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ANDERSON-FANO TRANSITIONS IN PHOTOLUMINESCENCE OF A TWO DIMENSIONAL ELECTRON GAS

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The many body interaction are investigated in polarization resolved photoluminescence in the magnetic field up to 23 T. The Fermi edge singularity, Anderson-Fano transition and neutral and negatively charged excitons (trions) are detected in the photoluminescence spectra. The experimental results are supplemented by realistic calculations.

Keywords: Two-dimensional electron gas; photoluminescence; trion; Anderson-Fano transition.

1. Introduction

Two-dimensional electron gas (2DEG) has been extensively studied in recent years as a correlated many-fermion system easy tunable by the external magnetic field[1,2]. Magneto-photoluminescence (PL) spectroscopy has been established as a very effective tool to study 2DEG in both integral and fractional quantum Hall regimes[3]. Field evolution of the PL spectra carries information not only about the single-particle energy levels of the 2D carriers, but also about the crucial role of the exchange interaction. In this article, we report the low-temperature magneto-PL studies of a high-quality 2DEG confined in a GaAs/$Ga_{1-x}Al_xAs$ quantum well. In the absence of magnetic field, we observe a broad line attributed to the Fermi-edge singularity[4]. When a magnetic field is applied, this line evolves continuously into a characteristic discrete spectrum of 2D Landau levels. At odd filling factors a remarkable doublet-like splitting, the so-called Anderson-Fano transition[5] is detected in the PL spectra. At integer filling factors, the ground state emission exhibits an abrupt blue shift. When the magnetic field was increased above the filling factor $\nu = 1$, we observed that the lowest-energy transition evolved into the singlet state of a negatively charged exciton[6] (trion), $X^- = 2e + h$. As the field is increased further, transitions due to the recombination of dark-triplet trions and free excitons ($X = e + h$) emerge in the spectra. We compare the observed experimental results with the exact calculations of the real structure.

2. Experiment, Results, and Discussion

The studied samples were a w = 15 nm 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, symmetrically on both sides. The low-temperature (T = 4.2 K) concentration of the 2D electrons measured in the dark varies from n = 1.17 to 3.64 x 10^{11} cm^{-2}. Under illumination, the concentration increased to the extent dependent on the density of light.

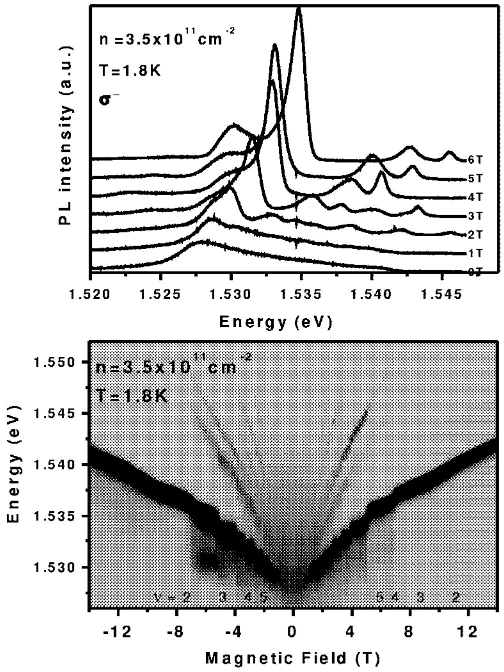

Fig. 1. The evolution of the PL spectra for the sample with 2DEG concentration n=3.5x10^{11}cm^{-2} (top). The grey color intensity coded evolution of PL spectra (down).

The 2D electron mobility was of the order of $\mu \sim 10^5$ cm^2/Vs in all of our samples. The PL measurements were carried out at low temperatures down to T = 1.8 K and in high magnetic fields up to B = 23 T applied perpendicular to the structure. We used the Faraday configuration, with a linear polarizer and wave quarter immersed in the liquid helium close to the sample. To switch between the σ^- and σ^+ polarizations, the direction of magnetic field was changed. PL was excited by the λ = 514 nm line of ion Argon laser.

In Fig. 1 the evolution of PL spectra for the sample with the 2DEG concentration n = 2.7 x 10^{11} cm^{-2} (in the dark) for magnetic fields up to B = 14 T are presented. The 2D electron concentration under the illumination was higher. In the present case, with the applied laser-power density of P = 1 mW/cm^2, it was n = 3.5 x 10^{11} cm^{-2}. At the zero magnetic field, in all studied samples the broad line, with the characteristic increase of intensity on both energy sides, is observed. We attributed it to the so-called Fermi edge singularity[4]. Its width grows with an increase of the 2D electron concentration. When the magnetic field is applied, this line evolves continuously into the characteristic spectrum of discrete Landau levels that are very well resolved, especially for the samples with the highest 2D electron concentrations. At integer filling factors, the abrupt blue-shift of the transition from the ground state is observed. This behavior can be explained as the crossover from the interband Coulomb binding of a conduction-band electron and a photo-excited thermalized valence-band hole to the electron–electron interaction in the Fermi sea. The first interaction is stronger above integer filling factors (at lower fields) whereas the second dominates below these values (at higher fields). That means that in our symmetrically doped structures the exciton Coulomb binding is dominant.

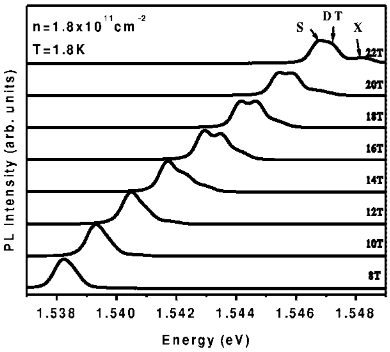

Fig. 2. The evolution of the PL spectra for the sample with 2DEG concentration n=1.8x10^{11}cm^{-2} (dark n=2.7x10^{11}cm^{-2}) in σ^- polarization.

At the odd filling factors, a "striking" doublet-like structure of ground-state emission is detected, but only in one (σ^-) polarization. This splitting is very well resolved for higher 2D electron concentrations and in magnetic fields in the range corresponding to filling factors 2 > ν > 3. This phenomenon was already observed earlier and it was attributed to the Anderson-Fano transition in the Fock space[5]. As the field is increased beyond the critical value corresponding to filling factor ν = 1, the ground state-emission changes its character. The recombination is now due to the negatively charged excitons (trions). The spectra measured in this field range for the sample with the lowest 2D electron concentration $n = 1.17 \times 10^{11}\mathrm{cm}^{-2}$ (in the dark) and in the stronger-intensity (σ^-) polarization are shown in Fig. 2.

The detailed analysis of the field evolution of the spectra and comparison with the realistic numerical calculations allowed us to reach the following conclusions. The lowest-energy line detected at sufficiently high magnetic fields, B > 8T (corresponding to ν < 1), is due to emission from the spin-singlet trion state. At the highest fields, two new lines emerge in the spectra on the high-energy wing of the singlet line. We attributed them to the transitions of the dark-triplet trions (the lower-energy line) and of the neutral excitons (the higher-energy line).

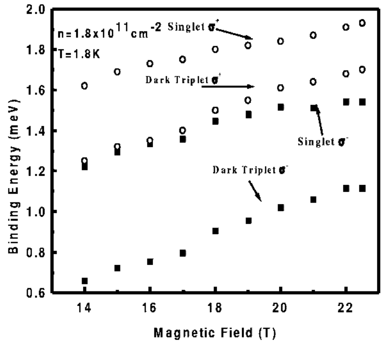

Fig. 3. The experimental energy difference of the neutral exciton and the trion (singlet and dark triplet states) for the sample with 2DEG concentration $n=1.8\times10^{11}\mathrm{cm}^{-2}$ (i.e., $n=1.7\times10^{11}\mathrm{cm}^{-2}$ in the dark).

In Fig. 3 we plot the experimental energy difference of the neutral exciton and the trion in singlet and dark triplet states. The difference observed for polarizations σ^- and σ^+ is connected with different Zeeman splitting. The "bare" Coulomb contribution is an average of the binding energies obtained for both helicities.

To allow positive identification of the exciton and trion lines we have carried out realistic exact-diagonalization numerical calculations of the 2e+h and e+h energy spectra. The many-body configuration-interaction bases were constructed in Haldane's spherical geometry, and the surface-curvature errors were eliminated by extrapolation. Up to five Landau levels and two quantum-well subbands were included for electrons and holes. The cyclotron and subband energy gaps, adequate for particular well width and magnetic field, were taken after experiment [8]. The two-body Coulomb matrix elements were integrated exactly using full 3D subband wavefunctions in a similar way as described in

Ref. 7. Diagonalization of the hamiltonian matrix was done using Lanczos algorithm. The resulting field dependence for both negative and positive trions is presented in Fig. 4. Note that only Coulomb contribution to the binding energy is plotted, neglecting the difference in the Zeeman energy of the hole(s) in exciton and different trion states. Theoretical data very well agree with experimental results for the dark triplet trion and are slightly higher for singlet.

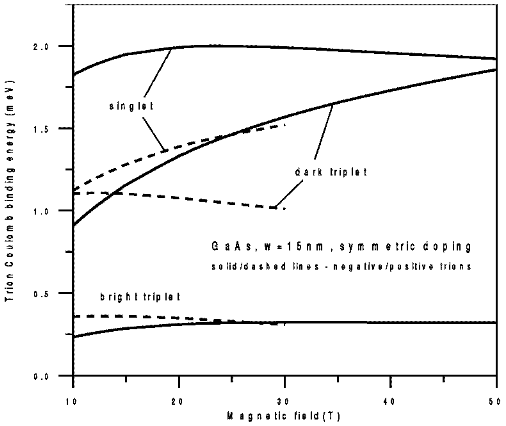

Fig. 4. The second-electron Coulomb binding energies calculated numerically for the singlet, dark-triplet, and bright-triplet trions in the 15nm symmetric GaAs quantum well.

3. Conclusion

The magneto-photoluminescence studies of two dimensional electron gas, performed in our work covered a wide range of the filling factor, and allowed the optical probe of different many-body phenomena in this system: (i) dynamics and recombination o excitonic complexes consisting of small number of valence holes and/or particles and vacancies in partially filled high electron Landau levels (Anderson-Fano transition); (ii) binding and radiative decay of excitons and trions in a nearly empty lowest Landau level. The experimental results are compared with exact realistic numerical calculation.

Acknowledgments

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