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MAGNETOOPTICAL PROPERTIES OF $Pb_{1-x}Mn_xSe$ *p–n* JUNCTIONS

LE VAN KHOI, G. KARCZEWSKI, W. DOBROWOLSKI, J. KOSSUT AND R.R. GAŁĄZKA

Institute of Physics, Polish Academy of Sciences
Al. Lotników 32/46, 02-668 Warszawa, Poland

The first experimental evidence of the magnetic quantum oscillation in the photovoltaic effect of $Pb_{1-x}Mn_xSe$ *p–n* junctions is reported. The *p–n* junctions were obtained in $Pb_{1-x}Mn_xSe$ crystals with manganese content $0 \leq x \leq 0.08$ by introducing Cd donors by diffusion. Measurements were performed between 5–85 K and in the presence of the magnetic field 0–7 T in the Faraday and Voigt configurations of the incident infrared radiation of various photon energies in the vicinity of the energy gap of a $Pb_{1-x}Mn_xSe$. Strong oscillatory behavior of the photovoltage was observed as a function of the magnetic field intensity at a constant wavelength of the incident light. Using the model of Adler of the energy band structure modified by the exchange terms, and after identification of the initial and final states of the transitions, we derive the band parameters of the $Pb_{1-x}Mn_xSe$ crystals.

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The interband magnetooptical transitions between Landau levels in $A^4_{1-x}Mn_xB^6$ crystals have been extensively studied in recent years [1–4]. In the majority of works the classical method of recording magnetoabsorption and magnetoemission oscillations have been used. In this paper we report the observation of the oscillations of the photovoltaic effect in $Pb_{1-x}Mn_xSe$ *p–n* junctions placed in a quantizing magnetic field. Using the model of Adler of the energy band structure modified by the exchange terms, we derive the band parameters of the $Pb_{1-x}Mn_xSe$ crystals.

1. Experimental technique

The diodes were prepared from $Pb_{1-x}Mn_xSe$ single crystals grown by the Bridgman method with manganese molar fraction $0 \leq x \leq 0.08$. The as-grown *p*-type crystals with carrier concentration of the order of 1×10^{19} cm^{-3} at $T = 77$ K were cleaved along (100) surfaces and annealed by the two-zone technique in Se or Cd atmosphere to achieve a constant carrier concentration for the holes and electrons, respectively, of 3×10^{18} cm^{-3} at $T = 77$ K. The mobility of the holes and electrons in these samples reached 4×10^3 and 1.4×10^4 cm^2/Vs at $T =$ 77 K, respectively. The *p–n* junctions were prepared by diffusion of Cd into *p*-type substrates. The fabrication of the diodes has been described in detail elsewhere [5].

Optical measurements were carried out using a thermal infrared source and a SPM-2 Zeiss monochromator with NaCl and LiF prisms. The photovoltaic response was registered by the lock-in amplifier. The temperature was continuously stabilized by controlling He-flow in a continuous-flow He dewar and measured with a calibrated Au(Fe)-Chromel thermocouple soldered to the ceramic wafer supporting the diodes placed in the superconducting magnet.

The *p–n* junction was illuminated from the side of the *n*-type layer, the thickness of which is about 25–40 μm. The measurements of photovoltage in the *p–n* junction were performed in the Faraday configuration for both σ^+ and σ^- circular polarizations of the incident light (as well as for unpolarized light) and in the Voigt configuration for linear polarization. The measurements were performed at fixed photon energy by sweeping the magnetic field.

2. Results and discussion

We show in Fig. 1 the zero bias photovoltage responses of the $Pb_{1-x}Mn_xSe$ diode with $x = 0.006$ recorded at photon energy $\varepsilon = 0.188$ eV in both Faraday and Voigt configurations. It can be seen that the photovoltage strongly oscillates in the

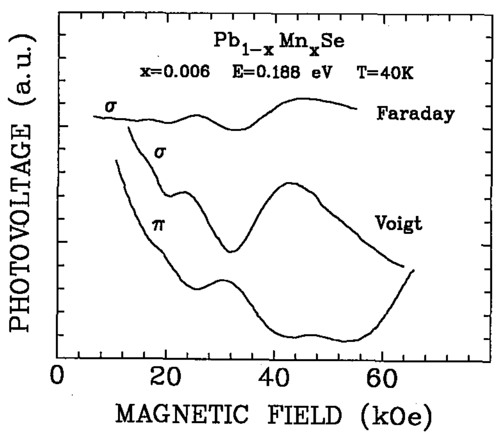

Fig. 1. Spectral responsivity vs. magnetic field for $Pb_{1-x}Mn_xSe$ *p–n* junction with $x = 0.006$ at photon energy $\varepsilon = 0.188$ eV and at $T = 40$ K for various polarizations of the incident light.

magnetic field. For investigated diodes with thick diffusion layers, the photovoltage in the p–n junction reaches its minimum (maximum of absorption) [6] when the interband magnetooptical transitions occur. As shown in Fig. 2 no difference of the minimum positions of the σ-lines in both Faraday and Voigt configurations is visible. We do not observe any splitting of the σ-line in the Voigt configuration.

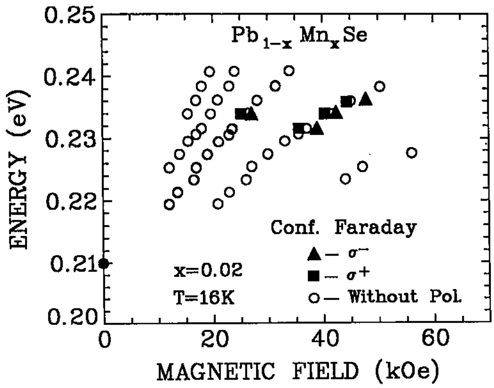

Fig. 2. Energies of the minima in the spectral response of $Pb_{1-x}Mn_xSe$ ($x = 0.02$) diodes vs.magnetic field.

The transition energies are also shown in Fig. 2 (for the $Pb_{1-x}Mn_xSe$ diodes with $x = 0.02$ at $T = 16$ K) in the Faraday configuration for σ^+ and σ^- polarized and monochromatic incident radiation. No splitting of the σ-lines is observable, and the minima for σ^+ and σ^- occur, within experimental accuracy, at the same fields. These facts indicate the absolute values of the spin splitting of the Landau levels in the valence band are equal to those in the conduction band. Basing ourselves on this fact we conclude that the absolute values of the exchange constants for both conduction band and valence band are equal.

TABLE

Band parameters of $Pb_{1-x}Mn_xSe$

x		0.00	0.006	0.02	0.06
E_g (eV), $T = 20$ K		0.150	0.168	0.210	0.290
dE_g/dT (10^{-4} eV/K)		4.6	4.25	4.0	3.1
$2P_t^2/m_0$ (eV)	$T = 5$ K	3.0±0.3	2.5±0.1	3.6±0.1	
	16 K< T < 85 K	3.0±0.3	1.9±0.1	3.0±0.1	3.0±0.1
$2P_l^2/m_0$ (eV)	$T = 5$ K	1.6±0.2	1.6±0.2	2.0±0.2	
	16 K< T < 85 K	1.6±0.2	1.1±0.2	1.8±0.2	1.8±0.2
A (eV)		0	−0.5±0.1	−0.5±0.1	−0.5±0.1
B (eV)		0	0.5±0.1	0.5±0.1	0.5±0.1

The magnitude of the spin splitting in $Pb_{1-x}Mn_xSe$ was determined from the measured splitting of the π-lines.

Using the Adler model of the energy band structure [7] modified by Kossut [8] by the exchange terms and by fitting it to experimental data we determined the band parameters of $Pb_{1-x}Mn_xSe$ crystals (see Table). A and B denote the exchange constants for the valence and conduction bands, respectively. It is to be noted that, because of the ambiguity of the identification of the magnetooptical transitions, another choice of the exchange parameters is also acceptable, namely $|A| = |B| = 0.15$ eV.

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