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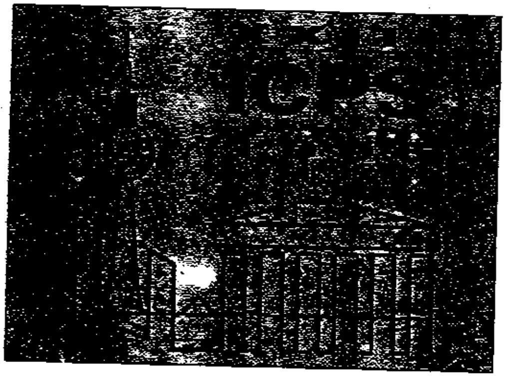

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EXCITON DYNAMICS AND VALENCE-BAND MIXING IN GaAsP TENSILE STRAINED QUANTUM WELLS

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ABSTRACT

We have studied the dependence of the photoluminescence rise, τ_{rise}, and decay, τ_{decay}, times on the heavy-hole or light-hole character of the excitons in tensile-strained quantum wells. τ_{rise} is considerably shorter for the wells with a degenerate ground state than for those with a heavy- or light-hole exciton. The samples with a light-hole ground state exhibit a τ_{decay} twice larger than those with a heavy-hole exciton. We have also obtained the dependence of the valence-band mixing with strain and well width from the behavior of the initial degree of polarization on excess excitation energy.

The presence of phosphorus in $GaAs_{1-y}P_y$ makes its lattice parameter smaller than that of $Ga_{1-x}Al_xAs$. Thus, the epitaxial growth of thin layers of $GaAs_{1-y}P_y$ between $Ga_{0.65}Al_{0.35}As$ gives rise to tensile strained quantum wells (QW's).[1] The final valence band structure, which arises from strain and confinement effects, can be tailored by changing the phosphorus composition and the well width.[1] This can give rise to QW's with a heavy-hole (*hh*), light-hole (*lh*) or degenerate *hh-lh* excitonic ground state. In this work, we present a study of the influence of the band structure on the exciton dynamics. We have also obtained the dependence of the valence-band mixing (VBM) on the energy splitting between the *hh* and *lh* subbands at **k**=0, and compared the experimental results with **k•p** calculations.[2]

We have investigated six different GaAsP QW's with phosphorus compositions of 5%, 8% and 12% and well widths of 80 Å and 120 Å. Their band structures, which depend on the P content and well width, have been previously reported in Ref. 3. The samples were optically excited, above their subband edges, with pulses from a dye-laser pumped with a mode-locked Nd-YAG laser. The photoluminescence (PL) was time resolved with an up-conversion spectrometer with a time resolution of ~5 ps. All the measurements have been performed at 5 K under low power excitation conditions. We found that high excitation densities cause exciton-exciton collisions and saturation effects which modify the characteristic times of exciton formation and recombination.[4]

For a fixed excitation density, we have observed that the rise time of the PL, τ_{rise}, which measures the time that the hot excitons need to reach their ground state, is shorter (~70 ps) for the QW's with a degenerate *hh-lh* excitonic ground state than for those with either a *hh* or *lh* ground state (>130 ps). Exciton cooling, which primarily occurs by means of acoustic phonon scattering, is the main process which contributes to τ_{rise}.[5] Since the scattering rate is proportional to the final density of states (DOS), the excitons lose their kinetic energy faster in the degenerate QW's, which have a larger DOS, than in those with a non-degenerate ground state.

On the other hand, we have found that the decay time, τ_{decay}, which is directly related to the excitonic radiative lifetime, depends only on the light- or heavy- character of the ground state. τ_{decay} is ~500 ps for QW's with a *hh* ground state, while its value is doubled to ~1 ns for QW's with a *lh* excitonic emission. This finding is in agreement with the oscillator strength of the *hh* excitons which is larger than that of *lh* excitons.[6]

Figure 1 shows the time evolution of the PL for two different samples. The solid and dotted lines correspond to the (5%,80Å) QW, with a *hh* ground state and to the (8%,80Å) QW, with a quasi-degenerate *lh* ground state, respectively. While the time-evolution of the former shows τ_{rise}~140 ps and τ_{decay}~400 ps, that of the latter presents τ_{rise}~70 ps and τ_{decay}~900 ps. This figure illustrates the influence of the band structure on the exciton dynamics.

We will concentrate on the changes of the VBM with confinement and strain. For this purpose, we have performed time-resolved optical pumping experiments. The samples are excited with σ^+ polarized light and we detect the intensities of the σ^+ (I^+) and σ^- (I^-) PL. The use of circularly polarized excitation allows us to select the third component of the angular momentum, j_z, of the excited electron-hole pairs. From now on, we call j_z the spin. The populations of the excited electrons and holes with a certain spin will change with the energy of excitation due to the dependence of the VBM on **k**. The magnitudes of the I^+ and I^- emission, at very short times, before any spin-relaxation of the electrons takes place, will reflect the initial population of electrons with a given spin. Thus,

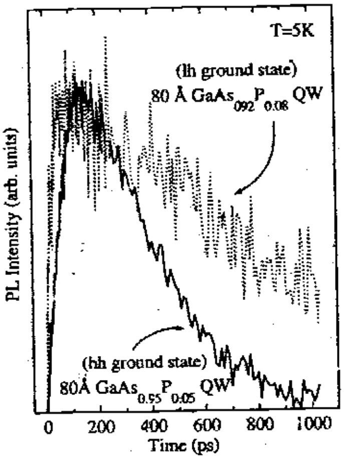

Fig. 1. Time evolution of the PL for two different $GaAs_{1-y}P_y$ QW's with y=0.08 (dashed line) and y=0.05 (solid line). The measurements are done at 5 K under low power excitation.

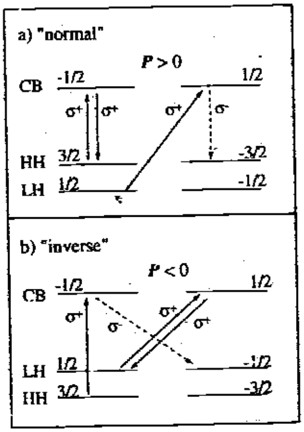

Fig. 2. Representation of the spin levels in the conduction band (CB) and *hh* and *lh* subbands. The arrows show the allowed transitions for σ^+ and σ^-. a) "normal" (*hh* above *lh*). b) "inverse" (*lh* above *hh*).

the study of the PL initial degree of polarization, $P(0)=(I^{+}(0)-I^{-}(0))/(I^{+}(0)+I^{-}(0))$, as a function of excess excitation energy ($\Delta E=E_{excitation}-E_{detection}$), provides important information about the dependence of VBM on **k**.

Figure 2 represents schematically the processes of excitation with σ^{+} light (up-arrows) and of emission (down-arrows) of electron-hole pairs for a "normal" QW (*hh* ground state) and for an "inverse" QW (*lh* ground state). HH and LH have to be understood as discrete levels for the emission, however they also represent electronic continua for the excitation. Let us consider first an ideal situation without VBM. For both cases, excitation of holes only from the first subband would obtain $P(0)=1$. Taking into account the oscillator strengths of the *hh* and *lh* transitions,[6] when holes from the second subband are also excited $P(0)$ should be +0.5 for case (a), while ideally should have a value of –0.5 for case (b). Any departures from these values originate from VBM effects. We have assumed that the hole populations, at t=0, in the first $\pm j_z$ subbands are equal, which is reasonable for our time-resolution and the usual spin-flip time of holes.[7]

Figure 3 depicts $P(0)$ as a function of ΔE (points) for a 80 Å-$GaAs_{0.95}P_{0.05}$ QW, which has a *hh* ground state. The dotted line corresponds to the PL excitation (PLE) spectrum. The zero of ΔE corresponds to the PL maximum, which has a Stokes shift of ~8 meV. The vertical lines indicate the onsets of the *hh* and *lh* subbands. The results of the **k•p** calculation are plotted as a solid line. Our experimental set-up and the low PL intensity limits ΔE to ~30 meV. At this energy, $P(0)$ has a value of 0.55. For excitation above the *lh* subband, a clear decrease of $P(0)$ is obtained to ~0.2. This is in qualitative agreement with the calculations, which show a large drop of $P(0)$ from ~1, below the *lh*

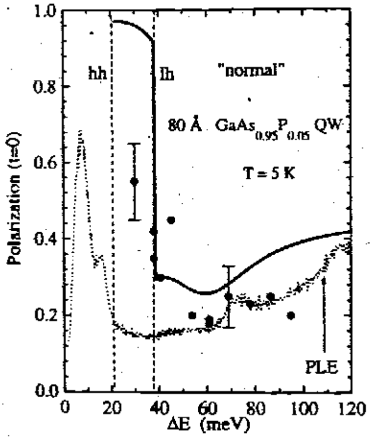

Fig. 3. Initial degree of polarization vs. excess excitation energy (points) for a "normal" QW. Solid line: results of the k•p calculation. Dotted line: PLE. The vertical lines indicate the onsets of the *hh* and *lh* subbands.

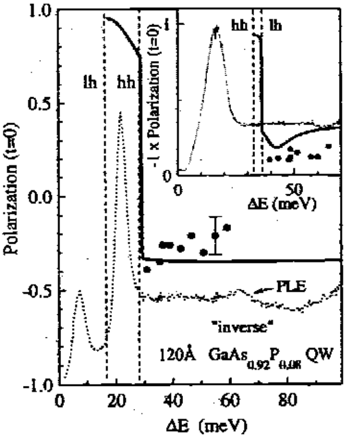

Fig. 4. Initial degree of polarization vs. excess excitation energy (points) for a "inverse" QW. Symbols: same meaning as in Fig. 3. Inset: results for a "degenerated" QW, note the change of sign of the ordinate.

subband, to 0.3-0.4 for ΔE > 40 meV. The difference with the ideal value of 0.5, mentioned previously, gives an indication of the VBM. The large discrepancy between theory and experiments for excitation below the *lh* edge could arise from the excitonic nature of the emission and the localization of the excitons, which are not taken into account in the calculations. The localization produces a violation of the K-conserving rule, which allows the creation of excitons in the high energy tail of the pseudo-absorption.[8]

The results for a 120 Å-$GaAs_{0.92}P_{0.08}$ QW are presented in Fig. 4. The PLE shows clearly the "inverse" situation of the holes. The two peaks at ΔE=7 meV and ΔE=22 meV correspond to the light- and heavy -hole excitons, respectively. Note that in this case, exciting above the *hh* subband edge we do obtain negative values of *P*(0), as expected from the model presented in Fig. 2. The **k•p** calculation predicts stronger VBM effects in the spectral range between the *lh* and *hh* subbands than those for the "normal" QW (Fig. 3). Unfortunately, we cannot access these energies. For excitation above the *hh* subband, the calculated degree of polarization is in very good agreement with the experimental results. The amount of VBM, seen as the difference between $|\pm 0.5|$ and the observed values, for the samples shown in Figs. 3 and 4 is similar. However, as can be observed in the inset of Fig. 4, the VBM becomes larger for a QW with a degenerate ground state. Both, theory and experiments obtain values of $|P(0)|$ smaller than 0.2, indicating a larger coupling between the *hh* and *lh* subbands, which has been also observed in previous magneto-optical experiments.[3]

In conclusion, we have shown that the band structure affects strongly the exciton dynamics in QW's. We have also obtained that the splitting between the *hh* and *lh* subbands determines the valence band mixing and therefore the spin dependent properties of the photoexcited carriers. The results are in good agreement with **k•p** calculation of the valence band structure.

Acknowledgments

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