Vol. 92 (1997) *ACTA PHYSICA POLONICA A* No. 4

Proceedings of the XXVI International School of Semiconducting Compounds, Jaszowiec 1997

EXCHANGE PARAMETERS OF CdCrS SEMIMAGNETIC SEMICONDUCTOR

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Free exciton magnetoreflectance and magnetization of $Cd_{1-x}Cr_xS$ ($0.0024 < x < 0.0031$) were measured at $T = 2.0$ K and magnetic field up to 5 T. Combining the heavy hole exciton splitting with the magnetization data the exchange integral $N_0\beta = +0.46 \pm 0.04$ eV was evaluated within the framework of mean field approximation.

PACS numbers: 71.70.Gm, 78.20.Ls, 78.30.Fs

The most characteristic feature of semimagnetic semiconductors (SMSC) [1] is a strong s, p–d exchange interaction between electrons localized on d-shell of paramagnetic impurity and delocalized band carriers (of s- and p-type). This interaction results in a considerable field induced band splitting, yielding the spectacular magneto-optical effects [1]. For the SMSC based on ions with no less than half filled d-shell (Mn^{++}, Fe^{++} and Co^{++}) p–d exchange interaction was found antiferromagnetic (AF). On the other hand, for the ions with less than half filled d-shell the ordering of spin-split valence band could be opposite, i.e., ferromagnetic [2]. For $Zn_{1-x}Cr_x$-based SMSC ferromagnetic (F) p–d exchange integrals ($N_0\beta$) [3–6] were found under assumption that s–d exchange integral $N_0\alpha = 0.2$ eV (available experimental results for II–VI SMSC confirm that the magnitude of $N_0\alpha$ is largely independent of the magnetic ion and host lattice). $Cd_{1-x}Cr_xS$ is the first material for which $N_0\alpha$ was obtained from Raman scattering experiment [6], which offers a chance to evaluate $N_0\beta$ directly. It is also the first hexagonal Cr-SMSC for which p–d exchange integral will be determined.

We studied exciton splittings in two crystals with chromium molar fractions: 0.0024, 0.0031 by magnetoreflectance measurements at 2.0 K with magnetic field up to 5 T in Faraday configuration (magnetic field parallel to hexagonal c-axis). In the wurtzite structure of $Cd_{1-x}Cr_xS$ light and heavy hole excitons are already split by the hexagonal crystal field. In this configuration ($H||c$) heavy hole bands do not mix with other bands allowing simple analysis as for cubic materials. The exciton splitting deduced from the reflectance spectra (see example in Fig. 1) exhibits the same ferromagnetic character (i.e. $N_0\beta > 0$) as it was found for Zn-based chromium SMSC [3–6].

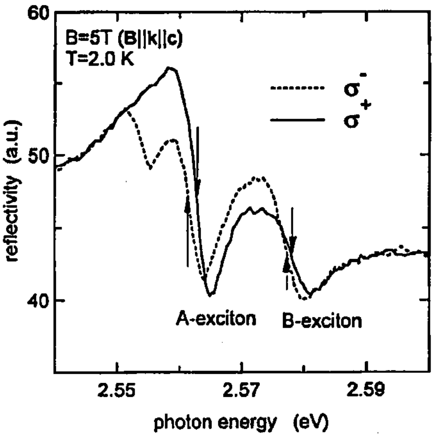

Fig. 1. The representative reflectance spectra in two circular polarizations of light: at 2.0 K and 5 T. The σ^- heavy hole exciton line (A-exciton) has lower energy than σ^+ pointing out the ferromagnetic character of p–d exchange interaction. The arrows indicate exciton energies transition energies (the structure in σ^- spectrum at 2.555 eV corresponds to the bound exciton).

We recall that within the framework of the mean field approximation (MFA) and the virtual crystal approximation (VCA) heavy hole exciton splitting ΔE_{hh} is proportional to the mean Cr^{++} spin value $x\langle -S_z\rangle$:

$$\Delta E_{\mathrm{hh}} = (N_0\alpha - N_0\beta)\chi\langle -S_z\rangle. \tag{1}$$

The magnetization of the samples measured in the SQUID magnetometer returns mean spin value according to the equation $x\langle -S_z\rangle = km\langle M\rangle/\mu_{\mathrm{B}}$, where $k = 0.523$ calculated within the crystal field model, reflects nearly spin-only magnetic moment (orbital momentum is almost quenched by the crystal field), m is the mass of $Cd_{1-x}Cr_xS$ "molecule" and $\langle M\rangle$ is the macroscopic magnetization. Therefore, the difference $(N_0\alpha - N_0\beta)$ can be determined by fitting one-parameter linear formula to the heavy hole exciton splitting versus mean spin value.

Taking into account that the reflectance data should be corrected for Zeeman splitting of heavy hole excitons of pure CdS (0.06 meV/T as measured by us) one obtains from the fitting: $N_0\alpha - N_0\beta = -0.24 \pm 0.03$ eV (see Fig. 2). Taking the value of s–d exchange integral known from spin flip Raman scattering $N_0\alpha = +0.22 \pm 0.02$ eV [7] the resulting value of p–d exchange integral is $N_0\beta = +0.46 \pm 0.04$ eV.

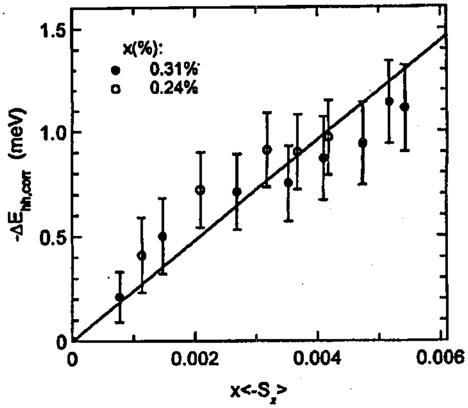

Fig. 2. Heavy hole exciton splitting for two different samples (chromium concentration x: 0.0024, 0.0031) at $T = 2.0$ K. The straight line corresponds to $N_0\alpha - N_0\beta = 0.24$ eV.

The obtained $N_0\beta$ is the lowest one from those of Cr-II–VI SMSC ($N_0\beta(\mathrm{Zn}_{1-x}\mathrm{Cr}_x\mathrm{Te}) \approx 4.25$ eV [4, 6], $N_0\beta(\mathrm{Zn}_{1-x}\mathrm{Cr}_x\mathrm{Se} \approx 0.95$ eV [3, 6], $N_0\beta(\mathrm{Zn}_{1-x}\mathrm{Cr}_x\mathrm{Se}) \approx 0.62$ eV [5, 6]), which is consistent with the valence band offsets of the host II–VI compounds.

This work was partially supported by the Committee for Scientific Research (Poland), in particular under grant No. 2 P03B 003 11.

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