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INFLUENCE OF TEMPERATURE AND DEFECTS INDUCED BY GAMMA RAYS ON THE TRANSPORT PROPERTIES OF $Hg_{1-x}Mn_xSe$

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Abstract. Electrical resistivity and Hall effect measurements have been performed on $Hg_{1-x}Mn_xSe$ crystal with manganese concentration $x=0.09$ in the temperature range $19\ K \leq T \leq 44\ K$. It was established that the electrical resistivity of this semimagnetic semiconductor increases with increasing temperature. However, the resistivity exhibits a minimum about 20 K. The Hall resistivity is a linear function of applied magnetic field ($H \leq 0.7$ T) and depends on temperature mainly through the magnetic susceptibility. The conduction electron concentration, determined from the low temperature Hall data, $n = 8.7\times10^{17}$ cm^{-3}, is only slightly lower than the room temperature value, $n = 9\times10^{17} cm^{-3}$. The same crystal was exposed to ^{60}Co gamma irradiation at 300 K. A dose of 70 kGy has reduced the conduction electron concentration by about 2.6 times.

1. INTRODUCTION

The $Hg_{1-x}Mn_xSe$ mixed crystals belong to a new group of semiconducting materials - semimagnetic semiconductors (SMSCs), which have been intensively studied in the past few years. The essential difference between ordinary semiconductors and semimagnetic semiconductors is connected with the presence of exchange interaction between localised magnetic moments on magnetic ions and mobile band electrons. The specific features of SMSCs are mostly revealed when the external magnetic field is applied. In particular, band parameters including exchange parameters have been determined in $Hg_{1-x}Mn_xSe$ from the Shubnikov-de Haas effect /1/,/2/. Magnetisation measurements were also

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/1/ S.Takeyama and R.R.Galazka, Phys. Stat. Sol. (b) 96, 413 (1979).

performed in high magnetic fields /3/, and the results explained within a cluster model. From the magnetic susceptibility measurements it was concluded that above the critical concentration of manganese, $x_c > 0.16$,, the spin glass phase exists at low temperatures /4/. The critical temperature was also observed in the EPR experiment for manganese concentration higher than 0.20, below which no EPR linewidth was found /5/.

However, a little is known about the transport properties in $Hg_{1-x}Mn_xSe$ and about the temperature dependence of the band structure. For these reasons we have examined the electrical resistivity and Hall effect in $Hg_{1-x}Mn_xSe$ with x=0.09 in the temperature range $19\ K < T < 44\ K$. The effects of radiation defects introduced by ^{60}Co gamma rays at room temperature are also discussed.

2. EXPERIMENT

The sample for resistivity and Hall effect measurements, prepared at the Institute of Physics of the Polish Academy of Sciences, was cut in a rectangular form (5x2.2x0.4 mm^3). Vacuum evaporated aluminium contacts were made for the Hall and resistivity probes. An open-cycle cryogenic refrigerator was used to obtain temperatures in the measured range. The temperature was measured by an iron doped gold vs chromel thermocouple. The voltage measurements were performed by a standard dc potentiometric method. Particularly the Hall voltage was found to be very sensitive to reversal of magnetic field direction.

3. RESULTS AND DISCUSSION

The electrical resistivity of the sample $Hg_{1-x}Mn_xSe$ with x=0.09 measured as a function of temperature in the range $19\ K < T < 54\ K$ is shown in

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/2/ P.Buszewski, M.Z.Cieplak and A.Mongird Gorska, J.Phys.C: Solid St. Phys. 13 5383 (1980).

/3/ W.Dobrowolski, M. von Ortenberg, A.M.Sandauer, R.R.Galazka, A.Mycielski and R. Pauthenet, Lect. Not. Phys. 152, 302 (1982).

/4/ G.D.Khattak, C.D.Amarasekara, S.Nagata, R.R.Galazka and P.H.Kcesom, Phys. Rev. B 23, 3553 (1981).

/5/ K.Leibler, A.Sienkiewicz, K.Checinski, R.Galazka and A.Pajaczkowska, 3rd Internat.Conf.Phys. of Narrow-Gap Semicond.,Warsaw, September 1977.

Fig. 1. As can be seen, the electrical resistivity of this semimagnetic

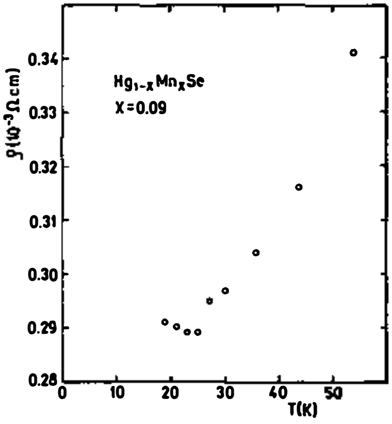

Fig. 1. Temperature dependence of the electrical resistivity of $Hg_{1-x}Mn_xSe$ with x=0.09.

semiconductor has a metal like behaviour. The increase of the electrical resistivity with temperature was also found in the same crystal of $Hg_{1-x}Mn_xSe$ at higher temperatures, 77-300 K, /6/. But, in the resistivity of this sample a minimum is observed around T=20 K. Although the amplitude of the resistivity anomaly is of the order of estimated error in measurements (~ 1%), the minimum around 20 K was detected in the two successive sets of measurements. In fact, it was established that $Hg_{1-x}Mn_xSe$ is a narrow gap semiconductor for $x > 0.06$ at liquid helium temperature with normal order of energy levels /1/, /2/. It should be mentioned also that the temperature range 19-44 K is far from any critical region and the possible transition to the spin glass state for $Hg_{1-x}Mn_xSe$ with x=0.09 /4/. We suppose that the observed minimum in the electrical resistivity around 20 K indicates the appearance of the forbidden energy gap and transition to the semiconducting state.

The Hall effect measurements were performed in the temperature range $19\ K \leq T \leq 44\ K$. The Hall resistivity is found to be a linear function of applied magnetic field (Fig.2) in accordance with the expression for the Hall resistivity in the paramagnetic region of the magnetic materials $\rho_H/H = R_0 + 4\pi X^*[R_0(1-N)+R_s]$, where H is the applied magnetic field, $X^* = X/(1+4\pi N X)$ is a magnetic susceptibility corrected for the demagnetising factor N, R_0 and R_s are the normal and anomalous Hall

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/6/ B.Stošić, M.Stojić, B.Babić Stojić and O.Žižić, Fizika 18, 65 (1986).

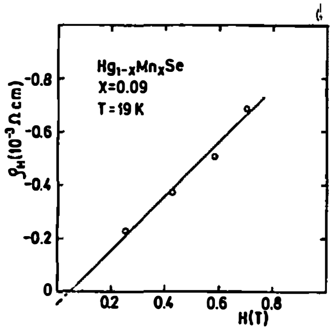

Fig.2. Hall resistivity of $Hg_{1-x}Mn_xSe$ with x=0.09 as a function of applied magnetic field at T=19 K.

coefficients. The Hall resistivity is also plotted as a function of the effective magnetic susceptibility χ^*(Fig.3.). The magnetic susceptibility data were used from the paper /4/. The effective magnetic susceptibility was then obtained by correcting the susceptibility for the demagnetising factor N=0.78, which was calculated from the geometry of the sample /6/. The Hall resistivity can be approximately described as a linear function of χ^*. It means that in measured temperature range both the Hall coefficients R_o and R_s are almost independent of temperature and that the whole temperature dependence of the Hall resistivity arises mainly from the magnetic susceptibility. In this case the Hall coefficients R_o and R_s are given by the intercept on the ordinate and

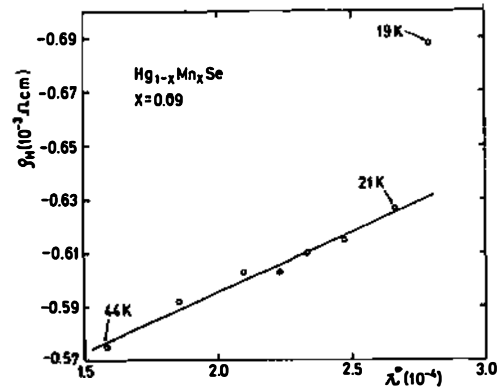

Fig.3. Hall resistivity as a function of the effective magnetic susceptibility of $Hg_{1-x}Mn_xSe$ with x=0.09.

by the slope of the line ρ_H against χ^*:

$$R_o = -7.226 \text{ cm}^3/\text{C}$$

$$R_s = -5.091\text{x}10^2 \text{ cm}^3/\text{C}$$

It appears that the conduction electron gas in $Hg_{1-x}Mn_xSe$ with the conduction electron concentrantion 10^{17} - 10^{18}cm^{-3} is highly degenerated at low temperatures. Namely, it was calculated that the Fermi energy in these crystals is $\xi \approx 0.1$ eV /1/, so at T=20 K $\eta = \xi /kT \approx 58$. In this case the conduction electron concentration can be determined from:

$$n = -1/R_oe$$

Taking the value of the normal Hall coefficient we obtain:

$$n = 8.7\text{x}10^{17}\text{cm}^{-3} \qquad 20 \text{ K} \leqslant T \leqslant 44 \text{ K}$$

As can be seen from Fig.3, the Hall resistivity rapidly increases at T=19 K, i.e. at the same place where the minimum in electrical resistivity is observed. Such behaviour of ρ_H corresponds to a rapid decrease of the conduction electron concentration.

The Hall resistivity was also measured at room temperature. In the previous paper /6/ it was concluded that at high temperatures, 77-300 K, the anomalous Hall effect in $Hg_{1-x}Mn_xSe$ is much smaller than the normal Hall effect. So, in the present work, the room temperature value of R_o in the sample $Hg_{1-x}Mn_xSe$ with x=0.09 has been found from the slope of the line ρ_H versus H, $R_o = -6.963 \text{ cm}^3/\text{C}$. The conduction electron concentration, determined from the above expression, is:

$$n = 9\text{x}10^{17}\text{cm}^{-3} \qquad T = 290 \text{ K}$$

It appears that the conduction electron concetration in the studied crystal increases only slightly with temperature from about 20 K to 290 K.

The same crystal of $Hg_{1-x}Mn_xSe$ with x=0.09 was irradiated with gamma rays of Co^{60} at room temperature. It was found that the doses up to 100 kGy affect very little the crystal lattice parameter, whereas the influence on the electrical and Hall resistivity is appreciable. A dose of 70 kGy reduces the conduction electron concentration at 290 K by about 2.6 times which is attributed to the appearance of acceptor states in the system.