Tr. J. of Physics
23 (1999) , 765 – 770.

Binding Energies of Excitons in Symmetric and Asymmetric Coupled Double-Quantum Well Structures in a Magnetic Field

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Received 01.03.1999

Abstract

The binding energy of excitons in the symmetric and asymmetric coupled double GaAs/$Ga_{1-x}Al_xAs$ quantum wells is calculated by using variational approach. Results have been obtained as a function of the potential symmetry, the size of the quantum well, and the coupling parameter of the wells in the presence of a magnetic field applied parallel to the growth direction. The role of the asymmetric barriers, magnetic field, barrier and well width in determining the tunability of the excitonic binding parameters of the GaAs/$Ga_{1-x}Al_xAs$ system is discussed.

1. Introduction

Double quantum well (DQW) structures have been extensively studied over the past several years. The interest in these structures is due to both their importance in understanding the fundamental processes in quantum structures and their applications in electro-optic devices [1-3]. There has been a considerable amount of experimental work done on the exciton states in these structures [4-10], and theoretical work done on quantum wells, coupled wells or superlattices structures [11-17]. The main advantage that a DQW structure offers over the single quantum wells is the enhanced exciton electro-optic response. The electro-optical properties of excitons in DQWs promise a number of potential applications in high-speed spatial-light modulators and switches. The main aim of this work is to determine the changes in the excitonic binding of a quantum well by

coupling it to a second asymmetric well and to see whether. This provides any flexibility to modify the excitonic properties of the system. The second objective of this work is to calculate the effect of a uniform magnetic field, applied parallel to the growth direction, on the excitonic properties in the symmetric and asymmetric coupled DQW's.

2. Theory

We consider a double quantum well (DQW) structure consisting of two quantum wells separated by a potential barrier. A schematic diagram of the DQW structure shown in Figure 1. A uniform magnetic field B is considered parallel to the growth direction. In the effective mass approximation the Hamiltonian of electron-hole system under the magnetic field is

$$H = \frac{1}{2m_e}\left[\vec{P}_e + \frac{e}{c}\vec{A}(\vec{r}_e)\right]^2 + \frac{1}{2m_h}\left[\vec{P}_h - \frac{e}{c}\vec{A}(\vec{r}_h)\right]^2 - \frac{e^2}{\varepsilon_0\left|\vec{r}_e - \vec{r}_h\right|} + V_e(z_e) + V_h(z_h). \tag{1}$$

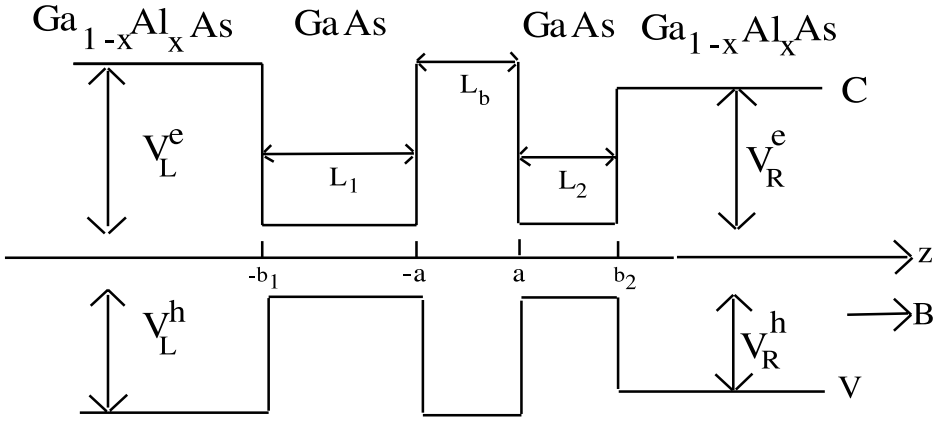

Figure 1. The schematic diagram of the DQW structure.

The wave function of the electron-hole system is taken as and it is a solution of the Schrödinger equation,

$$\tilde{H}(\tilde{\rho},\phi,\tilde{z}_e,\tilde{z}_h)\Phi(\tilde{\rho},\phi,\tilde{z}_e,\tilde{z}_h) = \tilde{E}\Phi(\tilde{\rho},\phi,\tilde{z}_e,\tilde{z}_h). \tag{2}$$

The motion of the exciton in the (x-y) plane is described by the wave function of the ground state of a two- dimensional hydrogen like atom:

$$\varphi(\tilde{\rho},\alpha) = \sqrt{\frac{2}{\pi}}\frac{1}{\alpha}Exp\left[-\tilde{\rho}/\alpha\right], \tag{3}$$

where is the variational parameter.

3. Results and discussion

In this study, we have calculated exciton binding energy associated with the electron and hole first subbands as a function of the right well width L_2, barrier width, and the potential ratios $\sigma = \frac{V_R^{(e,h)}}{V_L^{(e,h)}}$, and wells width ratio $\beta = \frac{L_1}{L_2}$ for several different values of the magnetic field. The values of physical parameters used in our calculations are $m_e = 0.067m_0, m_h = 0.45m_0, \mu = 0.04m_0, \varepsilon_0 = 12.5$ (static dielectric constant is assumed to be the same everywhere), $a_B = 165.591\mathring{A}$, Ryd=3.47369 meV, $V_L^e = 228meV$, $V_L^h = 176meV$.

In Figure 2 we show the variation of exciton binding energy in a DQW as a function of the right well with L_2 for several values of the magnetic field and for the barrier width $L_b = 10\mathring{A}$.

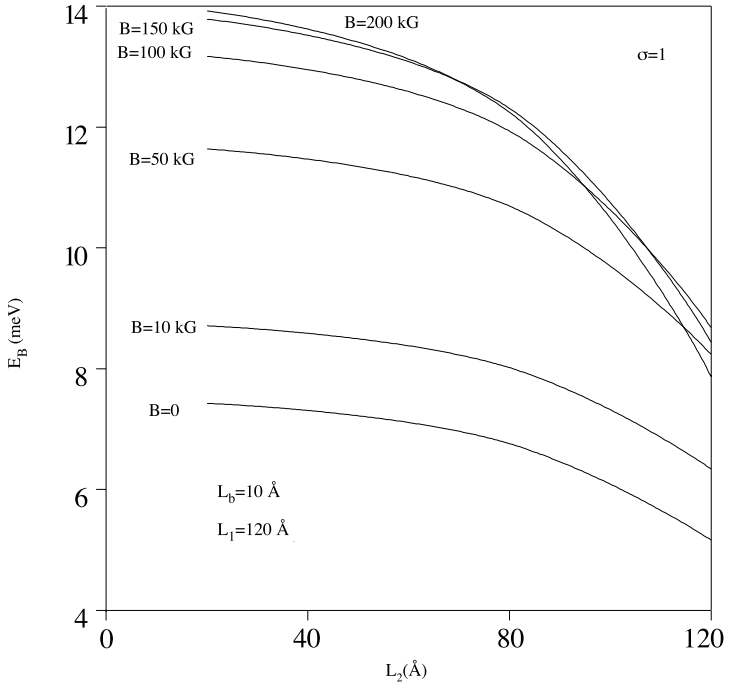

Figure 2. The variation of the exciton binding energy in a DQW as a function of the right well width for several magnetic field values.

Due to the decreasing average distance between the electron and the hole, exciton binding energy decreases monotonically as L_2 increases. Since the magnetic field provides an extra confinement of the wave function in the region with width L, the binding energy becomes

more sensitive to the right-hand side well with L_2 as magnetic field increase. In Fig.3 we show the variation of the exciton binding energy in DQW, the barrier width of which is $L_b = 10, 40, 60, 80\mathring{A}$ respectively, as a function of the right-hand side well width L_2 for the magnetic field value B = 100 kG.

In this figure, the coupling of the wells becomes small for wider barrier widths. The exciton binding energy increases up to a certain the right well width ($L_2 = 100\mathring{A}$) and then remains stable up to the small L_2 values. In Figure 4 the variation of the overlap function F(0) is given as a function of for $\sigma = 1$, and several values. L_b In the thin limit of the right well (L$\rightarrow$ 0), the wave function of the electron and hole becomes in effect single well wave function, thus the overlap function recovers its value for a single quantum well. Calculated results reveal that, using a heterostructure one can tailor the energy band structure. Furthermore by and appropriate choice of layer sequence one may improve upon the mechanism of light-induced modification to the band structure obtaining enhanced nonlinear optical properties.

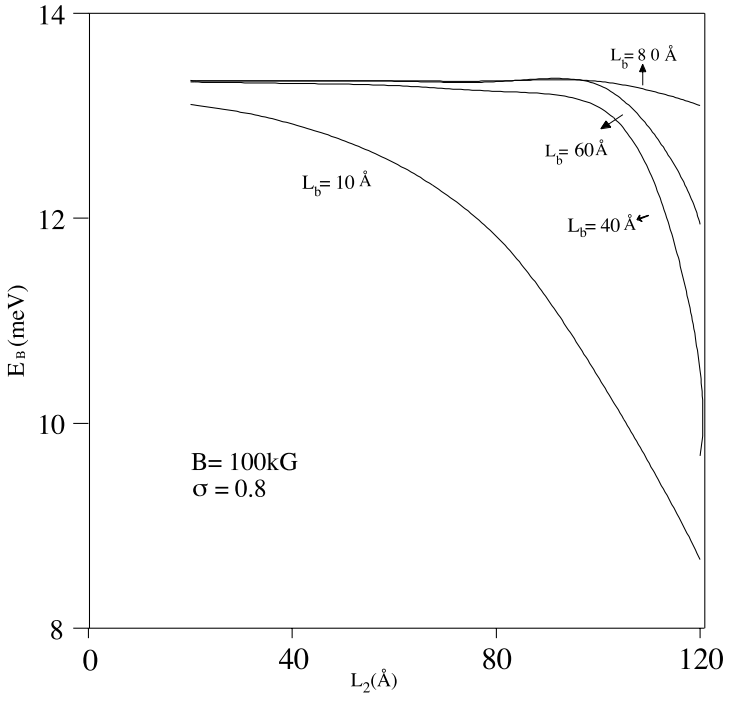

Figure 3. The variation of the exciton binding energy in a ADQW the potential ratio of which is as a function of the right well width.

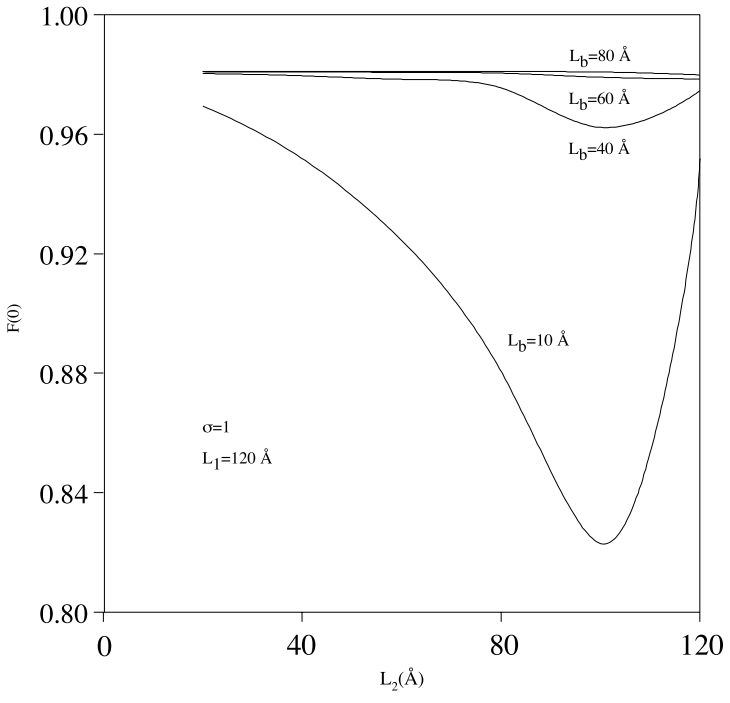

Figure 4. The overlap function F(0) between the electron and hole as a function of the right well width for different barrier width values.

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