

Increase of the Zeeman splitting of excitonic-polaritons due to their motion

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Reflectivity spectra from GaAs and CdTe based wide quantum wells (widths $L=50\text{--}1000$ nm) have been studied in magnetic fields in Faraday geometry. The magnitude of the exciton Zeeman splitting has been found to grow with increase of the quantization index N for the exciton energy levels. Since N is related to the magnitude of the exciton wave vector K , the observed effect means that the magnetic moment of the exciton gets larger as the kinetic energy increases.

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1 Introduction

Interest in exciton polariton states in quantum-confined structures has intensified significantly due to the prospects for developing the principles of optical information processing. Excitonic polariton quantization, originally observed in thin crystal layers, is now commonly studied in specially grown quantum well (QW) structures, microcavities and photonic crystals [1–6] based on different semiconductor compounds. As was shown in [1–3] the effect of exciton size quantization can be very effectively used to reconstruct bulk polariton dispersion curves. The effect has been used to measure exciton effective masses, oscillator strengths, refractive indexes and features of band structure in different semiconductors. The magneto-optical behaviour of the excitonic polaritons gives additional information about these states [7, 8].

On the other hand the exciton states in classical bulk semiconductors such as GaAs in applied magnetic fields have been studied in such detail that it is difficult to expect the observation of new phenomena in such materials, at least under normal conditions.

In the present work we studied the quantization spectra of excitonic polaritons in GaAs and CdTe wide quantum well (QW) structures in magnetic fields. Contrary to expectations, we have found that the value of the exciton g -factor depends dramatically on the exciton kinetic energy.

2 Experiment

We used GaAs/AlGaAs heterostructures containing a quantum well whose width was much larger than the exciton Bohr radius. The structures were grown by molecular-beam epitaxy (MBE) on semi-

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insulating GaAs [100] substrates. A typical structure contained a 100 nm GaAs buffer layer, a 400 nm $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ barrier layer, a wide GaAs quantum well with width in the range from 50 to 1000 nm, a second barrier layer symmetrical to the first one, and a 10 nm GaAs cap layer.

$\text{CdTe}/\text{Cd}_{0.9}\text{Zn}_{0.1}\text{Te}$ quantum wells with wide QW were grown by MBE on $\text{Cd}_{0.96}\text{Zn}_{0.04}\text{Te}$ substrates; here two types of structures have been studied, grown in the [100] direction and in the [110] direction. In the present work, reflectivity spectra at normal incidence were studied in magnetic fields in Faraday geometry $K \parallel H \parallel [100]$.

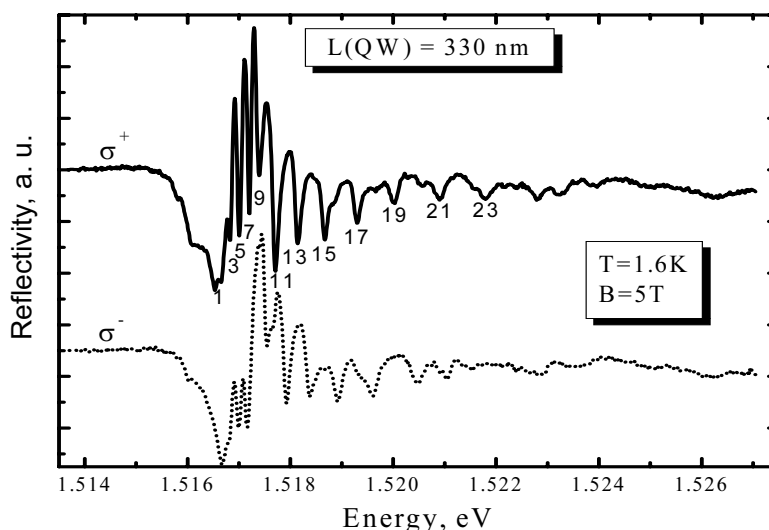


Fig. 1 Reflectivity spectra taken from a single quantum well of 330 nm width in a magnetic field of 5 T in right σ^+ and left σ^- circular polarizations at 1.6 K. The numbers indicate quantization index for the exciton in the QW.

Figure 1 shows reflectivity spectra taken from a GaAs quantum well with QW width of 330 nm in a magnetic field of 5 T in Faraday geometry in two circular polarizations σ^+ and σ^- . An interference structure located higher in energy than the exciton resonance frequency $\hbar\omega_{ex}$ is observed distinctly. The appearance of this structure is due to the size quantization of the exciton as a whole in the wide quantum well, in the conditions when the QW width ($L = 330$ nm) is much larger than the exciton Bohr radius ($a_B = 14$ nm). The numbers N indicates the quantization index for the exciton energy levels. In our samples we found up to 30 quantized levels. We observed only the interference features with even values of N because of the better overlap of the even exciton state with photon eigenmodes in these structure. The amplitude of the interference pattern decreases with increasing energy because of exciton damping due to scattering by phonons and defects.

Figure 2 shows the dependences of the Zeeman splittings on the quantization index N for the GaAs 330 nm QW. It is seen clearly that the value of the Zeeman splitting gets larger with increase of N . This means that the exciton magnetic moment or the exciton g -factor increases with increasing N . Taking into account that the quantization index N is connected with the exciton wavevector K through $KL = \pi N$, where L is the QW width, we conclude that the enhancement of the exciton magnetic moment with increase of its kinetic energy is one order of magnitude in the range of observation of the interference structure.

A similar result has been obtained for CdTe based structures grown in the [100] direction. Surprisingly, no such enhancement were observed for the [110] sample.

3 Discussion

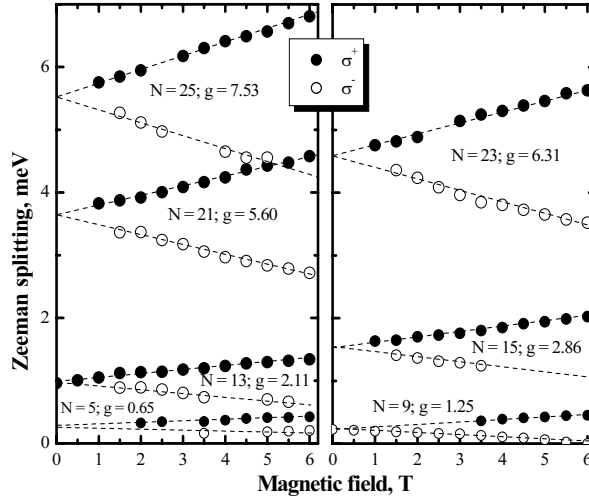


Fig. 2 The Zeeman splittings for the exciton quantized levels N in the QW as a function of magnetic fields; the effective g -values for the exciton are shown. The figure is split into two for convenience.

In Fig. 3 we have plotted the experimental g -factor dependence on the dimensionless parameter Ka_B for the GaAs and for the CdTe [100] samples. It is remarkable that there is a common dependence for both samples, which have completely different excitonic parameters.

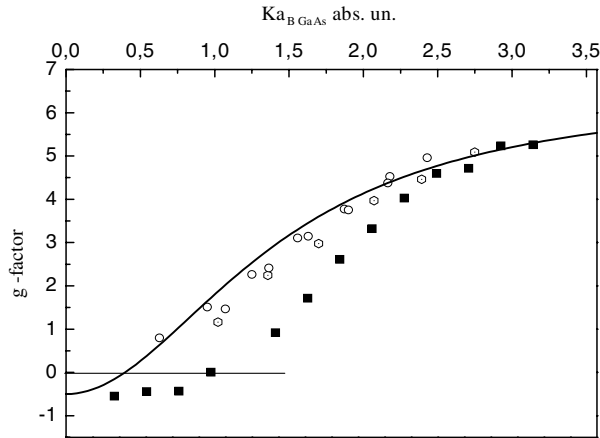


Fig. 3 Dependence of the effective exciton g -factor on the parameter (Ka_B) for GaAs and CdTe samples. Circles – CdTe data; squares – GaAs data. The solid line is from equation (1) in the text.

We have fitted the experimental data and deduced an empirical formula for the K -vector dependence of the exciton g -factor:

$$g_{eff} = g_0 + c \frac{(Ka_B)^2}{1 + \frac{1}{8}(Ka_B)^2}.$$

Here g_0 is unperturbed exciton g -factor at $K = 0$, K is the exciton wave-vector, a_B is the exciton Bohr radius, C is a constant of the order of 1.

This formula describes the observed effect for all studied QW structures with different QW widths. We relate this behaviour of the exciton g -factor to the effect of terms cubic in K in the exciton dispersion in zinc-blend type semiconductors. These cubic terms are just the terms that are responsible for the carrier spin relaxation via the D'yakonov-Perel mechanism. They have the form $\gamma_v \{a_1 \sum_i J_i^3 k_i (k_{i+1}^2 - k_{i+2}^2)\}$, leading to the splitting of heavy hole states in magnetic fields and vanish for the [110] direction.

4 Conclusion

An effect of the motional enhancement of the exciton magnetic moment has been found in GaAs and CdTe quantum well structures. The effect is explained by the contributions of terms in the exciton dispersion which are cubic in the wavevector K .

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