Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 324-326

Carrier Capture and Bandgap Renormalization in High Density Quasi-One Dimensional Electron- Hole Plasmas

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The photoemission from high density quasi- one dimensional electron- hole plasmas is analyzed regarding the filling of the electronic states of the wire and the wire barrier.

We find that the capture of carriers generated in the barrier is inhibited compared to the two dimensional case which manifest itself in a higher population of the barrier.

According to theoretical predictions the effect of the bandgap renormalization is distinctly weaker in 50 nm wide wires than in two dimensional electron- hole plasmas, when measured in excitonic units.

1. Introduction

The application of quantum wire structures in laser diodes promises a decrease in threshold current and an increase in modulation speed due to the concentration of the density of states at the band edge[1]. In real devices, however, the capture of carriers from the barrier into the wire can represent a serious problem which may jeopardize this effect[2,3].

Quantum wires are further an interesting system for basic research since exchange and correlation interaction are strongly modified [4] which should lead to a reduced bandgap shrinkage as compared to the case of two- and three-dimensional carrier systems. Calculations[5] predict a measurable deviation from the quantum film behaviour already for wire structures with a width of 50 nm.

In this contribution we want to present optical experiments under high excitation as a tool for basic research as well as for device related physics. We have studied the properties of electron hole plasmas (EHP's) confined in InGaAs/InGaAsP/InP wire structures with respect to the filling of the electronic states of the wire and of the wire barrier. As a second point the renormalization of the bandgap as a function of the plasma density is investigated.

2. Experimental

The starting structure consists of a 6.5 nm thick InGaAs quantum film embedded in an InGaAsP/InP waveguide structure 60 nm beneath the sample surface (see fig.1). The lateral confinement is produced by deep mesa etching and subsequent epitaxial regrowth with InP. The etch mask is defined by high resolution electron beam lithography and transferred 150 nm deep into the sample by Ar^+/O_2 reactive ion beam etching.

The wires are oriented in the <011> direction which we found to be best for epitaxial regrowth[6].

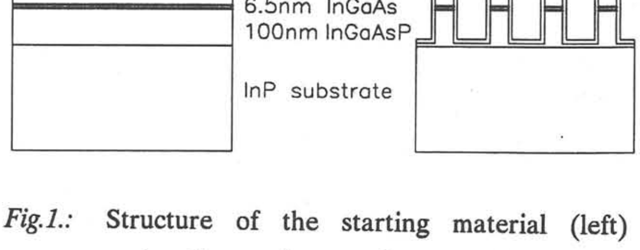

Fig.1.: Structure of the starting material (left) and the wires after etching and coating with 20 nm InP (right).

Using low pressure MOVPE, the wire structures are coated by a nominally 20 nm thick layer of InP. By this technique arrays of InGaAs wires are defined, where the lateral barrier consists of InP and the vertical barrier of InGaAsP material. In this structure the InGaAsP/InP potential step prevents a diffusion of carriers to the substrate as well as to the surface enabling the creation of high carrier densities in the wires.

Wire structures with good optical quality and lateral widths from 700 nm down to 50 nm are defined together with 2D areas on one sample. This enables a systematic comparison of two dimensional EHP's with plasmas confined to wires with different width.

Great care was taken in order to create a spatially and temporally homogeneous EHP. This is ensured by using wire arrays with dimensions smaller than the laser spot size which are excited continuous wave by an Ar^+- ion laser. The plasma density, the Fermi energies and the renormalized bandgap are obtained from the spectra by lineshape analysis. The spectral intensity I is given by :

$$I(\omega) \propto \omega^2 \sum_{ij} \int_{E_i}\int_{E_j} |M_{ij}|^2 D^{1D}(E_i,E_j)\, f_e(E_i)\, f_h(E_j) \cdot \delta_\Gamma(E_i+E_j+E_g-\hbar\omega)\, dE_i dE_j$$

where $D^{1D}(E) = \frac{1}{\pi}\left(\frac{m_i}{2\hbar}\right)^{1/2}\frac{1}{\sqrt{E-E_i}}$

and the energy levels E_i are calculated within a rectangular potential well model. The broadening function δ_Γ accounts for lifetime broadening [7)] and for the finite broadening of the energy levels as measured under low excitation.

The photoemission from the InGaAsP barrier can be analyzed within an analogous model for the 3D-case.

3. Results and discussion

Figure 2 displays a series of spectra with different excitation densities. The solid lines represent fits to the wire emission.

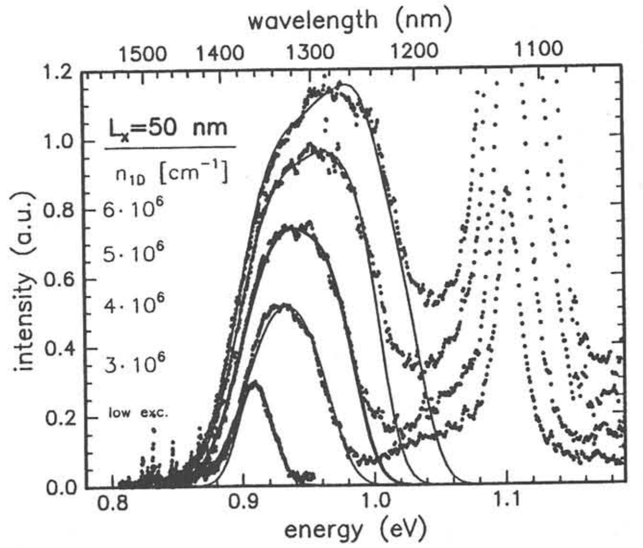

Fig.2.: Series of luminescence spectra from an array of 50 nm wide wires for different excitation intensities. The line on the high energy side of the wire emission represents luminescence from the InGaAsP wire barrier. The solid lines are lineshape fits to the experimental data depicted by dots.

With increasing excitation density a strong broadening of the wire emission is observed indicating strong filling of the 1D- subbands. For excitation power larger than 10 kW/cm^2 the bound states of the wires are completely filled and the carrier density in the InGaAsP wire barrier begins to rise, as shown in figure 3. At equal excitation power the density in the 2D array is higher and the density in the respective barrier lower compared to wires revealing a reduction in the capture of carriers from the barrier into the wire. Moreover the density in the 2D array tends to saturate with increasing power while the carrier density in the wires increases without saturation in the power range studied.

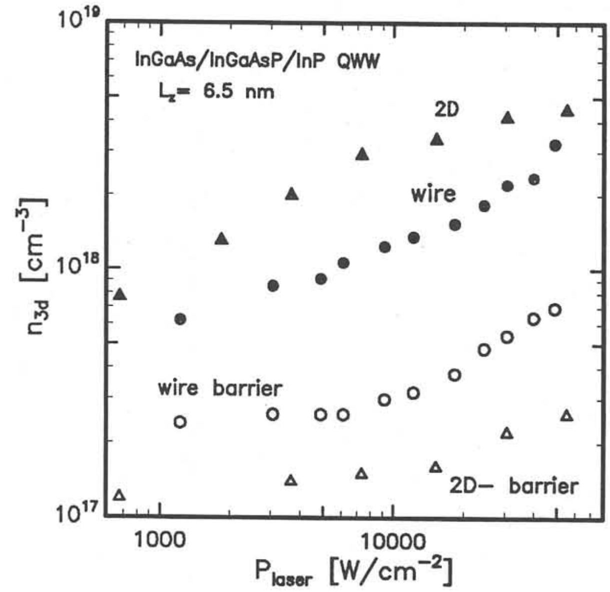

Fig.3.: Plasma densities as a function of excitation intensity for a 2D area (triangles) and an array of 50 nm wide wires (circles). The density is given for the well (filled symbols) and the barrier (open symbols) respectively. For comparison all densities are scaled to 3D- units.

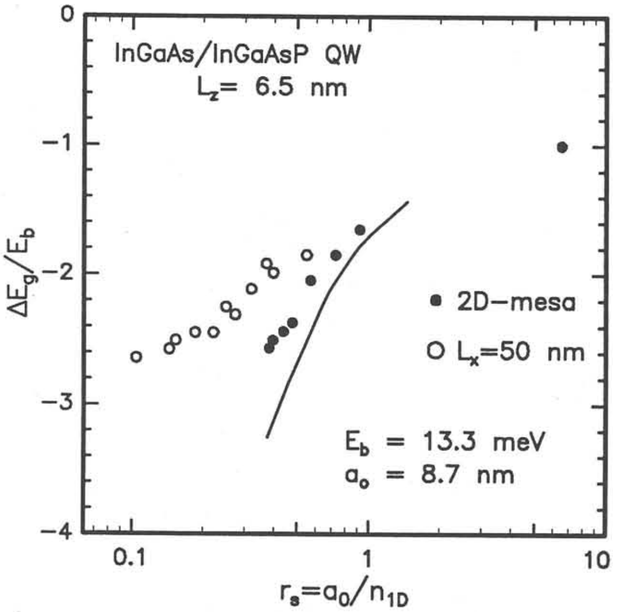

Fig.4.: Bandgap renormalization for a quantum film (filled circles) and quantum wires (open circles), scaled to the excitonic units given in the figure. The solid line depicts the theoretical result for a quantum well.

Figure 4 addresses the result for the bandgap renormalization scaled to excitonic units. The data are in reasonable agreement with theoretical results for quantum films. It is remarkable, however, that the renormalization is distinctly smaller for wires than for the film structure as is expected from theory.

4. Conclusions

Analyzing the photoemission of epitaxially buried InGaAs/InGaAsP/InP- wire structures we have studied the filling of the wire and the barrier states. Even though owing to the special structure of the sample a high carrier density can be obtained in the wire, we find that the capture of carriers from the wire barrier into the active region of the wire is inhibited compared to the two dimensional case.

The bandgap renormalization of quasi- one dimensional electron hole plasmas shows a reduction compared to the two dimensional case as is expected from theory.

References

1) Y. Arakawa and A. Yariv, IEEE J. Quantum Electron. QE-22, 1887 (1986) and references therein

2) R. Nagarajan, T. Fukushima, S.W. Corzine, and J.E. Bowers, Appl. Phys. Lett. 59 (1991) 1835

3) W. Rideout, W.F. Sharfin, E.S. Koteles, M.O. Vasell, and B. Elman, IEEE Phot. Techn. Lett. 3 (1991) 784

4) S. Benner and H. Haug, Europhys. Lett. 16 (1991) 579

5) B. Y-K Hu and S. Das Sarma, Phys. Rev. Lett. 68 (1992) 1750

6) G. Lehr, R. Bergmann, R. Rudeloff, J. Hommel, F. Scholz, and H. Schweizer, Superlatt. Microstruct. 11 (1992) 329

7) P.T. Landsberg, Phys. Stat. Sol. 15 (1966) 623