PROC. 15TH INT. CONF. PHYSICS OF SEMICONDUCTORS, KYOTO, 1980
J. PHYS. SOC. JAPAN **49** (1980) SUPPL. A p. 811–814

MAGNETOOPTICS IN SEMIMAGNETIC SEMICONDUCTING $Hg_{1-k}Mn_kTe$ MIXED CRYSTALS

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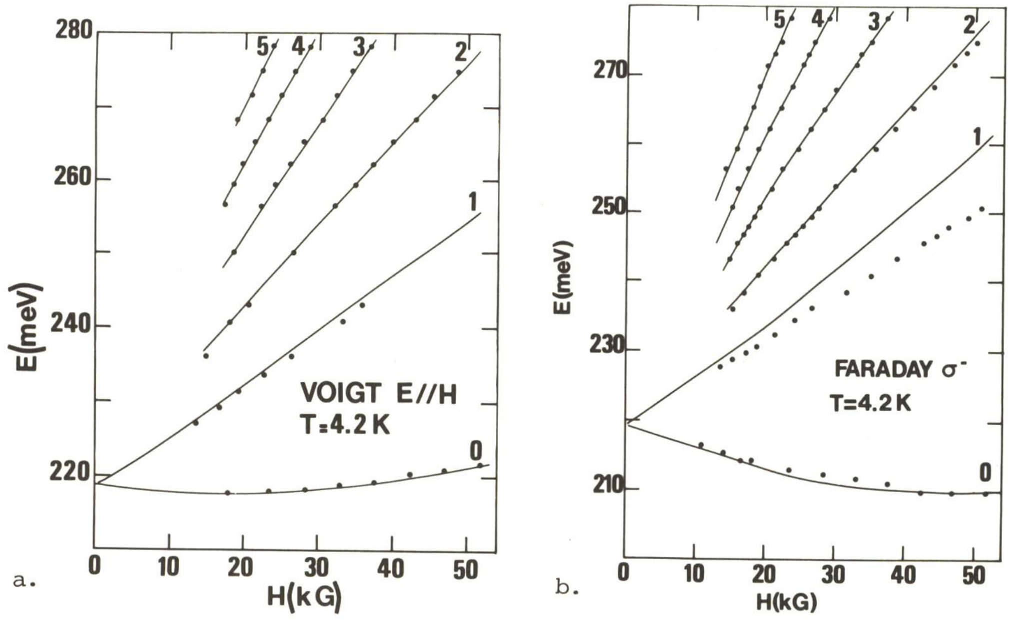
$\Gamma_8 \rightarrow \Gamma_6$ magnetooptical spectra in semiconducting $Hg_{1-k}Mn_kTe$ alloys are reported and interpreted within the "quasi Ge" model including exchange contributions. Low temperature magnetoabsorption provides evidence of an acceptor state.

Magnetooptical studies were performed on semimagnetic $Hg_{1-k}Mn_kTe$ alloys of open gap ranging from 80 to 300 meV. Magnetotransmission experiments were carried out, at T = 4.4K and 2K, on p-type samples for both linear ($\vec{\varepsilon}//\vec{H}, \vec{\varepsilon} \perp \vec{H}$) and circular radiation polarization, in the Voigt and Faraday geometries respectively. The experimental data obtained in the spectral region 100-350 meV provide observation of interband $\Gamma_8 \rightarrow \Gamma_6$ magnetooptical transitions. Moreover, transitions from acceptor states to Γ_6 Landau levels were evidenced. Far IR absorption and reflectance measurements were also carried out, using Fourier transform spectroscopy, on similar p-type samples, between 3 and 20 meV.

Interband $\Gamma_8 \rightarrow \Gamma_6$ Magnetooptical Data

Figures 1 (a,b,c,d) show the energies of the transmission minima vs the magnetic field, for ε^- and $\vec{\varepsilon}//\vec{H}$ polarization, at T = 4.2 and 2K, for an alloy of k ≃ 0.128.



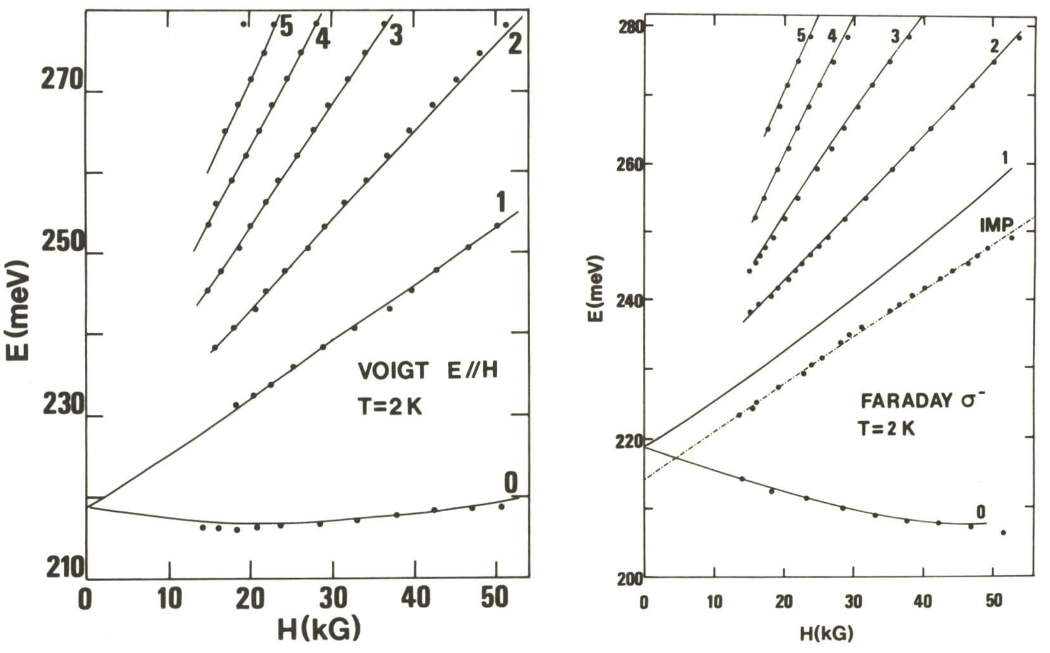


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Figure 1 Energies of the transmission minima vs magnetic field for an alloy of k ∿ 0.128. Dots : experiments. Solid lines : theoretical fits. The lines are identified according to eq. (1). n is reported on each transition.

The lines converge at vanishing field to the energy gap ε_g = 219 meV. The lowest energy transition, observed for ε^- polarization, exhibits a decreasing energy with magnetic field and this effect is more pronounced at T = 2K. In the high energy region ($\hbar\omega$ > 250 meV), the experimental lines of the ε^- and $\vec{\varepsilon}//\vec{H}$ spectra are almost coincident. For ε^+ polarization, the spectrum consists only of weak structures, in the high energy region, superimposed to a rapid increase of the transmission background.

A quantitative analysis of the magnetooptical spectra was made within the framework of the Pidgeon Brown model, modified by the inclusion of the s-d and p-d exchange contributions [1,2]. Neglecting warping and inversion asymmetry, Landau level energies and wave-functions in the Γ_6, Γ_8 (light and heavy), Γ_7 bands at $k_H = 0$ are the solutions of two 4×4 matrix Hamiltonians $\overline{D_a} = D_a + M_a$ and $\overline{D_b} = D_b + M_b$, written on the basis of the eight $u_{(J,M_J)}$ band edge Bloch functions [1-3] :

$$D = \left[\begin{array}{c|c} \overline{D_a} & 0 \\ \hline 0 & \overline{D_b} \end{array}\right] \begin{array}{l} u_1 \\ u_3 \\ u_5 \\ u_7 \\ u_2 \\ u_4 \\ u_6 \\ u_8 \end{array}$$

D_a and D_b are the Pidgeon Brown matrix Hamiltonian in the absence of exchange interactions. The exchange contributions M_a and M_b are expressed in terms of the exchange integrals $\alpha = \langle S|J(r)|S\rangle$ and $\beta = \langle X|J(r)|X\rangle$ by the following matrices :

$$M_a = \begin{bmatrix} 3Ar & & & \\ & 3A & & \\ & & -A & \\ & & & A \end{bmatrix} ; \qquad M_b = \begin{bmatrix} -3Ar & & & \\ & A & & \\ & & -3A & \\ & & & -A \end{bmatrix} ,$$

where $r = \alpha/\beta$ and $A = \beta \; N_o \frac{k}{6} < S_z > .$

N_o denotes the number of unit cells per unit volume, k is the molar fraction of Mn in the alloy and $< S_z >$ is the thermodynamical average of the localized spins along the applied magnetic field (H//z). The exchange contributions do not modify the form of the Landau level wave-functions $\psi_{a,n}$ $\psi_{b,n}$. For open gap semiconductors, the dominant $\Gamma_8 \rightarrow \Gamma_6$ magnetooptical transitions, allowed for the ε^-, ε^+, ε_z polarization, are as follows :

$$(\varepsilon^-) \; b_{\Gamma_8}(n-1) \rightarrow b_{\Gamma_6}(n) \quad ; \quad (\varepsilon^+) \; a_{\Gamma_8}(n+1) \rightarrow a_{\Gamma_6}(n)$$
$$(\varepsilon_z) \; a_{\Gamma_8}(n-1) \rightarrow b_{\Gamma_6}(n) \quad (n \geqslant 0) \qquad (1)$$

The analysis of the transition probabilities indicates that the dominant transitions originating from heavy holes should appear for ε^- and ε_z polarization. The experimental lines are identified according to (1). The comparison between theory and experiments ,at T = 4.2 and 2K, is shown on Fig.1 for the alloy of ε_g = 219 meV. The variables of the fitting procedure, performed at each field, have been restricted to $E_p = 2|\langle S|p_x|X\rangle|^2/m_o$ and the exchange parameters r,A. The Luttinger parameters and the spin orbit splitting were fixed to the values obtained for $Hg_{1-x}Cd_xTe$ [3] and zerogap $Hg_{1-k}Mn_kTe$ alloys [1] : Δ = 1eV ; γ_1 = 3 ; γ = 0,25 ; κ = - 1,65. For alloys in the composition range $0.12 \leqslant k \leqslant 0.17$, the best theoretical fits were achieved for $15.8 \leqslant E_p \leqslant 16$eV and $-0.9 \leqslant r \leqslant -0.7$. The relative magnetization A(H) deduced from the fit is shown in Figure 2 for the alloy of ε_g=219meV. A(H) exhibits a nearly linear field dependence and increases weakly between 4.2 and 2K. This behavior contrasts drastically with the results previously obtained on zerogap $Hg_{1-k}Mn_kTe$ alloys [1]: it originates from the strong antiferromagnetic interactions between localized spins. The experimental variations A(H) may be approximated by a Brillouin function corresponding to an effective temperature T + θ, where $\theta \sim$ 25K, which could explain the weak temperature dependence of the magnetization between 4.2 and 2K.

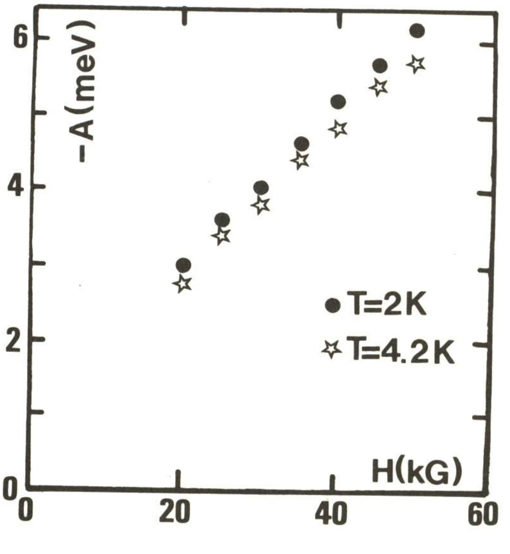

Figure 2 Relative magnetization vs magnetic field (ε_g = 219 meV)

Valence and conduction Landau levels are illustrated in Figure 3 (ε_g = 219 meV, T = 2K). The relative positions of the electronic sublevels a(n) and b(n) are inverted with respect to the usual disposition in zinc blende semiconductors. Semiconducting $Hg_{1-k}Mn_kTe$ alloys exhibit large and <u>positive</u> exchange-induced electron effective g factor.

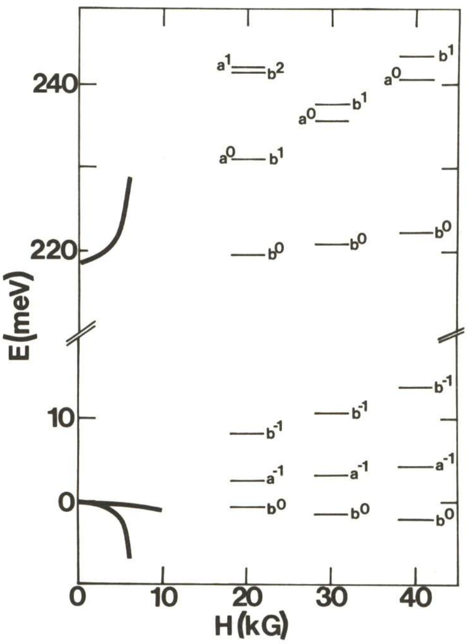

Figure 3 Scheme of the Γ_6 and Γ_8 Landau levels (T = 2K) (ε_g = 219meV)

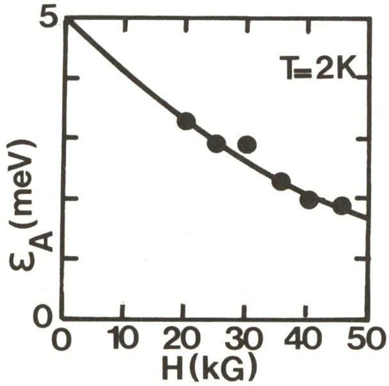

Figure 4 Position of the acceptor state vs magnetic field

In the Γ_8 band, the energy of the heavy hole Landau level b(-1) considerably increases in applied magnetic field due to the strong exchange contribution $\Delta E_{b(-1)} = -3A$. Exchange phenomena are responsable for the field decrease of $b_{\Gamma_8}(-1) \rightarrow b_{\Gamma_6}(0)$ transition energy.

Acceptor transitions

Magnetooptical spectra provide evidence of impurity transitions. For ε^- polarization, a strong absorption line (labelled Imp in Fig.1d) is systematically observed below the expected position of the interband $b_{\Gamma_8}(0) \rightarrow b_{\Gamma_6}(1)$ transition. This line cannot be attributed to an interband transition.[6] The strength and width of Imp line prevents the observation of the interband $b_{\Gamma_8}(0) \rightarrow b_{\Gamma_6}(1)$ transition. The same features were systematically observed in all investigated alloys of $0.12 \leqslant k \leqslant 0.17$. We identify "Imp" with the transition from an acceptor state to b(1) of Γ_6 band. The position of the acceptor level, at T = 2K, deduced from $b_{\Gamma_6}(1)$, is reported on Figure 4. The zero field binding energy is roughly estimated ($E_A \simeq 5 \pm 1$meV) and the field dependence implies a decrease of the absolute position of the acceptor level in applied magnetic field.

Transmission experiments were also carried out in the far IR region between 3 and 20meV. A strong absorption peak is observed, at T = 10K, near 5meV on several p-type samples of $Hg_{1-k}Mn_kTe$ alloys. The presence of this peak could be related to the existence of an acceptor transition originating from the valence band and involving the previously observed acceptor level.

Acknowledgments This work was supported by a DGRST contract. Two of us (J.K.F. and D.P.M.) gratefully acknowledge the support of the National Science Foundation through Grant DMR 77-23798.

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