Vol. 88 (1995) *ACTA PHYSICA POLONICA A* No. 5

Proceedings of the XXIV International School of Semiconducting Compounds, Jaszowiec 1995

s,p–d EXCHANGE CONSTANTS OF ZnFeTe DILUTED MAGNETIC SEMICONDUCTOR

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Reflectance and degree of polarization of reflectance of the free exciton in $Zn_{1-x}Fe_xTe$ ($x \approx 0.002$) was measured at $T = 1.9$ K and magnetic field up to 5 T. Combining the exciton splitting with the magnetization data we estimated the exchange constant $N_0(\alpha - \beta) = 2.1$ eV.

PACS numbers: 71.70.Gm, 78.20.Ls

The most characteristic feature of diluted magnetic semiconductors (DMS) [1] is a strong s,p–d exchange interaction between localized d electrons of transition metal magnetic ions and delocalized band electrons (of s- and p-type). This interaction results in a strong band splitting in an external magnetic field, yielding spectacular magneto-optical effects [1]. For some systems the exchange interaction can be satisfactorily described by a simple isotropic, Heisenberg-type exchange [2]. This observation is true for Mn-, Co- and Fe-based DMS. Unfortunately, the available experimental data for Fe-based materials are limited to only a few systems (ZnFeSe [3], CdFeSe [4–6] and CdFeTe [7]). Completing the data for some other systems is crucial for the analysis of chemical trends of exchange and next the understanding of the exchange nature. In this communication we report results of s,p–d exchange study for recently grown $Zn_{1-x}Fe_xTe$ ($x < 0.003$).

The $Zn_{1-x}Fe_xTe$ crystals were grown by a modified Bridgman technique. The single phase crystals were only obtained for rather low Fe content, $x < 0.003$. Attempts to grow crystals with higher concentrations resulted in the creation of Fe_yTe_z precipitates. For the present work we used a crystal with $x \approx 0.002$.

We studied the s,p–d exchange by measuring the splitting of a free exciton in a magnetic field. We recall that in the Faraday configuration 4 exciton lines are visible: 2 in σ^+ polarization (denoted as lines A and B) and 2 others in σ^- polarization (lines C and D). If an isotropic, Heisenberg-type exchange is assumed, the energies of these four lines are given by $E_A = E_0 + 3B - 3A$, $E_B = E_0 + B + 3A$, $E_C = E_0 - B - 3A$ and $E_D = E_0 - 3B + 3A$, where E_0 is the zero-field exciton energy, $A = (1/6)N_0\alpha\ x\langle S\rangle$, $B = (1/6)N_0\beta\ x\langle S\rangle$, $N_0\alpha$ and $N_0\beta$ are exchange constants for the conduction and valence bands, respectively and $\langle S\rangle$ is the mean value of the magnetic ion spin along the applied magnetic field [8]. We notice that lines A and D are approximately 3 times stronger than lines B or C. If the exchange splitting is small (which is the case for small x, or weak magnetic field or high temperature) the two lines in one polarization usually cannot be separately resolved. In such a case the observed exciton structure may by mostly ascribed to the stronger lines (A or D) [9]. The $\sigma^+ - \sigma^-$ splitting (D–A) measures the exchange constants

$$E_D - E_A = (N_0\alpha - N_0\beta)\ x\langle S\rangle. \tag{1}$$

The sign of $E_D - E_A$ is determined by the sign of $N_0\beta$, since $N_0\alpha > 0$, as resulting from a direct exchange [1, 2].

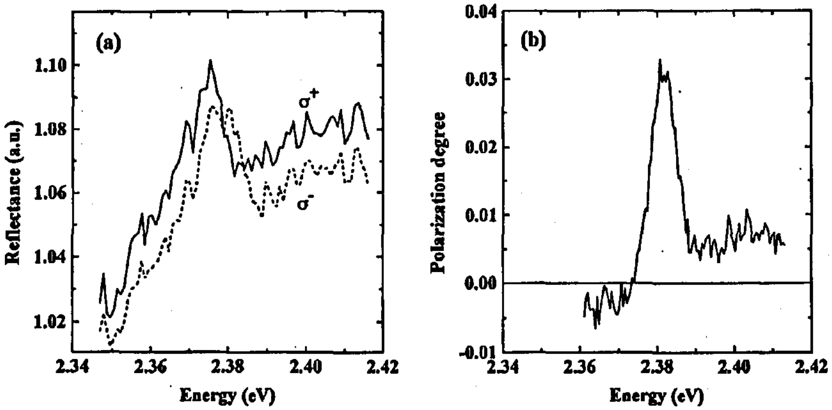

Fig. 1. Reflectance spectra of $\mathrm{Zn_{1-x}Fe_xTe}$, $x \approx 0.002$ (a) and degree of polarization of reflectance $\mathcal{P}$ (Eq. 3) (b) at $T = 1.9$ K and magnetic field $B = 5$ T.

In Fig. 1 we show reflectance spectra of ZnFeTe. Due to the small exciton splittings lines A and B (C and D) are not resolved. However, $E(\sigma^-) > E(\sigma^+)$ indicating the AF p–d exchange, similarly as for other Fe, Mn and Co-DMS [1]. Having in mind a small exciton splitting we also measured the degree of polarization of reflectance

$$\mathcal{P} = \frac{I(\sigma^-) - I(\sigma^+)}{I(\sigma^-) + I(\sigma^+)}, \tag{2}$$

where $I(\sigma^\pm)$ is the intensity of reflected light for two circular polarizations. We note that if $E(\sigma^+) < E(\sigma^-)$ then a peak in the $\mathcal{P}$ spectrum is observed, whereas for $E(\sigma^+) > E(\sigma^-)$ a dip in $\mathcal{P}$ is found. In Fig. 1b the polarization spectrum is shown. A peak at the exciton energy range is clearly visible, proving the AF splitting of the valence band.

Combining polarization and reflectance spectra one can determine the exciton splitting [10]

$$\Delta E = \frac{2\mathcal{P}(E)}{\frac{\partial}{\partial E}\ln I(E)}, \tag{3}$$

where $I(E)$ is the intensity of the reflected light ($I = (1/2)[I(\sigma^+) + I(\sigma^-)]$. This method is particularly useful in the case of small splittings, for which it is more accurate than the standard way using the separate σ^+, σ^- spectra.

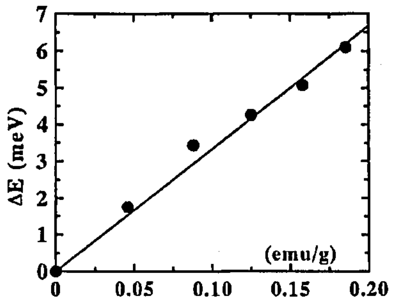

Fig. 2. Exciton splitting $E(\sigma^-) - E(\sigma^+)$ versus macroscopic magnetization of $\mathrm{Zn}_{1-x}\mathrm{Fe}_x\mathrm{Te}$, $x \approx 0.002$ at $T = 1.9$ K. The straight line corresponds to $N_0\alpha - N_0\beta = 2.1$ eV.

In Fig. 2 we display the exciton splitting $E(\sigma^-) - E(\sigma^+)$ (corrected for the splitting of pure ZnTe) as a function of magnetization measured on the same sample. The observed linear dependence is compatible with the Heisenberg form of p–d exchange interaction. Using Eq. (1) and noting that the mean spin $\langle S\rangle$ is measured by macroscopic magnetization ($M = (\mu_{\mathrm{B}}x/m)\langle L + 2S\rangle = (\mu_{\mathrm{B}}x/m)\langle S\rangle/k$, where $k = 0.447$)* we evaluated the exchange parameter $N_0\alpha - N_0\beta = 2.1$ eV. Since exciton lines A and B (C, D) are not resolved we are not able to determine $N_0\alpha$ and $N_0\beta$ separately. However having in mind that $N_0\alpha$ depends very weakly on magnetic ion or host lattice [1,3–7], we assumed $N_0\alpha \approx +0.2$ eV and then obtained the estimate for $N_0\beta = -1.9$ eV. This value matches well the reported variation of $N_0\beta$ for ZnFeSe [3], CdFeSe [4–6] and CdFeTe [7].

This work was partially supported by the State Committee for Scientific Research (Republic of Poland).

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*The detailed spin calculations similar to those presented in Refs. [3] and [4] show that $k = 0.447$.

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