Signature of Singlet-Triplet Crossing in PL in GaAs QW's

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Abstract. Positively charged excitons in a two-dimensional hole gas in symmetric and asymmetric GaAs/$Ga_{1-x}Al_xAs$ quantum wells are studied in polarization-resolved photoluminescence experiments in high magnetic fields B (up to 23 T) and low temperatures (down to 300 mK). The experiments are accompanied by numerical calculations of a real structure. The whole family of trions (the singlet and a pair of triplets) are observed. The Coulomb energies crossing of singlet and triplet is found: hidden in symmetric and visible in asymmetric structures.

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INTRODUCTION

The two-dimensional (2D) gases are unique systems for investigation of many body interactions [1]. In the last years the negatively charged excitons (trions) in 2D electron gas have been studied very intensively, while the positively charged excitons in a hole gas are considerably less explored. Trions often determine the photoluminescence (PL) spectra [2,3].

We report on the studies of positively charged excitons in symmetric and asymmetric GaAs quantum wells (QW) with a 2D hole gas. We performed polarization resolved PL measurements accompanied with transport experiments in high magnetic fields (up to B=23T) and at low temperatures (down to T=300mK). Experimental PL and transport studies were supplemented with realistic configuration-interaction calculations. In experiment we detected the entire family of positively charged excitons: the pair of bright and dark triplets and the singlet. We found crossing of the singlet and triplet Coulomb energies: hidden in symmetric and visible in asymmetric structures.

EXPERIMENT, RESULTS, AND DISCUSSION

The studied samples were GaAs/$Ga_{0.65}Al_{0.35}Al$ quantum wells fabricated by molecular beam epitaxy on a (001) semi-insulating GaAs substrate and δ C-doped in the barrier. We studied two types of samples. The symmetric structure was a 15 nm GaAs/AlGaAs QW, doped in both barriers, with the 2D hole concentration (measured in dark) $p=1.15x10^{11}/cm^{-2}$ and mobility $\mu=1.01x10^5$ cm^2/Vs. The asymmetric structure was 22 nm GaAs/AlGaAs QW, doped on one side, with concentration $p=1.8x10^{11}/cm^{-2}$ and mobility $\mu=1.2x10^5$ cm^2/Vs. From transport measurements we determined the actual 2D hole gas concentration under illumination.. The PL measurements were carried out at low temperatures down to T = 300 mK and in high magnetic fields up to B = 23 T applied perpendicular to the structure. Experiments were performed in the Faraday configuration.

In zero magnetic field in PL spectra one line attributed to positively charged excitons in the singlet state is observed. When magnetic field is applied the PL spectra develop and reveal much richer structure.

In Fig. 1 the PL spectra for symmetric structure in both $\sigma^{\pm}$ are presented. From the detailed analysis of the evolution of PL spectra as a function of the magnetic field (not presented) and comparison of experimental data of Coulomb binding energies in the trion complex with realistic numerical calculations, we identified all observed lines (for more detailed explanation see ref. [6, 7]). The order of energy positions of the trion lines in respect to X is different in both polarizations. In σ^- descending energy from X we detect: "bright triplet"

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X^+_{tb}, "dark triplet" X^+_{td} and finally the singlet X^+_S. In σ^+ the order of singlet and dark triplet lines is reversed.

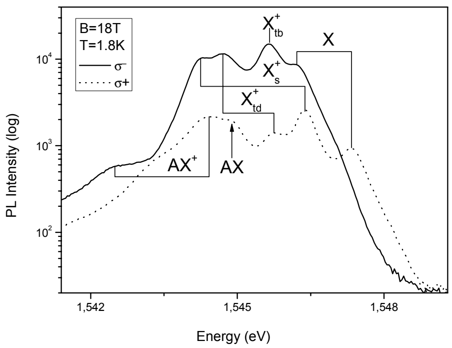

FIGURE 1. Photoluminescence spectra for symmetric 15 nm QW in magnetic field B = 18 T.

The bright triplet line is not observed in this polarization. We also observe radiative recombination of excitons bound to neutral and positively charged acceptor – AX and A^+X (i.e., AX^+).

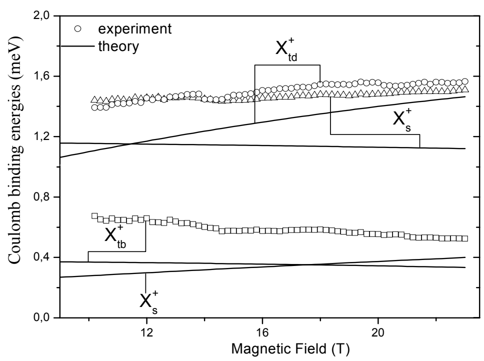

FIGURE 2 The second-hole Coulomb binding energies: symbols – experiment, solid lines calculated numerically for the 15nm symmetric GaAs quantum well.

To remove Zeeman contribution from the trion binding energy, the exciton (X) and trion (X^+) peak positions measured in PL must be averaged over both ($\sigma^{\pm}$) polarizations. The resulting curves of X^+_s and X^+_{td} are displayed in Fig. 2. The results of realistic numerical calculations are also plotted. A singlet-triplet crossing is found at B ≈ 12 T (relatively low field compared to the crossing of negative trions in typical n-doped wells). Due to the strong difference in the Zeeman splitting this crossing is hidden in PL spectra. Notice that nevertheless the numerical calculations give a slightly lower binding energy for the additional hole the singlet – triplet crossing is obtained almost in the same magnetic field.

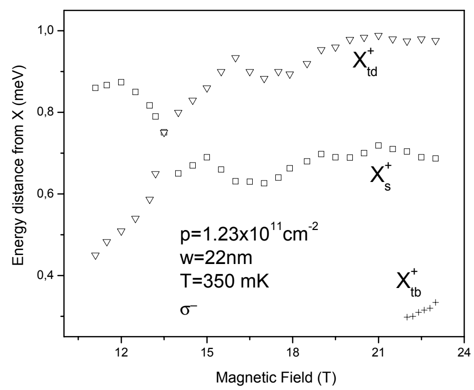

FIGURE 3. The experimental second-hole Coulomb binding energies for the 22 nm asymmetric GaAs quantum well.

In Fig. 3 the energy distance of singlet X^+_s and triplet X^+_{td} lines from excitons are shown as a function of B. These energies agree well with theoretical calculations of Coulomb binding energies of additional hole in the asymmetric sample with lower concentration, which satisfied experimental conditions. Due to high density of laser power excitation we decreased strongly the 2D hole concentration to $p=1.23x10^{11}/cm^{-2}$.

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