OPTICAL PROPERTIES OF TRIONS IN ZNSE/ZNMGSE QUANTUM WELLS

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Negatively charged excitons (trions) were observed in unintentionally donor doped $Zn_{0.90}Mg_{0.10}Se$/ZnSe single quantum wells by magneto- luminescence experiments. The binding energy of the trion singlet ground state is about 2.7 meV. Additionally, an excited triplett state of the trion was detected being stable at magnetic fields above 3 Tesla. Four wave mixing experiments were performed in order to distinguish the trion singulett ground state from biexcitonic signal contributions.

Introduction

The concept of trions as effective mass complexes consisting of negatively or positively charged excitons was introduced by Lampert [1], who calculated binding energies for this quasi-particles to be in the range of a few meV. Since the presence of excess carriers leads to Coulomb-interactions and under sufficient carrier densities to a complete screening of excitonic states, the ability to observe trions in a specific material system depends crucially on its excitonic binding energies. Therefore, first experimental observations of trions were reported after investigating excitonic luminescence properties of quantum well (QW) systems, where the binding energies of trions can reach an amount of 0.3 times the 3D donor Rydberg energy in the 2D limit, as shown by Stèbè et al. in GaAs/AlGaAs for $m_e^*/m_h^* = 0.5$ [2]. Especially II-VI quantum wells are suitable for a clearly spectrally resolved detection of trions due to their large donor binding energies.

In this paper the occurrence of negatively charged excitons in unintentionally donor doped ZnSe/ZnMgSe single quantum wells is demonstrated. Polarization dependent luminescence spectroscopy under high magnetic fields and four wave mixing experiments were used in order to prove the existence and term structure of trion states.

Experimental Methods

All samples were grown pseudomorphically on (001) GaAs-substrates by MBE [3]. The ZnSe single QWs were embedded in 30 nm thick barrier layers of $Zn_{1-x}Mg_xSe$ with x varying between 0.05 and 0.10. The well width was varied in the range between 8 nm and 30 nm. The donor background concentration in the barriers providing free excess electrons in the well is about 10^{16} cm^{-3} (for x=0.1) introduced by an unintentionally aluminum and silicon contamination in the Mg-source.

Magnetic field dependent luminescence spectra were recorded using a 15 T split coil superconducting magnet equipped with a He immersion cryostat. The luminescence was excited with a HeCd- laser and detected by a bialkali photomultiplier tube attached to a 0.85 m double monochromator. The orientation of the sample with respect to the magnetic field was varied in the range between Faraday (k ∥ B; k ∥ (001)) and Voigt (k ⊥ B; k ∥ (001)) configuration.

Spectrally resolved sub-picosecond degenerate four-wave mixing experiments (DFWM) were performed in reflection geometry using a frequency doubled Titan-Sapphire laser in the low excitation density regime. The pump and probe polarization was adjusted separately in order to check the selection rules valid for the investigated emissions.

Results

In Fig.1 luminescence spectra recorded in Faraday configuration under different magnetic fields are depicted. The luminescence at 2.8076 eV originates from purely X_{hh} contributions, since induced by the compressive strain in the well the X_{lh} exciton is shifted by 13.2 meV to the high energy side.

Starting at 5 Tesla, a twofold Zeeman splitting of the X_{hh} exciton can be observed, according to the separation of the $m_j = \pm 3/2$ subvalence bands resulting in two counter-polarized circular components σ^+ and σ^-.

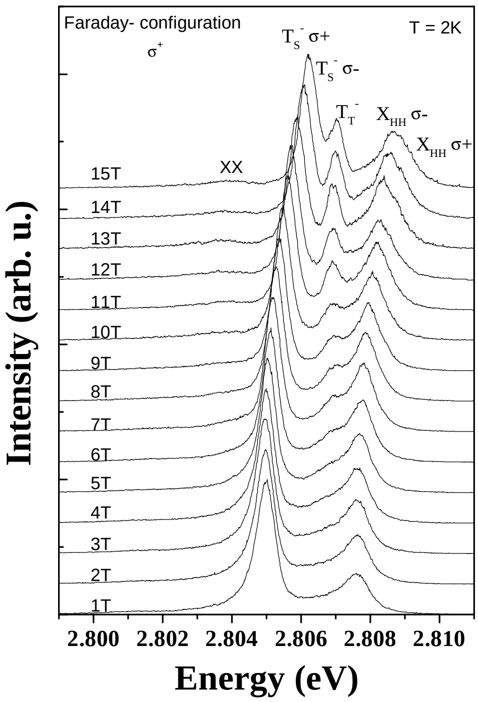

Figure 1: Magnetic field dependent luminescence spectra of a 20 nm ZnSe/ $Zn_{0.90}Mg_{0.10}Se$ single quantum well in Voigt-configuration.

At 1 Tesla an additional strong emission is observed 2.7 meV below the X_{hh}-exciton. An assignment to a donor bound exciton can be excluded, because of its expected binding energy of about 5 meV.

In order to examine the polarization properties of this luminescence line the sample was used in spectral resolved four wave mixing experiments as depicted in Fig.2. The recorded spectrum obtained with cocircular polarized fields is compared with the DFWM signal from a 20 nm single QW with a reduced Mg content of x = 0.06. The polarization configuration used in this experiment ensured that the

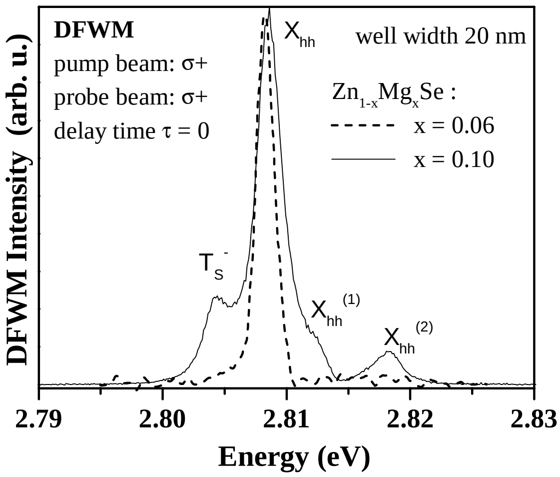

Figure 2: Spectrally resolved DFWM signals recorded at 10K and τ€= 0 in reflection geometry after exciting with a 100 fs pulse for two samples with a Mg content of x=0.10 and x=0.06, respectively. The pump and probe beams were circular σ^+polarized.

creation of a biexciton is forbidden, since biexcitons consist of two excitons with antiparallel spins. Therefore, the emission at 2.804 eV in the x=0.10 sample cannot be explained by a biexciton induced DFWM signal. We attribute this signal to the formation of a trion singlet state denoted with T_S^-, since the intensity of this line is correlated to the Mg and thus to the donor concentration in the barriers. The free QW electrons essential for the creation of trions are provided by diffusion of photoexcited donor electrons into the QW. No line is observed in the x=0.06 sample, because the background donor concentration in this sample is nearly 2 times smaller and the decreased conduction band offset causes a weaker electron localization in the QW.

The twofold Zeeman splitting of the T_S^- line derived from magneto-luminescence experiments as shown in Fig. 1 can be explained as the recombination of the trion ground state consisting of a complex with two electrons in anti-parallel spin configuration and either a m_j = +3/2 or a m_j = -3/2 hole [4].

The spectral difference between the exciton and the trion with about 3.7 meV is somewhat higher than observed in the luminescence experiments, because the X_{hh} emission is slightly blue shifted in the reflected DFWM spectra induced by reabsorption effects.

If the orientation of the magnetic field was changed to angles between Faraday and Voigt configuration, we observe an additional spectral splitting of the T_T^- complex consisting of 4 sub-structures. We assign these peaks to the 4 dipole allowed sublevels of the J = 5/2 excited trion state [4].

The energetic difference between the T_T^- lines and the X_{hh} increases with the magnetic field. This is explained by an enhancement of the binding energy of the excited trion state due to the additional magnetic confinement energy. The triplet state seems to be stable only at magnetic fields higher than 3 Tesla, which is consistent to results obtained in GaAs/AlGaAs QW´s [4].

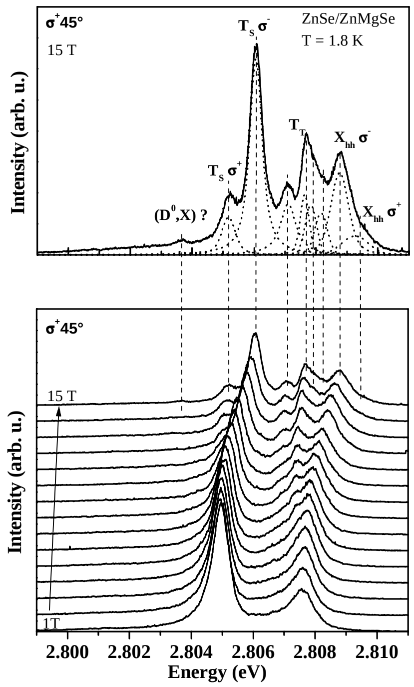

Figure 3: Magnetic field dependent luminescence spectra of a 20 nm ZnSe/ $Zn_{0.90}Mg_{0.10}Se$ single quantum well with magnetic field orientation 45° to (100).

Acknowledgments

We thank H. Preis and W. Gebhardt for providing the ZnMgSe/ZnSe single quantum wells.

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