ENERGY STATES IN A CERTAIN TYPE COAXIAL GAAS/AL$_x$GA$_{1-x}$AS QUANTUM WELL WIRES AND ELECTRIC AND MAGNETIC FIELD EFFECTS

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Abstract

In this work, the energy states of an electron that is confined in coaxial GaAs/$Al_xGa_{1-x}As$ quantum well wires with interesting geometry are investigated in the presence of electric and magnetic fields. The calculations are performed by using the finite difference method. The results are given as functions of the inner barrier width, electric and magnetic field strengths. It is found that the variations in the energy states, which may be useful in technological applications, depend strongly not only on the geometry of the wire but also on the applied electric and magnetic field in coaxial GaAs/$Al_xGa_{1-x}As$ quantum well wires.

Keywords: Quantum well wire, electric field, finite difference.

INTRODUCTION

In recent years, the energy states and transport properties of spatially confined electrons in low-dimensional quantum systems have received great attention [1-8]. In particular, many theoretical and experimental studies have been performed on the energy states of an electron in quantum well-wires (QWWs) due to the possible technological applications in optoelectronics.

The application of external fields has become an interesting probe for studying the physical properties of QWWs, both from the theoretical and technological point of view. Applying an electric field in the growth direction of the system causes a polarization of the carrier distribution and shifts the quantum energy states [9]. These effects cause considerable changes in the energy spectrum of the carriers, which may be used to control and modulate the intensity output of devices. The application of a magnetic field to a crystal changes the dimensionality of electronic levels and leads to a redistribution of the density of states [10,11].

In the present work, the energy states of an electron in coaxial quantum well wires (CQWWs) are obtained in the presence of electric and magnetic fields. The wavefunctions and energy eigenvalues in the presence of electric and magnetic fields are directly calculated by using the finite difference method [11,12].

THEORY

The structure of CQWWs with interesting geometry which is studied in this work is shown in Fig. 1. The structure considered in Fig. 1 consists of two coaxial GaAs wires one within the other and each surrounded by $Al_xGa_{1-x}As$ layers such that these layers build finite potentials in between the wires and outside the whole system. The outer wire has a cylindrical potential profile shape and the inner wire has a conic potential profile shape which forms a finite barrier potential.

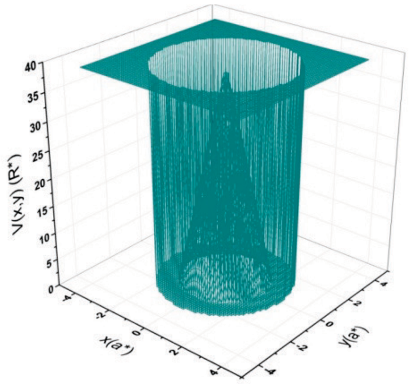

Fig.1. *Potential profile of a sample CQWWs.*

Using the effective-mass approximation, the Hamiltonian equation of the studied CQWWs structure lying along the $+z$ direction, under an electric field applied in the $+x$ direction and uniform magnetic field in the $+z$ direction is taken to be

$$H_0 = \frac{1}{2m^*}\left[\vec{p} + \frac{e\vec{A}}{c}\right]^2 + |e|F + V(x,y) \ , \qquad (1)$$

where effective-mass and momentum operator of the electron are denoted by m^* and $\vec{p}$, respectively. e is the elementary charge. The potential $\vec{A}$ is chosen as $\vec{A} = \left(-\frac{1}{2}B_y, \frac{1}{2}B_x, 0\right)$ yielding $\vec{B} = (0,0,B)$. F defines the strength of the electric field and $V(x,y)$ is the confining potential. The confining potential is

$$V(x,y) = \begin{cases} 0 & r > R_0 \\ V_0(1 - r/r_0) & r \le R_0 \end{cases} \ . \qquad (2)$$

In above equation, r ($r = \sqrt{x^2 + y^2}$) is the radius and R_0 is the radius of the inner conic wire potential, respectively.

By using $\vec{p} = -i\hbar\vec{\nabla}$, and reduced units a^* for length and R^* for energy units, the Hamiltonian in Eq. 1 can be rewritten as

$$H_0 = -\nabla^2 + \eta x + \gamma L_z + \gamma^2\frac{(x^2+y^2)}{4} + V(x,y) \quad , (3)$$

where $\gamma = \frac{e\hbar B}{2m^* c R^*}$ and $\eta = \frac{|e| a^* F \left(\frac{kV}{cm}\right)}{R^*}$ are zero-dimensional measurements for magnetic and electric fields, respectively. B is applied magnetic field strength and L_z indicates the z component of the angular momentum operator.

By employing the finite difference technique, the exact numerical solutions of the studied QWW can be obtained from the following equation

$$H_1\Psi_1(x,y) = E_1\Psi_1(x,y) \quad , \qquad (4)$$

where $\Psi_1(x,y)$ and E_1 are the ground-state wave function and energy, respectively. H_1 in Eq.4 is given by

$$H_1 = -\frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} + \eta x + \gamma^2\frac{(x^2+y^2)}{4} + V(x,y) \qquad (5)$$

The finite difference method is employed to obtain the numerical solutions in Eq.(1) [11,12].

RESULTS AND DISCUSSIONS

The results are presented in reduced effective units of length and energy, which are given by an effective Bohr radius a^* and effective Rydberg R^*, respectively. They are $a^* \cong 100$ Å and $R^* \cong 5.83\ meV$ in GaAs/$Al_xGa_{1-x}As$ QWWs. A potential barrier of $V_0 = 228\ meV$ is considered.

The wavefunctions and the energy eigenvalues of an electron in the studied CQWWs structure are obtained for different values of the inner conic barrier's radius R_0 and electric and magnetic field.

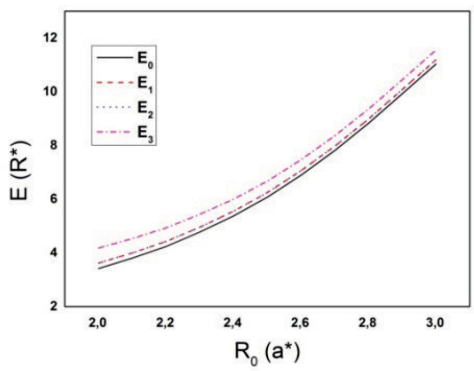

Fig. 2. *The energy eigenvalues of an electron which is confined in CQWWs with interesting geometry as a function of the conic barrier radius R_0.*

In Fig. 2, the energy eigenvalues of an electron which is confined in CQWWs with interesting geometry are shown as a function of the conic barrier radius R_0. It is seen that the energy values increase as the barrier radius R_0 increases. The point that attracts our attention is that the differences in the energy eigenvalues decrease when approaching the outer cylindrical wire radius with increasing R_0 values. Another considerable point is that the E_1 and E_2 energy states are degenerate. In order to explain this situation, the wavefunctions are shown in Fig. 3 for different R_0 values. It is seen in Fig. 3 that since the electron probability distributions are almost the same, the energy eigenvalues are very close to each other for E_1 and E_2 states.

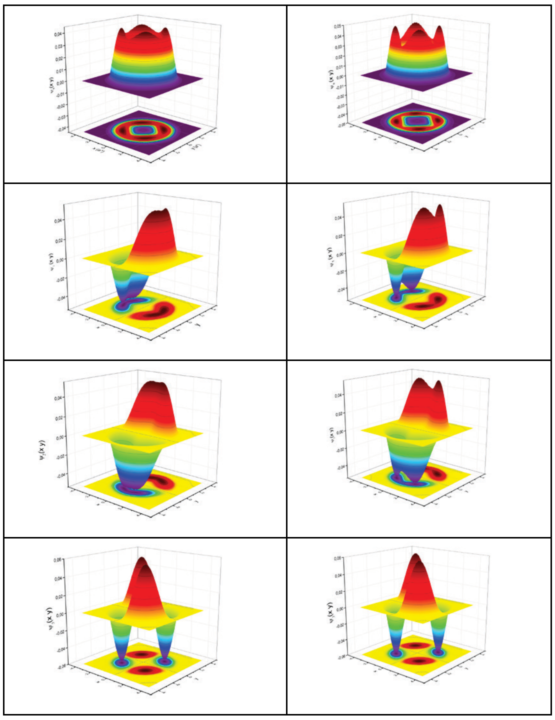

Fig. 3. *The wavefunctions of an electron for $R_0 = 2a^*$ in the left column and $R_0 = 2.4a^*$ in the right column.*

In Fig.4 the four energy states are given as a function of the applied electric field for $R_0 = 2a^*$. As the electric field increases, E_0 and E_1 energy eigenvalues show almost a linear decrease. E_2 and E_3 are constant until a fixed value and they decrease for lower electric field strengths.

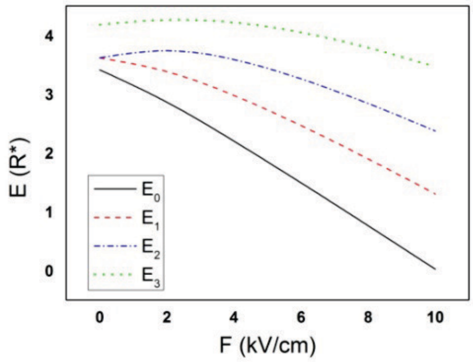

Fig. 4. *The energy eigenvalues of an electron that is confined in CQWWs with interesting geometry as a function of the applied electric field.*

In Fig. 5 the four energy states are given as a function of the applied magnetic field $R_0 = 2a^*$. When the magnetic field increases, the energy eigenvalues show almost a linear increase since the magnetic field causes a stronger confinement for electron in CQWWs.

CONCLUSION

In conclusion, the CQWWs with interesting geometry is defined. The defined CQWWs consist of a conic potential barrier inside a finite cylindrical wire. It is observed that the energy eigenvalues increase as the radius of the conic potential barrier potential R_0 increases. The energy eigenvalues decrease with increasing applied electric field for $R_0 = 2a^*$. When the magnetic field is applied to the structure, the energy values increase as the magnetic field increases. It is shown that the energy eigenvalues of an electron in the CQWWs depend strongly on the structural geometry and also the electric and magnetic field which cause considerable effects on the CQWWs. The finite difference method is usable and effective in this sort of calculation. The obtained results in this work may hopefully guide experimenters who study QWWs.

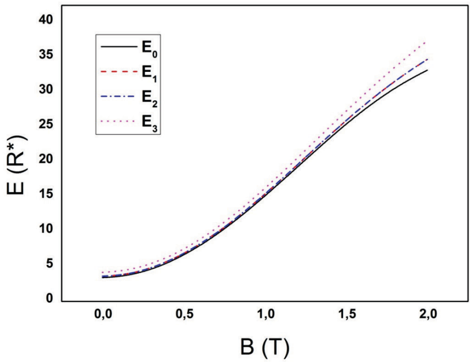

Fig. 5. *The energy eigenvalues of an electron that is confined in CQWWs with interesting geometry as a function of the applied magnetic field.*

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