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EXCITONS IN SMALL PERIOD GaAs/GaAlAs SUPERLATTICES

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Abstract

We report the optical determination of exciton binding energies in small period GaAs/Ga0.7Al0.3As superlattices by means of low temperature photoluminescence excitation spectroscopy and photoluminescence spectroscopy as a function of temperature. The heavy-hole exciton binding energy decreases with superlattice period. Our experimental findings are in agreement with a variational calculation.

Optical properties of semiconductor quantum wells (QW) are now increasingly documented [1-9]. Due to their quasi-two-dimensional nature, excitons in QWs of GaAs sandwiched between Ga(1-x)AlxAs layers have binding energies (\(B_{1s}\)) greater than bulk ones [1-4] and give rise to excitonic photoluminescence lines up to room temperatures [1, 5-7].

When the width of the GaAlAs barriers decreases, neighbouring wells become electronically coupled and the electron and hole gases progressively loose their 2-D character. They are able to move in the direction perpendicular to the layers [10] and their eigenenergies form minibands. In these structures, called small period superlattices (SL), low temperature luminescence spectra reveal excitonic lines [11] corresponding to heavy and light hole excitons.

In this paper we report the results of photoluminescence (PL) and photoluminescence excitation (PLE) spectroscopies on several small period GaAs/ GaAlAs superlattices with near equal well and barrier thicknesses and compare the binding energies thus obtained for heavy-hole excitons with the results of a variational calculation. Starting from isolated QW situation where the exciton is confined in the wells, the heavy-hole exciton binding energy is found to decrease with decreasing superlattice period and to tend to about 4 meV when the SL period tends to zero. This limit is quite close to the value of the exciton binding energy in bulk GaAs.

The samples studied here were all grown in a Riber molecular beam epitaxy system. They consist of about 1 \(\mu\)m of GaAs/Ga(1-x)AlxAs superlattice grown on a 0.7-\(\mu\)m-thick GaAs buffer. The aluminium concentration \(x\) is kept around 0.3. The well and barrier widths are determined by x-ray diffraction. The PL and PLE spectra are recorded with the samples merged in super-fluid Helium at about 2 K. The excitation
The low-temperature excitation spectra of our samples exhibit two very different kinds of shape:

(i) The PLE spectrum of a superlattice with a large enough period ($d > 100 \text{ Å}$) looks like the spectrum of a MQW [1-9] (see Fig. 1a) and thus allows a direct determination of $B_{1S}$. Two well resolved peaks correspond to the heavy-hole and light-hole excitons. Between these two peaks a step can be seen which is more or less well resolved depending on the sample and can be attributed either to the excited 2s state of the heavy-hole exciton [9] or to the onset of the continuum [1, 13]. However assuming that the intermediate structure is the onset of the continuum and taking for the 1s binding energy $B_{1S}$ the distance between this step and the maximum of the Figure 1: Photoluminescence excitation spectra of three samples. The detection energy is set in the low-energy tail of the heavy-hole exciton line.

This procedure yields a value of $B_{1S}$ for all the samples with a period greater than 50 Å.

(ii) The PLE spectra of the two samples with the smallest periods are quite different. Whereas the spectrum of sample n°417 (Fig. 1b) still exhibits two peaks corresponding to the heavy-hole and light-hole excitons, only one peak, broadened on its high-energy side, can be seen on the spectrum of sample n°447 (Fig. 1c).

For high enough temperatures (say $T > 60 \text{ K}$), as a result of the ionization of the exciton, the nature of luminescence changes from exciton to band-to-band recombination and the maximum of the PL line, $E_{PL}(T)$, follows the variation of the GaAs gap, $E_{GaAs}(T)$; that is, if $\Delta(T) = E_{PL}(T) - E_{GaAs}(T)$, for $T > 60 \text{ K}$ $\Delta(T)$ reaches a plateau $\Delta_0$. $B_{1S}$ can thus be determined by measuring the energy difference.
between $\Delta$ and $\Delta$ ($T = 2$ K), also subtracting the PL-PLE Stokes shift if it exists. We have used this procedure on the four samples with the smallest periods. The results obtained for samples n°342 (30 Å-30 Å) and 330 (39 Å - 39 Å) are very close to the values derived from PLE. On samples n°447 (10 Å/10 Å) and 417 (17 Å/20 Å), $B_{1s}$ is found to be equal to 3.8 meV and 3.5 meV. The heavy-hole exciton binding energies for all the measured samples are reported on figure 2: when the superlattice period decreases, the well and barrier widths being kept nearly equal, $B_{1s}$ decreases down to a value close to the GaAs binding energy. An indication of this trend was found by photoluminescence excitation under magnetic field [13].

To understand the behaviour of the heavy-hole excitons in a superlattice as a function of the SL period $d$, we have calculated their binding energy using a variational approach [15]. In the trial wave function we use trial parameters: one corresponds to the in-plane exciton radius and the other is linked to the z exciton radius. Fig. 2 shows the calculated variations of the 1s heavy-hole exciton binding energy as a function of the SL period $d$ when the well and barrier widths are equal. When the period tends to zero $B_{1s}$ tends to the GaAs bulk value. $B_{1s}$ reaches a maximum near $d = 140$ Å and then decreases. The latter behaviour is the same as that of single QWs. The experimental values are also reported in Fig. 2 and their variations upon $d$ are correctly reproduced by the calculations.

![Figure 2](image-url)

**Figure 2**: Calculated dependence of the 1s heavy-hole exciton binding energy $B_{1s}$ (full line) as a function of the SL period $d$ for equal well and barrier thicknesses and an aluminium concentration $x = 0.3$ in the barriers. The stars with and error bar are experimental values.

**REFERENCES**

1 - For a review see R.C. Miller and D.A. Kleinman, Journal of Luminescence 30, 520 (1985) and references therein.


15 - Details will be published elsewhere.
