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Effects of electric field and position dependent effective mass on hydrogenic impurity in a gaas quantum well

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ABSTRACT

Electric field induced donor binding energy in a GaAs/AlGaAs finite quantum well are discussed. It is calculated with and without the inclusion of position dependent effective mass. We find the energy eigen values to obtain the subband energy and thereby the hydrogenic impurity binding energies. In all the calculation, we follow the variational formulism within the single band effective mass approximation. We find that results are different when the position dependent effective mass included in the Hamiltonian. Moreover, we find that the reduction of binding energy when the electric field is applied in the growth direction.

Introduction

Theory

Hydrogenic impurity plays a vital role in low dimensional semiconductor systems such as quantum wells, quantum well wires and quantum dots since the electronic and opto-electronic properties change when added [1]. In addition to that the energy spectrum of the hydrogenic carrier can be modulated with the application of some external perturbations, for example, the electric field is applied in the growth direction in a quantum well which decreases in the effective well width. A lot of research works with various confinement potentials and external perturbations have been devoted to understand the behaviour of confined impurity in low dimensional semiconductor systems [2].

Theory

The Hamiltonian of the hydrogenic donor impurity, in the effective mass approximation, in a finite GaAs/AlGaAs quantum well under the influence of electric field in the z-direction, given by

$$H = -\frac{\eta^2}{2m^*}\nabla^2 + V_{imp}(\bar{r}) + |e|Fz + V_o(z) \qquad (1)$$

where F is the externally applied electric field and $V_o(z)$ represents the confining potential. The units of length and energy used throughout are the effective Bohr radius $R^* = \eta^2\varepsilon_o / m^* e^2$ and the effective Rydberg $R_y^* = m^* e^4 / 2\varepsilon_o^2\eta^2$ where ε_o is the dielectric constant and m* is the effective mass of electron in the conduction band minimum of GaAs with these values, R* = 103.7Å and R_y^* = 5.29meV.

For the position effective mass, the following expressions are used. Since the tunneling is not possible, in the infinite barrier model, the position dependent effective mass is given by,

$$\frac{1}{m(L)} = \frac{1}{m^*} + \left(1 - \frac{1}{m^*}\right)\exp[-\gamma L], \qquad (2)$$

where m* is the effective mass in the well (0.067 m_o a.u., if the well consists of GaAs material. The free electron mass m_o = 1 in a.u., and γ is a constant which we choose to be 0.01 a.u. This choice is used taking into account that as L→ 0, the particle is strongly bound within a δ function well, whereas as L $\to\infty$, the system is three dimensional characterized by the conduction band effective mass m*.

The trial wave function, for a finite well with the inclusion of position dependent effective mass in the presence of electric field is given by,

$$\frac{1}{m(L)} = \frac{1}{m_W^*}\left[1 - \frac{\Delta z^2}{L^2}\right] \qquad (3)$$

where $\Delta = \frac{0.0835x}{m_W^*}$ and the calculations are performed for x = 0.2. For a trial wave function for the ground state of the impurity in the presence of electric field, we have used

$$\psi = \begin{cases} N_2 \cos(\delta z)(1+\lambda Fz) & -L/2 < z < L/2 \\ N_3 \exp(-\tau z)(1+\lambda Fz) & |z| \geq L/2 \end{cases} \qquad (4)$$

where N_1 is the normalization constant, F is the strength of the electric field and α is the variational parameter.

The donor binding energy is given by

$$E_b = E_{sub} - \langle H \rangle_{\min,} \qquad (5)$$

where E_{sub} is the subband energy which is calculated without the inclusion of impurity in the Hamiltonian. And hence, the binding energy is obtained, varying α , for each electric field and well size.

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Results and discussion

We have calculated the binding energy of a hydrogenic impurity in the influence of electric field and the geometrical confinement. The spatial dependent effective mass is included in the Hamiltonian. We have taken GaAs semiconductor as quantum well which is embedded on an AlGaAs as barrier.

We present the donor hydrogenic binding energy as a function of well width of a GaAs quantum well with and without the inclusion of the effect of position dependent effective mass in the presence electric field. The effect of electric field on a hydrogenic donor in a quantum well in the finite barrier is clearly brought out in the figure. In all the cases, the donor hydrogenic binding energy increases with a decrease of well width, reaching a maximum value and then decreases when the well width is still decreased. The Coulomb interaction between the electron and impurity ion is increased which ultimately causes the decrease in binding energy when the well width decreases. The binding energy decreases further as the well size approaches zero since the confinement becomes negligibly small, and in the finite barrier problem the tunneling becomes huge. Also, the contribution of confinement is dominant for smaller well size making the electron unbound and ultimately tunnels through the barrier. It is seen that as the field strength increases, the peak value is shifted towards a smaller well width. Also there is a reduction in the value of binding energy when using the constant effective mass and the variable mass.

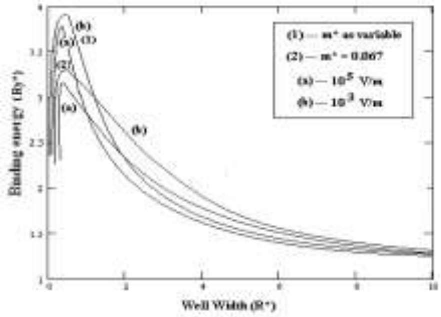

Fig.1 Variation of binding energy with well width for two different electric fields in a finite well with and without the position dependent effective mass

The effect of electric field on the impurity binding energy is shown in Fig.2. The variation of donor binding energy values as a function of electric field for a well size of 100Å with the electron effective mass as variation and mass as $0.067m_o$ is drawn. It is shown clearly that the electric field reduces the binding energy effectively for both cases. It is because as the electric field is increased the electron is pulled towards one side of the quantum well resulting the overall decrease of the binding energies. Further, we notice that the smaller well width shows the greater donor binding energy due to the geometrical confinement. The effect of electric field has more significant only for smaller well widths.

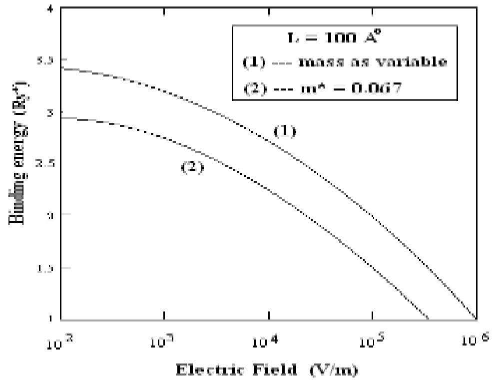

Fig.2 Variation of binding energy as a function of electric field strength with mass as variable and mass as 0.067 m_o for a constant well width 100Å.

Conclusion

The binding energy using the constant effective mass (m* = 0.067 a.u., for GaAs) and the position dependent effective mass) for various well sizes in the influence of electric field applied in the z-direction have been investigated. Thus, the variable nature of carrier effective mass plays an important role in other types of devices such as interband quantum well photodetectors and lasers that employ optical transitions between the valence and the conduction bands. Electronic devices such as the resonant tunneling diode are also affected by the position-dependence of carrier mass and thus the results are applicable to both optoelectronic and electronic quantum devices.

References

1. G. Rezaei, S.F.Taghizadeh and A.A.Enshaeian, Physica E44(2012)1562.

2. M.Revathi and A.JohnPeter, Solid State Communication1 50(2010)816.