TRANSITION ENERGIES OF EXCITONS IN GaAs-GaAlAs DOUBLE QUANTUM WELLS

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ABSTRACT
We have calculated the transition energies between ground states and 2P-like, 3P-like states of heavy hole excitons in GaAs-GaAlAs double quantum wells, in the framework of effective mass equation and with an applied magnetic field in the growth direction using a variational procedure. The transition energies are shown as a function of the barrier width and the magnetic field. Our result show that the transition energies increase with the magnetic field and the barrier width.

INTRODUCTION

Since 1990 the study of excitons in double quantum well (DQW) have had a growing interest, due to their potential application in electro-optical devices[1-3]. Cen and Bajaj [4] calculated the ground state binding energy of excitons in symmetric double quantum well as a function of the barrier width and the magnetic field applied in the growth direction. Naputkina and Lozovik [5] showed the effect of transversal magnetic field, when the carriers (electron and hole) are spatially separated, upon lower-energy level. Kaspoglu et al. [6] calculated the ground state binding energy of excitons in symmetric and asymmetric DQW as a function of an applied magnetic field in the growth direction.

THEORETICAL FRAMEWORK

We have considered a GaAs-$Ga_{0.7}Al_{0.3}As$ double quantum well grown in z-direction. The band structure in z-direction is shown in figure 1.

The Hamiltonian, in dimensionless units, can be written

$$H(\rho,\phi,z_e,z_h) = H_e(z_e) + H_h(z_h) + H_{exc}(\rho,\phi,z_e,z_h) \qquad (1)$$

Where each term is defined as

$$H_e(z_e) = -\frac{\mu}{m_e}\frac{\partial^2}{\partial z_e^2} + V_e(z_e) \qquad (2)$$

$$H_h(z_h) = -\frac{\mu}{m_h}\frac{\partial^2}{\partial z_h^2} + V_h(z_h) \qquad (3)$$

$$H_{exc}(\rho,\phi,z_e,z_h) = -\left(\frac{1}{\rho}\frac{\partial}{\partial\rho}\left(\rho\frac{\partial}{\partial}\right) + \frac{1}{\rho}\frac{\partial^2}{\partial\phi^2}\right) + \left(\frac{m_h}{M} + \frac{m_e}{M}\right)\gamma i\frac{\partial}{\partial\phi} + \frac{1}{4}\gamma^2\rho^2 - \frac{2}{r} \qquad (4)$$

With $r = \sqrt{\rho^2 + (z_e - z_h)^2}$ and $\gamma = \frac{e}{c\hbar}\left(a_0^2\right)B$, where B is the applied magnetic field.

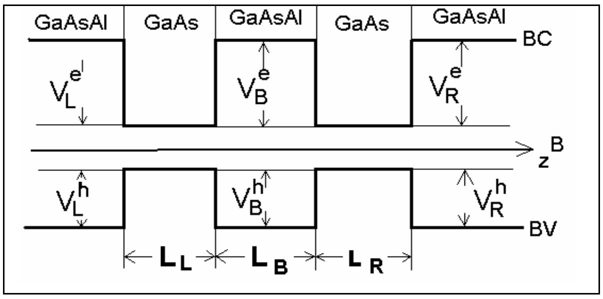

Figure 1: Double quantum well scheme. $V^{e,h}$ is the barrier height for electrons (e) and holes(h). $L_{L,R}$ and L_B are the width of the left and right well, and central barrier respectively.

The trial function for Eq. (1) is

$$\Psi_{n,l,m} = f_e(z_e) f_h(z_h) \exp\left(-\frac{\gamma}{4}\rho^2\right)\rho^{|m|} \exp(-im\phi) \mathrm{P}_{n,l}(r, \beta_{n,l,m}) \exp(-\lambda_{n,l,m} r) \tag{5}$$

Where $f_{e,h}(z_{e,h})$ are the solutions at the equations (2) and (3), $P(r)$ is a hidrogenic-like polynomial [7] and λ is a variational parameter for each hidrogenic-like state. The transition energies were calculated as the differences between ground state energy (E_{1s}) and the excited state energies (E_{2P}, E_{3P}) as a function of applied magnetic field and the barrier width.

RESULTS

Our results were obtained within the effective mass approximation and using a variational procedure. The values of the parameters for the numerical calculations are the same used in reference [6]. For all the situations we have used 228 meV as the barrier height for electrons and 176 meV for holes.

In fig 2 it can be observed the transition energies between 1S-like and 2P-like excitonic states for a double quantum well (DQW) with different barrier widths. Bold symbols (open symbols) are for a DQW with 10Å (20Å) for central barrier width, with right well width (L_R) of 120Å and 80Å, and left well width (L_L) of 120Å, as a function of the applied magnetic field. The figure shows the decrease of the transition energy between 1S-$2P_-$ like states for the symmetric case (L_R=L_L=120Å and L_B=10Å, bold square symbol), whereas in the other cases the transition energies increase with the applied magnetic field. In all cases the behavior of the transition energies is not monotonous, due basically to the competition between the magnetic and geometric confinement influenced by the barrier width. We also found that for low magnetic fields the behavior is similar to the case of a single quantum well [8]. When the width of the barrier increases the transition energy increases due to the diminishing of the coupling between the wells. For an asymmetric double quantum well (L_R=80Å, L_L=120Å) the exciton transition energy is greater than in the symmetric case (L_R=L_L=120Å), due to diminishing of the right well width.

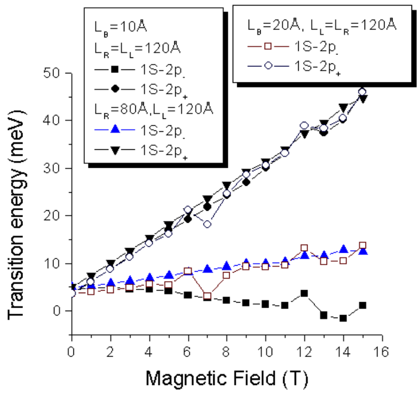

Figure 2: Transition energies between 1S-like state and $2P_{\pm}$ like state of heavy hole excitons as a function of the magnetic field for a left well width of 120Å, and barriers size of 10Å (bold symbols) and 20Å (open symbols).

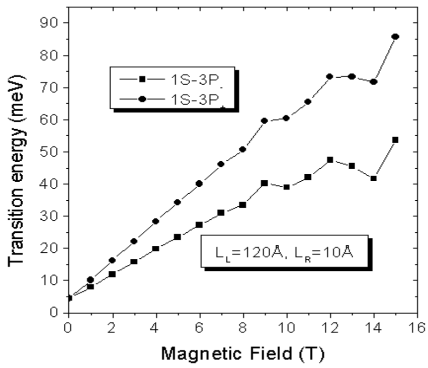

Figure 3: Transition energies between 1S-like state and 3P-like state of heavy hole excitons for a double quantum well. Right well width is 120Å.

In fig. 3 it is observe the effect of the magnetic field on the 1S-3P like transition energies for symmetric double quantum well ($L_L=L_R=120$Å) with $L_B=10$Å. Transition energies increase as a function of the applied magnetic field.

CONCLUSIONS

We have calculated the 1S-2P like and 1S-3P like transition energies of heavy hole excitons in double quantum wells as a function of an applied magnetic field and the barrier width. Our results show that for low magnetic fields the behavior of the transition energies is similar to that in single quantum wells, whereas for high magnetic fields or large barrier widths this behavior deviates from that found in single quantum wells.

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