



Electron And Hole Energy Levels In GaAs-Al_wGa_{1-w}As Double Quantum Wells In Presence Of A Uniform Magnetic Field

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Abstract

In this work we studied the behavior of electron and hole energy levels in GaAs-Al_wGa_{1-w}As double quantum wells within the effective mass approach. The system studied was in presence of a uniform magnetic field. In our case, we considered a configuration in which the magnetic field is applied in the growth direction of the heterostructure. We present the explicit analysis to identify the no-correlated electron-hole transition energy as a function of the Aluminium's concentration, heterostructure geometry and the applied magnetic field.

Keywords : Double quantum wells, effective mass approach, Landau levels.

Resumen

Dentro de la aproximación de la masa efectiva realizamos un estudio de los niveles electrónicos y de huecos en sistemas de doble pozo cuántico de GaAs-Al_wGa_{1-w}As bajo la acción de un campo magnético uniforme aplicado en la dirección de crecimiento. Estudiamos las energías de transición electrón-hueco no correlacionados en función de la concentración de aluminio, geometría de la heteroestructura y el campo magnético uniforme aplicado. Encontramos que la energía del estado fundamental y de los estados excitados aumenta con el ancho y altura de la barrera y se incrementa con el campo magnético aplicado. Los resultados obtenidos están en muy buen acuerdo con resultados experimentales y teóricos recientes.

Palabras : Dobles pozos cuánticos, aproximación masa efectiva, energías de transición, niveles de Landau.

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1. Introduction

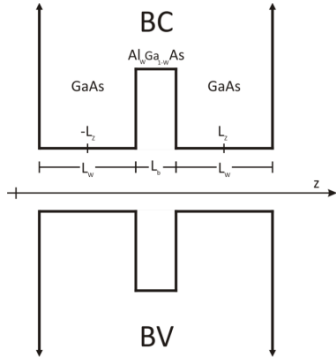
The physics of low-dimensional heterostructure semiconductor systems has been widely studied in the last few decades due to its potential applications in electronic and optoelectronic devices as a semiconductor nanotechnology. It has become possible the production of wide variety of semiconductor quantum heterostructures, such as superlattices, quantum wells, QWs (2D), quantum well wires, QWWs (1D), and quantum dots, QDs (0D)¹. It is well known that in the GaAs-Al_wGa_{1-w}As structures, potential wells are formed in the GaAs layers, leading to quantized subbands whose energies are determined by the well width and depth². In this work we studied not only the effects of

the geometric confinement parameters (well and barrier width) of double quantum wells on the electron and hole energy, but also the effects of the uniform magnetic field. All quantities appearing in the present work are given at low temperature.

The work is organized as follows: in section 2 we present our theoretical framework, in section 3 we give our results and discussion, and finally in section 4 we present our conclusions.

2. Theoretical framework

A scheme of the band structure in a GaAs-Al_wGa_{1-w}As double quantum well (DQW) is shown in Fig. 1. In this figure BC (BV) is the conduction (valence) band, L_w are the



well width, L_b is the width of the central barrier, and z is the growth direction of the structure.

Fig.1 Scheme of the band structure in a GaAs-Al_wGa_{1-w}As DQW.

The Hamiltonian of the system, in the effective-mass approximation, can be written as³

$$H = \frac{1}{2m_{e,h}^*} \left(p_x \pm \frac{eBy}{2} \right)^2 + \frac{1}{2m_{e,h}^*} \left(p_y \pm \frac{eBx}{2} \right)^2 + \frac{1}{2m_{e,h}^*} p_z^2 + V(z) \quad (1)$$

In the above expression $m_{e(h)}^*$ is the effective mass of the electron (hole), and $V_{e(h)}(z)$ is the height of the barrier for the electron (hole). The magnetic field is applied parallel to the z axis

The height of the barrier is determined by the expressions⁴

$$V_B(z) \begin{cases} V_1 \rightarrow \infty, \text{ para } z < -L_z - \frac{L_W}{2} \rightarrow & \text{region I} \\ 0, \text{ para } L_z - \frac{L_W}{2} \leq -z \leq L_z + \frac{L_W}{2} \rightarrow & \text{region II} \\ V_2, \text{ para } -\left(L_z - \frac{L_W}{2}\right) \leq z \leq L_z - \frac{L_W}{2} \rightarrow & \text{region III} \\ 0, \text{ para } L_z - \frac{L_W}{2} \leq z \leq L_z + \frac{L_W}{2} \rightarrow & \text{region IV} \\ V_3 \rightarrow \infty, \text{ para } z > L_z + \frac{L_W}{2} \rightarrow & \text{region V} \end{cases} \quad (2)$$

where $V_e = (1.36w + 0.22w^2)0.6$ eV for electron and $V_h = (1.36w + 0.22w^2)0.4$ eV for hole. The trial wave function is given by

$$\psi(x, y, z) = C e^{\left[\frac{x^2}{2l_B^2}\right]} e^{\left[\frac{y^2}{2l_B^2}\right]} H_{n-1}\left(\frac{x}{l_B}\right) H_{n-1}\left(\frac{y}{l_B}\right) \psi_n(z) \quad (3)$$

where C is a normalization constant, l_B is the magnetic width and H_n are the Hermite polynomials. The energy for the electron and hole is obtained by the expression

$$E_{n,m}(x, y, z) = E_n(x, y) + E_m(z) \quad (4)$$

3. Results and discussion

For the numerical calculation we used an Al concentration $w=0.3$, the effective mass for the electron is $m_e^*=0.0665$, the effective mass for the heavy hole is $m_{hh}^*=0.51$ and for the light hole is $m_{lh}^*=0.082$. In Fig. 2, we present the energies of E_T transitions vs the width of the central barrier L_b for the first state ($m=1$) of an electron to $m=1$ heavy hole (hh) and $m=1$ light hole (lh) without magnetic field, using an infinite confinement potential.

Disconnection of the wells is showed in Fig. 2 and 3 when we increases the widths of the central barrier, as we can see when the transitions energies approach (pairs states; circles, and odd-number states; squares). In Fig. 4 and 5, we present the energies against the magnetic field B for two width of the L_b

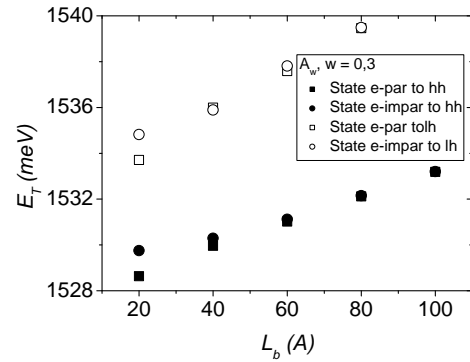


Fig.2 Transition Energy (E_T) against the width of the central barrier L_b from the first level ($m=1$) of an electron (e) to $m=1$ heavy hole (hh) and $m=1$ light hole (lh) without magnetic field and Al concentration $w=0.3$.

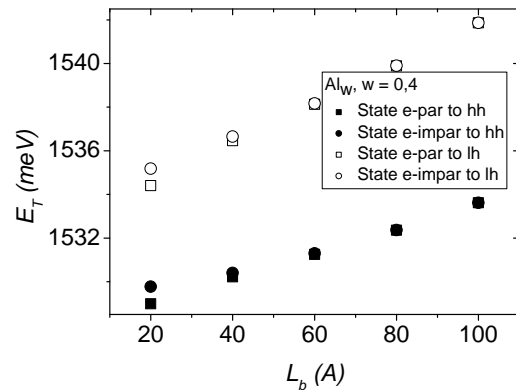


Fig.3 As in Fig. 2, for Al concentration $w=0.4$.

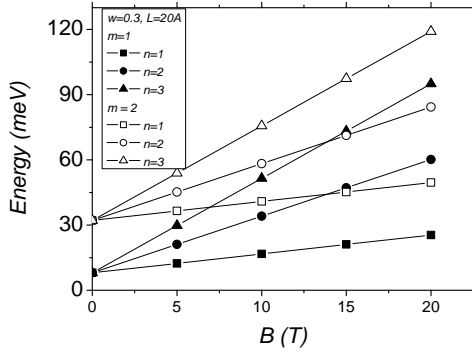


Fig.4 Electronic Landau levels (n) in a $L=500\text{\AA}$ with a $L_b=20\text{\AA}$ GaAs-Al_{0.3}Ga_{0.7}As DQW as function of the growth-direction applied magnetic field.

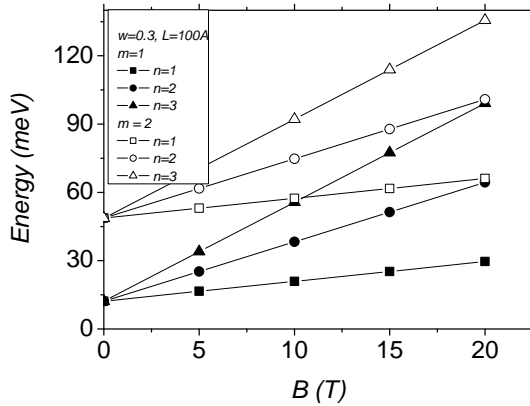


Fig.5 As in Fig. 4, for a width of $L_b=20\text{\AA}$.

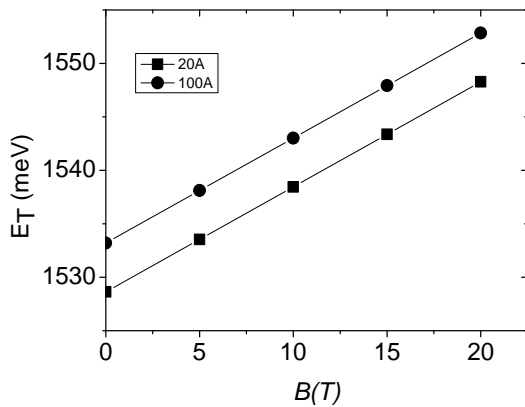


Fig. 6 Energies of E_T transitions $m=1$ electron's pair to $m=1$ heavy hole's pair as a function of the magnetic field for two width of the central barrier.

In Fig. 4 and 5, we can observe that the levels (wells levels m and Landau levels n) increase and its separation augment against with the magnetic field⁵. In Fig. 6, we can see that transitions energies increases with the magnetic field. The separation of the transitions energies are showed in Fig. 6 for two widths of the central barrier. Here we can observe that the transition energy is greater for greater widths central barriers^{2,6}. Our results are in agreement with the sintony of emission for the information shipment.

Conclusions

We have studied theoretically the effects of the applied magnetic field in a double quantum well structure using the effective mass-approximation. Our results show the disconnect of the wells with the increases of the central barrier. Also we have shown the linear increases with the magnetic filed.

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