7th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 14–18, 1999

Magneto-reflectivity studies of ZnSe/ZnMgSSe QWs with low density 2DEG

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Abstract. Magneto-reflectivity has been studied in modulation-doped ZnSe/ZnMgSSe quantum well structures with low and moderate carrier concentrations. Negatively charged exciton (trion) lines were observed in the reflectivity spectra. Magnetic-field-induced circular polarization of the trion reflection line has been found to correlate with the polarization of electron gas at filling factor $\nu < 2$.

It has been found recently that at low free electron concentration in a semiconductor quantum well (QW) the exciton-electron interaction results in the formation of bound exciton-electron complexes (trions) [1]. Such trion states were observed in II–VI (CdTe/CdZnTe and CdTe/CdMgTe) as well as in III–V (GaAs/AlGaAs) semiconductor QWs in transmission, reflection and photoluminescence spectra [1–3]. The main feature of the trion reflection (transmission) line is its strong circular polarization in magnetic fields. This polarization is due to the fact that the trion ground state is a singlet. In a sufficiently strong magnetic field and at temperatures low enough for all electrons to fall to the lowest Zeeman sublevel, only a photon with a certain circular polarization can create a trion. In the present paper we report on a magneto-reflectivity study of trion states in modulation-doped ZnSe/ZnMgSSe quantum wells (QWs) at various electron concentrations.

Samples grown by molecular-beam epitaxy on (100)-oriented GaAs substrates were 100-Å thick ZnSe/$Zn_{0.89}Mg_{0.11}S_{0.18}Se_{0.82}$ QWs with n-type modulation doping with chlorine in the barrier layer (30-Å thick doped layer separated from the QW by a 100-Å spacer). A set of structures with different concentrations of two-dimensional electron gas (2DEG) was grown. The 2DEG concentration was varied from about zero (compensated structure) up to 10^{11} cm^{-2}. We have chosen the ZnSe-based QW structures owing to the strong Coulomb interaction in this material (exciton binding energy in ZnSe is 20 meV). This leads to a strong enhancement of the exciton-electron interactions. As a result, the characteristic energy of such interactions becomes much larger than the potential fluctuations in the sample.

Figure 1 shows reflectivity spectra taken from the ZnSe/ZnMgSSe structures under study in zero magnetic field at 1.6 K. The top panel of this figure shows a reflection spectrum taken from nominally undoped structure (2DEG concentration less than 4×10^9 cm^{-2}). Only one strong line (X) ascribed to the exciton resonance is observed in the spectrum at 2.8195 eV. At higher electron concentrations an additional line attributed to the negatively charged exciton (X^-) appears in the spectra about 5 meV below the exciton resonance. With increasing electron density, the intensity of this line grows and the exciton line broadens. At an electron concentration $n_e \approx 1.5 \times 10^{11}$ cm^{-2} the intensity of the trion line much exceeds

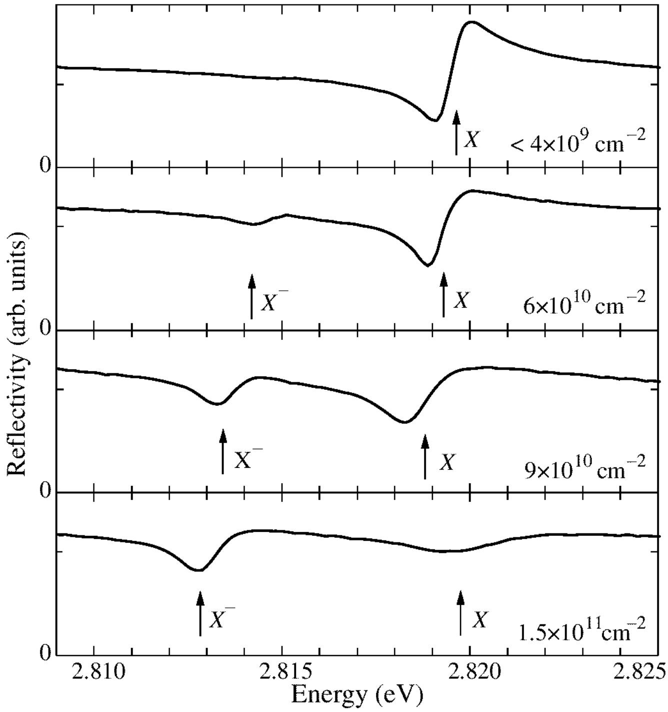

Fig. 1. Reflectivity spectra of 100-Å-thick ZnSe/$Zn_{0.89}Mg_{0.11}S_{0.18}Se_{0.82}$ single QWs with different 2DEG concentrations. The concentration increases in the direction from top to bottom panel. $T = 1.6$ K. Arrows indicate exciton X and trion X^- states.

that of the exciton line. The strong reflectance associated with the trion line indicates the fundamental character of the trion state. We believe that the trion has the same significance for 2DEG optics as the exciton for the optics of dielectrics.

In external magnetic fields, the X^- reflection line becomes strongly polarized. The degree of polarization of the X^- line is presented in Fig. 2 as a function of magnetic fields for different 2DEG concentrations. In the case of a low electron concentration in the QW ($n_e \approx 6 \times 10^{10}$ cm^{-2}—the upper panel), the magnetic field dependence of the polarization of the X^- line is described by the Brillouin function ($B_{1/2}[B] = th[\mu g_e B/kT]$, where μ is the Bohr magneton, T is temperature, and B is magnetic field) with electron g-factor $g_e = +1.15$ (dotted line). A slight disagreement between the experimental data (circles) and the Brillouin function is observed in weak magnetic fields. This disagreement becomes much more pronounced at higher electron concentrations. For the highest electron concentration ($n_e \approx 1.5 \times 10^{11}$ cm^{-2}), the X^- line is found to be completely unpolarized at $B < 3$ T. In order to describe correctly the behaviour of the X^- in a dense 2DEG in weak magnetic field, one should use the Fermi–Dirac statistics instead of the Boltzmann one for calculating the electron population of the Zeeman sublevels.

The electron spin polarization in a dense 2DEG in magnetic fields occurs when Landau levels pass through the Fermi energy. The spin polarization is zero at even filling factors (the filling factor is $\nu = n_e(hc/eB)$), when two Zeeman components of the Landau level are filled by electrons, and reaches maxima at odd filling factors. The dependences of the 2DEG

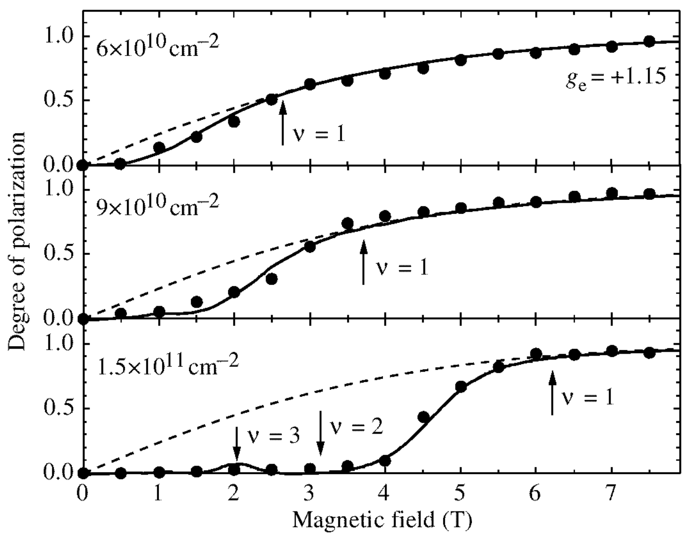

Fig. 2. Degree of polarization of the X^- line vs magnetic field in 100-Å-thick ZnSe/$Zn_{0.89}Mg_{0.11}S_{0.18}Se_{0.82}$ single QWs with different 2DEG concentrations, circles—experiment, dotted line—Brillouin function with $g_e = +1.15$, solid line—calculation using the Fermi–Dirac statistics. Arrows indicate integer values of filling factor.

polarization calculated with a Fermi–Dirac distribution of electrons in Landau levels are plotted in Fig. 2 (solid line) together with the experimentally observed circular polarization of the trion line. It can be seen that the 2DEG polarization oscillates (bottom panel), while the experimental dependence exhibits a monotonic behaviour. This experimental dependence is similar to that we would observe if only the lowest Landau level ($\nu < 2$) contributed to the polarization. This fact indicates an important role of the lowest Landau level in the trion formation, mentioned in Ref. [4]. The absence of the circular polarization of this line at filing factors $\nu > 2$ could mean that in these conditions of a dense 2DEG the observed line should be attributed to multi-electron-exciton complexes containing more than three particles. The polarization properties of such complexes must be different from those of the trions, with the binding energies being, contrariwise, very close.

The above considerations can be used to deduce the 2DEG concentration. The concentrations determined in this way are shown in Fig. 2.

In conclusion, we have carried out a magneto-optical study of ZnSe/ZnMgSSe modulation-doped QWs. In the presence of excess electrons in the QW, a line attributed to the negatively charged exciton appears in the reflectivity spectra. We have analysed the degree of polarization of the X^- line as a function of magnetic field. An optical method to determine the 2DEG concentration in quantum wells is proposed. The magnetic-field-induced circular polarization of the X^- reflection (absorption) line correlates with the polarization of the lowest Landau level. Our results support the viewpoint that the lowest Landau level is the most important for the trion state formation.

This work was supported by the NATO grant HTECH.LG 974702, Russian Foundation for Basic Research (Grants No 98-02-04089 and No 98-02-18219) and the Program "Nanostructures" of the Russian Ministry of Science and Technology.

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