,0)$ charge configuration was upgraded to the ground state. Graph (1) (b) shows that degeneracy was converted by the external magnetic field B. Graph (1) (a) also shows the splitting of charge configuration. In carbon nanotubes the hole was tuned to the right dot only by the transition to the same spin and valley states. Graph (1) (b) also present the transition to the states of different spin of valley and produced that the symmetry of the nanotube was broken. It was found that mixing of the spin or valley degree of freedom was obtained by binding the nanotube. Graph (2) (a) shows the lowest energy levels of two electron system as a function of potential difference Δ. Graph (2) (b) shows the effect of the magnetic field B on the energy levels. Graph (2) (b) also present that in non-zero magnetic field the two electrons in the quantum dots occupied the same spin and valley states and the tunneling from one dot to the other was suppressed. The obtained results were compared with previously obtained results of theoretical and experimental research works and were found in good agreement.



Graph 1: Plot of single hole energy levels in quantum dot as function of potential difference between the dots.



Graph 2: Plot of two electron energy levels in quantum dots as a function of potential between the dots.

CONCLUSION

We have studied the photon assisted tunneling in strong micro cavity within double quantum dots in semiconducting nanotubes. An atomistic tight binding method and the time dependent configuration interaction process was applied to explain the behavior of the systems of a few confined electrons and holes. It was found that for charge configurations for which the ground state was Pauli blocked and was utilized for resolution of the transitions which produced spin flips. The photo assisted tunneling and Landau-Zener-Stueckelberg interference was found in quantum dots in semiconducting carbon nanotubes. The graphene related material with strong spin orbit coupling due to the curvature of the carbon plane was observed. For strong microwave fields within double quantum dots the photo assisted tunneling entered the regime of the Landau-Zener-Stueckelberg interference when the system was driven by an ac electric field across the sample in absence of crossing between energy levels of different charge occupation. The system was tuned by voltages into a regime where only the ground state was below the Fermi energy of the drain. The results found were in good agreement with previously obtained results.

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