ONE-DIMENSIONAL EXCITONS IN V-SHAPED QUANTUM WIRES.

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(received August 22 1994)

We report a detailed study of one-dimensional excitons in a planar array of single V-shaped GaAs quantum wires. Two-photon absorption, magnetoluminescence and linear photoluminescence spectroscopy have been used to measure the exciton binding energy, the excited *2p* states of the excitons, the higher index transitions and the extension of the confined wavefunctions in the V-shaped region of the quantum wires.

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1.Introduction.

Usually in quantum wires it is very difficult to observe intrinsic excitonic luminescence, due to the presence of defects or non-radiative recombination mechanisms [1]. As a consequence there is a lack of experimental confirmation of the theoretical predictions about the confined excitons (enhanced exciton bohr radius, oscillator strength and non-linear exciton susceptibility). In this paper we present a study of the excitonic properties of one-dimensional excitons confined in V-shaped GaAs quantum wires of lateral dimension of about 20nm [2] by means of linear photoluminescence, magnetoluminescence and two photon absorption spectroscopy.

2.Experimental.

The investigated wires were fabricated by MBE deposition of a GaAs quantum well embedded in two $(GaAs)_8(AlAs)_4$ superlattices onto non planar V-shaped GaAs substrates. The V-grooves in the substrates were obtained by means of holographic lithography and wet chemical etching . The groove period was 260nm. From TEM micrographs we observed that the bent GaAs quantum well narrows along the sidewalls of the V, originating a lateral modulation of the potential. The confined states were then evaluated following the method reported in Ref.[3] and are listed in Table 1. The extimated wire width was of the order of 20nm.

Table 1

j	E_{gj} (eV) experimental	E_{gj} (eV) calculated	E_b (meV) TPA-PLE	E_b (meV) MGL
n_x=1	1.568± .001	1.5713	10±1	12.5
n_x=2	1.587± .001	1.5895	8±1.5	9.7

Photoluminescence (PL) experiments were performed by using the green line of an Ar^+ laser . The samples were immersed in liquid He at a temperature of 3.5K in a superconducting cryostat (Oxford Spectromag 4000) providing magnetic fields up to 9 Tesla.
The two-photon absorption (TPA-PLE) measurements were performed by scanning the excitation photon energy in the transparency region of the sample $(0.75eV \le \hbar\omega \le 0.82eV)$ at 10K for different polarization directions of the exciting laser beam [4].The detection energy was set at the lowest energy side of the ground state exciton (n_x=1) , as obtained from linear PL .

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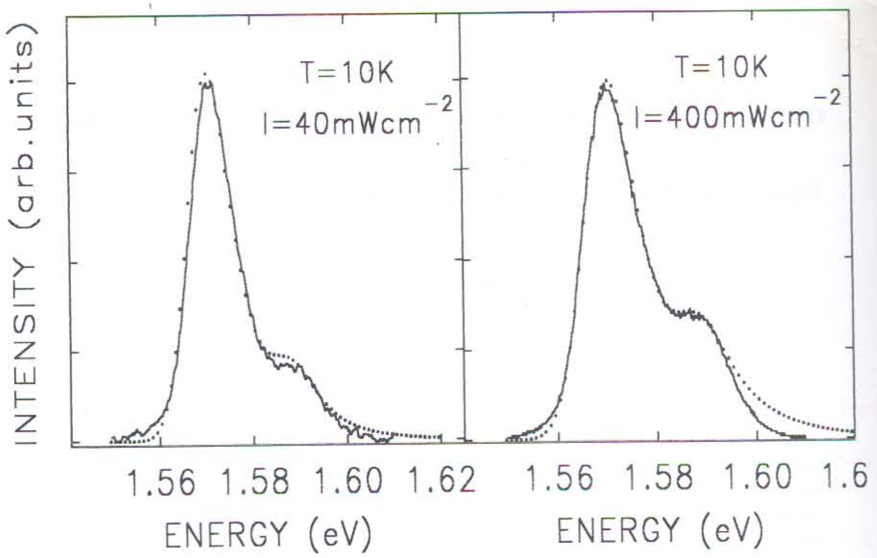

Fig.1 - Line shape fitting (dotted lines) of the c.w. PL spectra (continuous line)of the investigated wires for two different excitation intensities.

3.Results and Discussion.

The c.w. PL spectra of one of the investigated samples (continuous line of Fig. 1) exhibit two bands. These have been attributed to the recombinations of the first two confined excitons of the wires [2]. A line shape fitting of the intensity and temperature dependent PL spectra was performed by using the spectral density of emission given by

$$I(\hbar\omega) \approx \int D(E) \cdot G(\hbar\omega - E)dE \cdot f(\hbar\omega) \qquad (1)$$

where $D(E)=\sum_j 1/\sqrt{E-E_{gj}}$ is the one dimensional density of states convoluted with a gaussian function to account for the inhomogeneous broadening , E_{gj} is the excitonic transition energy of the j-th subband, and $f(\hbar\omega)$ is the Boltzmann distribution function for the excitons. This is valid for a low density exciton population. In Fig.1 the results of the fit are shown (dotted line). The best fit E_{gj} values for the first two quantized subbands are reported in Table 1. The agreement between the calculation and the experimental results is quite good, taking into account that the theoretical calculation does not include excitonic effects. The obtained spectral broadening is of the order of 8 meV. This is mostly due to fluctuation in the width of the quantum well at the bottom of the grooves.

The linear PL spectra (Fig.2a)) are compared to the two-photon absorption induced photoluminescence excitation (TPA-PLE) spectra in Fig.2b). The vertical lines indicate the transition energies obtained from the fit. The two-photon absorption spectra obtained from the investigated wires evidence a strong anisotropy of the transition matrix elements of the non-linear absorption processes , depending on the relative orientation of the exciting polarization vector (ε) with respect to the carrier confinement direction (x) .

In the ε ∥ x geometry *1s* excitons associated with $\Delta n_x = \pm1, \pm3....$ transitions are allowed as final states of the non-linear absorption processes. In this case we can observe two structures whose relative splitting is consistent with the energy positions of *1s* exciton states associated with $\Delta n_x = \pm1$ transitions in the quantum wires. The lines on Fig.2b) were obtained by adding the calculated confinement energies of the one-dimensional conduction and valence subbands to the evaluated *1s* state of the n_x=1 exciton.

On the other hand, *2p* excitons associated with the $\Delta n_x = 0$ transitions are expected in the ε⊥x geometry. In this case, the two clear structures in the spectrum exhibit the same spectral splitting of the linear PL

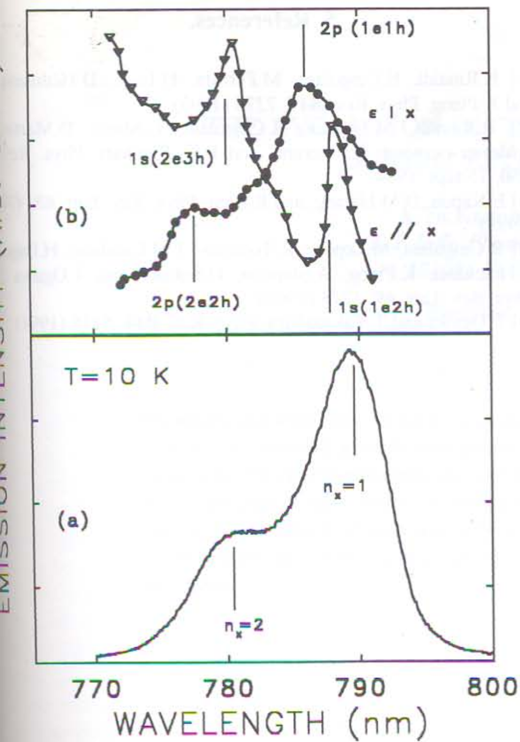

Fig.2 - a) Linear PL spectrum measured at 10 K . b) TPA-PLE spectra measured with the laser polarization vector parallel (triangles) and perpendicular (dots) to the carrier confinement direction. *1s* and *2p* label the final exciton state associated with electron (e) and hole (h) subbands of quantum number n_x.

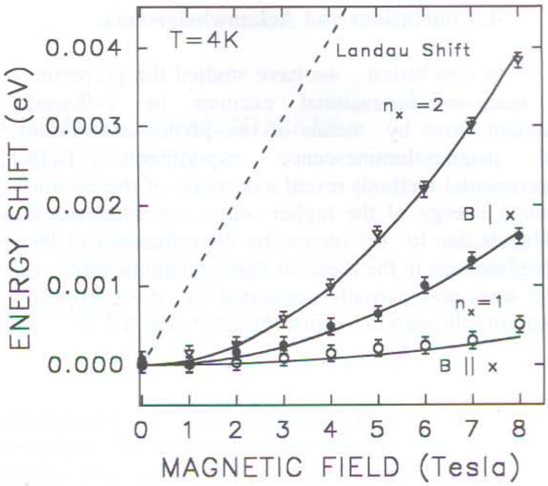

Fig.3 - Diamagnetic shift of the quasi-one-dimensional n_x=1 (dots) and n_x=2 (triangles) excitons of the quantum wires. The continuous curves represent the best fit diamagnetic shift. The full dots and empty dots represent the diamagnetic shifts measured with the magnetic field perpendicular and parallel to the carrier confinement direction (x), respectively. The dashed line is the Landau shift of the bulk GaAs

bands and are blue-shifted by the *2p-1s* splitting The blue-shift amounts to about 7.5±1 meV for the lowest energy transition (1e-1h) and to about 6±1 meV for the higher index state (2e-2h transition). Assuming a perfect one-dimensional hydrogenic series [5], we can evaluate the exiton binding energy for the n_x=1 and n_x=2 excitons. Neglecting the *2p-2s* angular momentum splitting , the *2p* exciton is expected to have a binding energy equal to one fourth of the ground state exciton binding energy. Therefore for the n_x=1 exciton results $E_b = (E^{2p} - E^{1s})/0.75$=10 meV ±1 meV and for the n_x=2 exciton E_b=8 meV ± 1.5 meV. These results indicate that in these V-shaped wires the excitonic wavefunctions become more delocalized as the quantum number increases. This is attributed to the finite height of the lateral potential barrier and to the $U/\cosh^2(\alpha x)$ shape of the lateral confining potential (U is the potential depth and α a paramenter proportional to the potential width).

A direct manifestation of the increasing delocalization of the wavefunctions can be seen in the different diamagnetic shifts of the n_x=1 and n_x=2 excitons in high magnetic fields. This is shown in Fig.3 for applied magnetic field *B* perpendicular to the wire confinement direction (dots and triangles, respectively). In order to reproduce the observed shift we used the usual B^2 dependence taking the reduced exciton mass as a fitting parameter. The best fit value for the reduced mass give an exciton Bohr radius for the n_x=2 exciton that is about 25% larger than the n_x=1 one. This results in a larger exciton binding energy for the n_x=1 exciton. To evaluate the exciton binding energy and the anisotropy of the ground state exciton wavefunction, we measured the diamagnetic shift of the n_x=1 excitonic transition for different orientation of the magnetic field *B* with respect to the wire axis [6]. From these experiments we obtaned the exciton Bohr radius along the different directions. The resulting exciton binding energies were of the order of 12.5 meV for the n_x=1 and 9.7 meV for the n_x=2 in agreement with the data of TPA-PLE.

4. Conclusions and Acknowledgments.

In conclusion , we have studied the properties of quasi-one-dimensional excitons in V-shaped quantum wires by means of two-photon absorption and magnetoluminescence experiments. Both experimental methods reveal a decrease of the exciton binding energy of the higher index one-dimensional subbands due to the increasing delocalization of the wavefunctions in the crescent shape quantum wires.

This work was partially supported by the European Comunity through the Esprit Project NANOPT.

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