PROC. 15TH INT. CONF. PHYSICS OF SEMICONDUCTORS, KYOTO, 1980
J. PHYS. SOC. JAPAN 49 (1980) SUPPL. A p. 815–818

THE RELATION BETWEEN MAGNETOOPTICAL AND MAGNETIC PROPERTIES OF $Hg_{1-x}Mn_xTe$ AND $Hg_{1-x}Mn_xSe$

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We studied interband magnetooptical transitions in $Hg_{1-x}Mn_xTe$ and $Hg_{1-x}Mn_xSe$ alloys in 10 - 60 K temperature range and compositions x up to 0.16. The results are analysed using the Pidgeon-Brown model modified to account for the exchange interaction, and the band parameters are determined. We measured also the temperature dependence of magnetic susceptibility of the same samples. In zero - gap $Hg_{1-x}Mn_xTe$ we observe an acceptor state degenerated with the conduction band.

I. Introduction

Recently it became apparent that positions of spin - sublevels in semimagnetic - semiconductors are strongly influenced by the exchange part of Coulomb interaction between band electrons and electrons of $3d^5$ - shell of Mn ions. This interaction may be represented by a Hamiltonian of Heisenberg form, $H=J\cdot\vec{s}\cdot\vec{S}$, where $\vec{S}$ is the total spin of manganese ion, $\vec{s}$ is the spin of mobile electron and J is an appropriate exchange integral [1]. According to the models developed so far [2,3,4] one can essentially reduce (in the spirit of the molecular field approximation) the Heisenberg Hamiltonian to the Ising form. The exchange interaction of this form can be incorporated as a perturbation into ordinary $\vec{k}\vec{p}$ calculations of the band structure in the magnetic field. In the framework of this model energy shifts of spin sublevels due to exchange interaction are proportional to the product of the exchange integrals and the thermal average of Mn spin component along the magnetic field $\langle S_z \rangle$ and thus macroscopic magnetization of the sample. The experiments on $Cd_{1-x}Mn_xTe$ ($0.005 \leqslant x \leqslant 0.3$) at 1.5 K have demonstrated that this proportionality is in fact observed [5]. The above model is a starting point for an interpretation of our magnetoabsorption data in $Hg_{1-x}Mn_xTe$ and $Hg_{1-x}Mn_xSe$.

II. Experimental Results and Discussion

Interband magnetotransmission was investigated in seven $Hg_{1-x}Mn_xTe$ samples ($0.001 \leqslant x \leqslant 0.16$) and three $Hg_{1-x}Mn_xSe$ samples ($0.01 \leqslant x \leqslant 0.115$) in the photon energy range 230 - 370 meV and magnetic fields up to 70 kG for several temperatures from 10 K to 60 K. The transmission measurements were carried out in the Faraday geometry with σ^- and σ^+ circularly polarized radiation and also in the Voigt configuration with linearly polarized radiation $\vec{E} \parallel \vec{H}$. The positions of transmission minima vs. magnetic field and photon energy ie. the transition energies between magnetic sublevels are determined by the following parameters of the exchange modified Pidgeon - Brown model: energy gap $E_0 = E_{\Gamma_6} - E_{\Gamma_8}$, momentum matrix

element $P = -(i\hbar/m) \langle S|p_x|X\rangle$, spin orbit splitting energy Δ, set of Luttinger parameters describing higher bands, two exchange integrals $\alpha = (1/\Omega_0)\langle S|J|S\rangle$ and $\beta = (1/\Omega_0)\langle X|J|X\rangle$ and the magnetization of the sample M.

The interpretation of the results was performed in the following way: for each temperature and composition we fitted E_0 and P. The higher band parameters and spin - orbit splitting were assumed to be temperature and composition independent and were taken as for HgTe [6] and HgSe [7]. The analysis of the terms α M and β M was done in two ways, depending on the alloy composition x. For low x values $x \leqslant 0.011$, magnetization was calculated according to the model in which isolated and interacting nearest neighbour manganese pairs are responsible for the magnetization. This model is known to give a good description of experimental values of M for the compositions temperatures and magnetic fields of interest [2].

The exchange integrals obtained in this manner are:

$Hg_{1-x}Mn_xTe$: $\alpha = -0.4$ eV $\beta = 0.6$ eV

$Hg_{1-x}Mn_xSe$: $\alpha = -0.4$ eV $\beta = 0.7$ eV

Using these parameters we were able to describe quantitatively a strong temperature dependence of transmission minima observed for $x \leqslant 0.011$.

For higher compositions $x \geqslant 0.115$ we observed a weak temperature dependence of transmission minima. Interpretation of these results assumed that the exchange integrals are composition independent and equal to those obtained for low compositions. Therefore we fitted E_0, P, and magnetization M. We obtained the following results:

Energy gap E_0. Figures (1) and (2) present variation of energy gap vs. composition for $Hg_{1-x}Mn_xTe$ and $Hg_{1-x}Mn_xSe$ respectively. Our data are compared with those obtained by other authors. All these data agrees with each other and show that semimetal - semiconductor transition occurs for $Hg_{1-x}Mn_xTe$ in 4.2 K at $x=0.075$ and for $Hg_{1-x}Mn_xSe$ in 10 K at $x=0.06$.

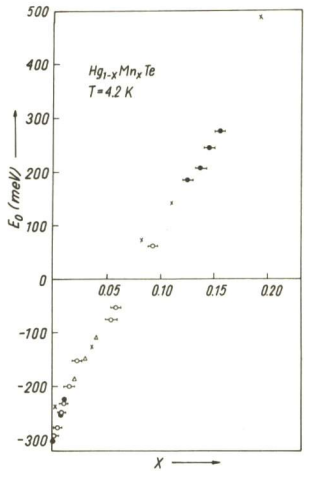

Fig.1 Energy gap E_0 versus composition in $Hg_{1-x}Mn_xTe$ alloys. Experimental points: o [3], Δ [2], x [8], • our data

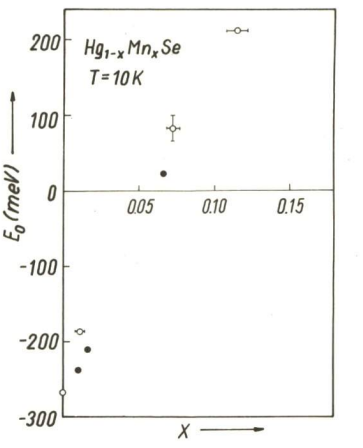

Fig.2 Energy gap E_0 versus copmosition in $Hg_{1-x}Mn_xSe$ alloys. Experimental points: •[9], o our data

We found that the dE_0/dT in the investigated range of compositions of $Hg_{1-x}Mn_xTe$ is negative and changes linearly from -5.2×10^{-4} eV/K for x=0 to -2.1×10^{-4} eV/K for x=0.16. It tends to change its sign for energy gap E_0=0.5 eV i.e. for x=0.24. Note that the change of sign of dE_0/dT occurs at similar value of E_0 as in $Hg_{1-x}Cd_xTe$ [10]. This seems to indicate that the value of E_0 is responsible for this change of sign rather than the value of the composition itself.

Momentum matrix element P. We observed in both alloys a strong linear dependence of the momentum matrix element P on the composition. We estimated $dP/dx = -7.5\times10^{-8}$ eV cm for $Hg_{1-x}Mn_xTe$ and -10.7×10^{-8} eV cm for $Hg_{1-x}Mn_xSe$. This dependence is stronger by one order of magnitude than usually observed in mixed zinc - blende semiconductors. It is worth to notice that a strong decrease of P with Mn composition has been previously reported basing on analysis of effective masses variation from Shubnikov-de Haas effect in both alloys [9,11]. At present moment we have no firm model that can explain stronger increase of the effective mass with the composition than expected from the composition dependence of E_0 only.

Magnetization M. We found that the magnetization obtained from magnetooptical measurements, up to 50 kG for all samples and up to 70 kG for majority of them is linear in the magnetic field, $M = \chi_{mo} H$. The magnetic susceptibility deduced in this way shows a very weak temperature dependence reflecting weak temperature dependence of transmission minima of the samples with $x \gtrsim 0.115$ between 10 K - 60 K.

We have measured also directly the susceptibility for samples taken from the same ingots using the mutual inductance a.c. method in 40 G at 38 Hz. Figure (3) shows that the temperature coefficient of χ is at least two times larger than that of χ_{mo} .

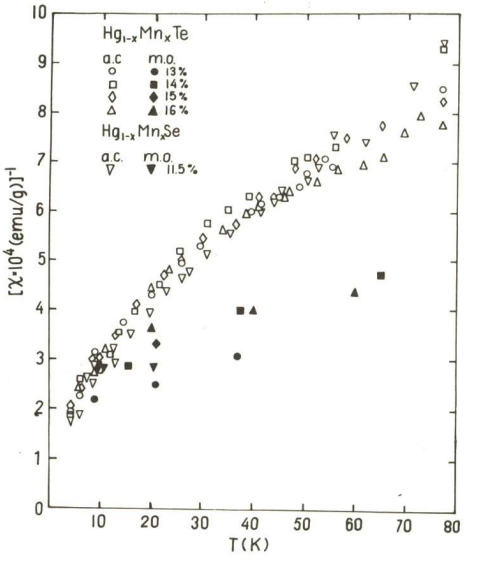

Fig.3 Temperature dependence of inverse magnetic susceptibility measured directly χ_{ac} and deduced from the interband magnetoabsorption χ_{mo}

The main objection to the above comparison is that χ_{mo} is deduced from the data obtained in 20 kG - 70 kG , whereas χ_{ac} is measured in 40 G . However, taking into consideration the ealier measurements of χ [12,13] performed in stronger magnetic fields $H \gtrsim 10$ kG ,it turns out that they are in agreement with χ_{ac} values. It can indicate either strong temperature dependence of an exchange integrals or, more probably, breakdown of a simple relation between macroscopic magnetization and exchange-induced shift of the magnetic sublevel energies.

In zero-gap $Hg_{1-x}Mn_xTe$ ($x \lesssim 0.011$) we have observed transition from Γ_6 magnetic sublevel b(0) to the acceptor level. The zero field extrapolated energy corresponds to a binding energy of 1.5 meV at H=0 and is independent of the alloy composition for $x \lesssim 0.011$. The magnetic field behaviour of the acceptor energy depends on Mn concentration x, and for constant x on the temperature. This is due to exchange induced modification of the valence band magnetic

sublevels.
Figures (4) and (5) show magnetic field dependence of acceptor energy for samples with x = 0.001 and x = 0.011 respectively. As it seems, the

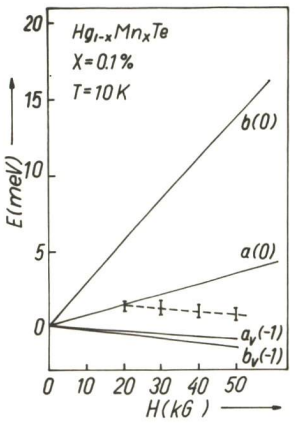

Fig.4 Acceptor energy vs magnetic field for $Hg_{1-x}Mn_xTe$ with x = 0.001

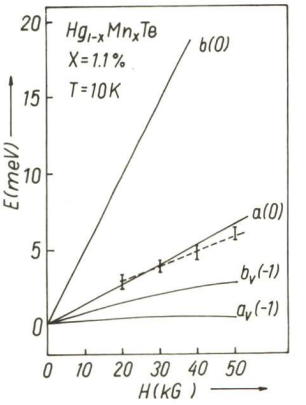

Fig.5 Acceptor energy vs magnetic field for $Hg_{1-x}Mn_xTe$ with x = 0.011

acceptor energy follows the edges of the valence band sublevels labeled b_v (-1) and a_v (-1). These two levels form in usual semiconductor the top of the valence band while in the case of $Hg_{1-x}Mn_xTe$ they are pushed into the conduction subband region.

Acknowledgements The authors are greatly indebted to Dr. A. Mycielski for valuable and helpful discussions.

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