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DETERMINATION OF EXCITON ZEEMAN SPLITTINGS IN $Cd_{1-x}Mn_xTe$ FROM FARADAY ROTATION MEASUREMENTS

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Reflectivity and Faraday rotation measurements were carried out on $Cd_{1-x}Mn_xTe$ bulk crystals in the complete zinc-blende range of composition $0 < x \leq 0.71$. From a comparison of the results of these two experiments for samples with $x \leq 0.3$, we demonstrate that the Faraday angle Θ, measured in limited spectral range, is proportional to the energy splitting of exciton states ΔE, measured at the same temperature (2 K) and magnetic field B (up to 5 T). The determined proportionality constant was used to calculate ΔE values also for $x > 0.3$. This allowed us to find an empirical description of ΔE values for the whole range of compositions as a function of B and x.

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1. Introduction

$Cd_{1-x}Mn_xTe$ bulk crystals are among the most intensively studied diluted magnetic semiconductors (DMS). They grow in zinc-blende structure in a limited range of concentrations of Mn $0 \leq x \leq 0.72$ [1]. There is also a possibility to grow zinc-blende $Cd_{1-x}Mn_xTe$ epitaxial films in the whole range of x using the nonequilibrium molecular beam epitaxy (MBE) method. Introduction of DMS materials into low-dimensional structures made possible studying of many interesting phenomena [2], related e.g. to a variation of energies of the band edges in an external magnetic field. Recently, a magnetooptic method of interface characterization in CdTe/CdMnTe heterostructures has been worked out [3]. This method requires precise knowledge of the values of splittings of the exciton states ΔE in the barrier material (CdMnTe) in a magnetic field.

Usually ΔE values are obtained from the magnetoreflectivity spectra as the energy separation between the σ^+ and σ^- strong components of exciton. Unfortunately, uncertainties of ΔE measured in this way increase with x mainly due to a decrease in the amplitude and an increase in the width of the observed structures. In this paper we propose another way of obtaining exact values of the exciton Zeeman splitting ΔE by analyzing Faraday rotation Θ. It is known that these two magnitudes are related to each other [4]. The first part of our paper contains a test of the Faraday method for $Cd_{1-x}Mn_xTe$ crystals with $0 < x \leq 0.3$. The next step is to apply this method to samples with high concentration $0.3 < x \leq 0.71$.

2. Samples and experiments

The samples of $Cd_{1-x}Mn_xTe$ were cut from ingots grown by the modified Bridgman technique. The x values were determined from exciton energy values obtained from reflectivity spectra at $B = 0$ T and $T = 2$ K. The best reflectivity spectra were obtained on cleaved surfaces. Therefore, for many samples with high x, we first measured the reflectivity from such surfaces and next we ground and polished the sample for the Faraday experiment. These two experiments were carried out in a standard setup, in the Faraday geometry (σ^+ and σ^- circular polarizations) at temperature $T = 2$ K and in magnetic field up to $B = 5$ T.

3. Results

The values of Zeeman splittings ΔE obtained from the magnetoreflectivity measurements fit well the usual description by the modified Brillouin function

$$\Delta E(B) = A_0 B_J \left(\frac{g\mu_B JB}{k_B(T+T_0)} \right) \tag{1}$$

where k_B — Boltzmann constant, μ_B — Bohr magneton, $g = 2$, $J = 5/2$ and $B_J(x)$ is the Brillouin function. The values of phenomenological parameters T_0 and A_0 depend on the concentration of Mn.

An example of the results of the Faraday rotation experiments (for the sample with $x = 0.15$) is shown in Fig. 1. To compare directly the obtained data for various samples, the energy scale was normalized to the zero-field exciton energy E_0 determined at $T = 2$ K.

We check the proportionality of Zeeman splittings ΔE to Faraday rotation Θ by dividing each of the Faraday curves (Fig. 1a) by a corresponding ΔE value — Fig. 1b. As expected, the curves coincide provided that we are not too close to the exciton energy E_0, namely in range of E/E_0 up to 0.92. Next we choose the value of the relative energy E/E_0 for which we want to study the angle of Faraday rotation Θ as a function of the magnetic field. The best choice valid for all the concentrations was $E/E_0 = 0.82$. It is so low due to the absorption at about 2.2 eV related to the transitions within manganese ions.

The dependence of Faraday rotation Θ on magnetic field can also be described using the Brillouin function. Figure 2 presents a comparison of two saturation values obtained from the Faraday rotation (Θ_0) and the reflectivity (A_0) measurements for all studied samples. As expected, for crystals with low concentration x the ratio of these saturation values is almost constant. For higher Mn concentrations, the scatter of points is related to increasing experimental errors. In this range, the direct Faraday rotation values are more reliable.

Using the determined proportionality coefficient we obtained the values of the Zeeman splitting from the results of the Faraday rotation experiments: $\Theta \frac{1}{0.0195} = \Delta E^{\mathrm{Far}}$. We found that the modified Brillouin function describes well the obtained results, although at high x values, the parameters A_0 and T_0 are

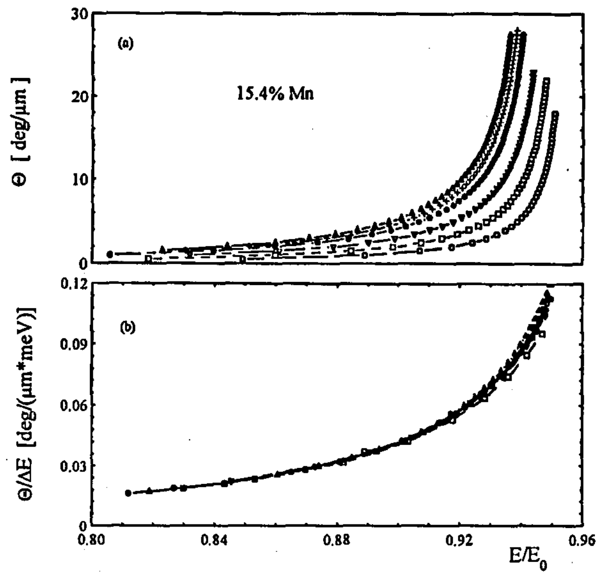

Fig. 1. Faraday rotation spectra measured for sample 15.4% Mn for different magnetic fields (0.5 T, 1 T, 1.8 T, 3 T, 4 T, 5 T): absolute (a) and divided by corresponding exciton splitting values (b).

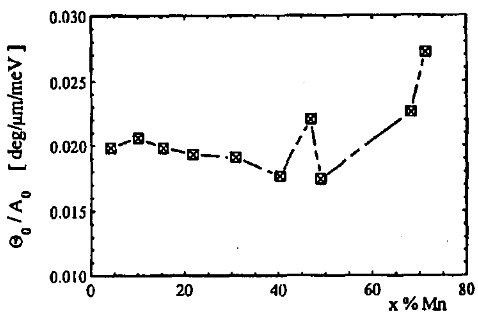

Fig. 2. Ratio of saturation values of the modified Brillouin functions corresponding to Faraday rotation Θ_0 and exciton Zeeman splitting A_0, plotted versus Mn mole fraction.

strongly correlated. To represent the dependence of these parameters on Mn mole fraction x, we propose the following empirical expressions based on best fit to our experimental data

$$A_0 = E_x \left[a \exp\left(-\frac{E_x}{b}\right) + c \exp\left(-\frac{E_x}{d}\right) + e \right], \tag{2}$$

$$T_0 = \frac{f E_x}{1 + g E_x} + h E_x^2, \tag{3}$$

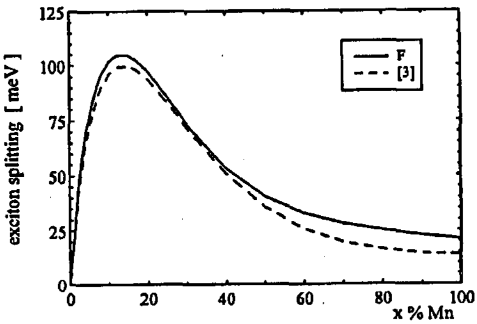

Fig. 3. The concentration dependence of the exciton splitting for $B = 5$ T and $T = 2$ K obtained from empirical equations of this work (dashed line) and of Ref. [3] (solid line).

where $E_x = E_0(\text{CdMnTe}) - E_0(\text{CdTe})$ and $a = 0.4287$, $b = 40.75$, $c = 1.363$, $d = 203.8$, $e = 0.0659$, $f = 0.05287$, $g = 0.02971$, $h = 1.421 \times 10^{-5}$. The splittings computed using Eqs. (2) and (3) are compared in Fig. 3 to the results of the previously used description [3]. We estimate that the difference between the two empirical descriptions is significant, however, knowing the approximate character of the model used in the interface characterization we do not think that the procedure used in [3] requires revision.

4. Conclusions

We performed systematic measurements of magnetoreflectivity and Faraday effect for a series of $Cd_{1-x}Mn_xTe$ crystals at the temperature $T = 2$ K. For the samples with $0 < x \leq 0.3$ the Faraday rotation Θ for energies below $0.92E_0$ was found to be proportional to the exciton Zeeman splitting ΔE. The proportionality coefficient at $E = 0.82E_0$ is equal to 1/0.0195 deg/(μm$\cdot$meV). Using this value we determined the ΔE^{Far} values from Θ in the whole range of Mn concentrations. An empirical expression describing ΔE as a function of magnetic field and composition is proposed. Our results are slightly different from those available in the literature.

Acknowledgment

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