PROC. 15TH INT. CONF. PHYSICS OF SEMICONDUCTORS, KYOTO, 1980
J. PHYS. SOC. JAPAN 49 (1980) SUPPL. A p. 775–778

EXPERIMENTAL EVIDENCE OF THE RESONANT ACCEPTOR LEVEL E_2 IN $Hg_{0.82}Cd_{0.18}Te$ FROM HALL AND SdH MEASUREMENTS VS T, B, P ON VARIOUS ANNEALED SAMPLES

M. Averous, J. Calas, S. Charar, C. Fau and A. Raymond
CEES (LA 21) Université des Sciences
34060 Montpellier, France

A set of transport measurements like resistivity, Hall effect and Shubnikov de Haas, has been performed as a function of : Temperature (1.8-300K), magnetic field up to 18 Tesla and hydrostatic pressure up to 6 Kbars on samples of $Hg_{1-x}Cd_xTe$ with $0.17 < x < 0.20$. The conduction band perturbation due to the E_2 acceptor level is shown. The conduction band effective mass has been determined, and the departure from the non parabolic law $m^* (E_F) = m^*_0(1 + \frac{2E_F}{E_g})$ near the E_2 level, explained. The discrepancy between the carrier concentration deduced both from the Hall and SdH measurements is removed. The SdH as a function of P shows a decrease of the Fermi energy due to the increase of the effective mass.

Non-monotonic variations in the temperature dependences of the Hall coefficients, electrical conductivity and Hall mobility of electrons in small gap material are generally attributed to the presence of acceptor levels which interact with the continuous energy of the conduction band. When the temperature increases, the Fermi level shifts upward in the conduction band ; when it coincides with an acceptor level, resonant scattering of electrons takes place and their mobility is reduced. The theoretical problem has been treated successively by Gelmont and D'Yakonov [1] , Liu and Brust [2] Mauger and Friedel, [3] , Bastard and Nozieres [4] in several ways and recently in a complete form by Joos et al. [5] . Experimentally, in HgTe three resonant acceptors have been pointed out by Finck et al [6] with the corresponding energies E_0 = 0.7meV, E_1 = 2.25meV and E_2 = 9.2meV. The two first levels were attributed to mercury vacancies by transport measurements [6] , [7] on various annealed HgTe samples, as well as by magnetoabsorption measurements. The E_2 level has not been observed in magnetooptics. Another explanation of this E_2 anomaly has been proposed [8] . It could be due to contribution from interband optical-phonon scattering which operates when the recombination energy of electron is equal to the optical phonon energy. The two models can be applied also in the case of $Hg_{1-x}Cd_xTe$ and agree rather well with the experimental results [10] , [8] . Recently Averous et al. [11] have shown the deformation of the conduction band by modulated SdH measurements as a function of magnetic field, due to this anomaly, on a lot of samples of $Hg_{1-x}Cd_xTe$ in the composition range, x = 0.17-0.20 with the Fermi level on different positions with respect to the energy of the anomaly. This deformation corresponds to a usual peak of density of state due to the increasing of the conduction band effective mass and then it seems that the assumption of a E_2 resonant acceptor level is reasonable.

Figures (1) and (2) give the resistivity and Hall constant as a function of the reciprocal temperature for the studied samples. The anomaly on the Hall constant curve corresponds to a possible level situation at 2meV under the conduction band [12] .

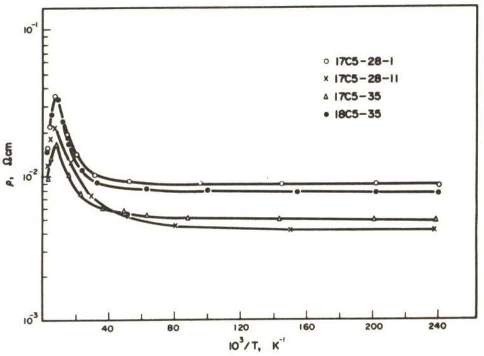

Fig.1 Resistivity of four samples vs reciprocal temperature

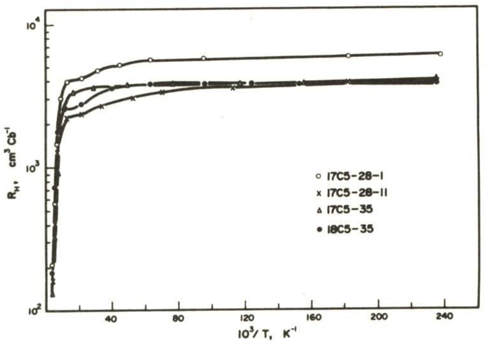

Fig.2 Hall coefficient vs reciprocal temperature

Figures (3) and (4) show the longitudinal and transverse magnetoresistance as an example.

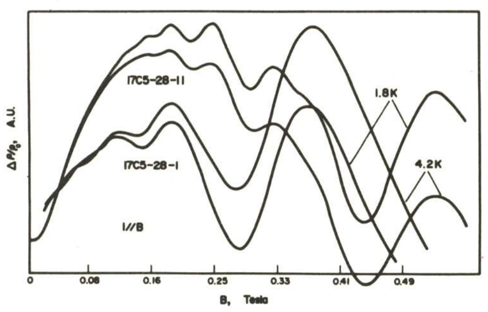

Fig.3 Longitudinal magnetoresistance of different samples at 1.8K and 4.2K

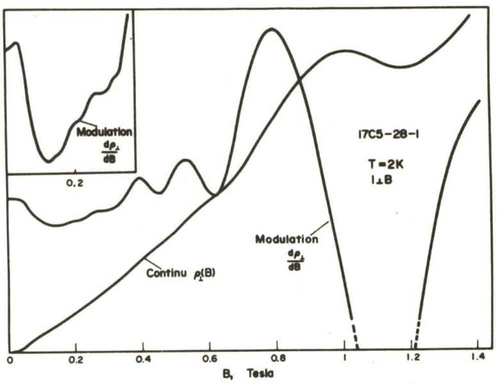

Fig.4 Transverse magnetoresistance

Figure 5 shows the electron effective mass $m^*(E_F)/m_o$ versus Fermi level at 4.2K obtained by the method described in [11]. Now we can explain the discrepancy in the determination of carrier concentration by SdH and Hall coefficient. In SdH

$$\Delta\left(\frac{1}{B}\right) = \frac{2e}{\hbar}\left(3\pi^2 n\right)^{-3/2} .$$

If the effective mass at the Fermi level coincides with the one expected for the given configuration taking into account the non parabolicity this determination makes sense and is in agreement with the carrier concentration obtained from Hall effect measurements. It is the case for the samples 17C5-35 and 19C-35-I (table 1). For the samples 17C5-28I and 17C5-28II, where the Fermi level is near the acceptor level, the effective mass is perturbed and so is the carrier concentration, (table 1). But if one takes the non-perturbated effective mass and the Fermi energy determined by SdH for these samples one obtains $n_{4.2} \simeq 1.2\ 10^{15}$ cm^{-3} and by Hall coefficient, $n = 1.4\ 10^{15}$cm^{-3} and the results now agree well.

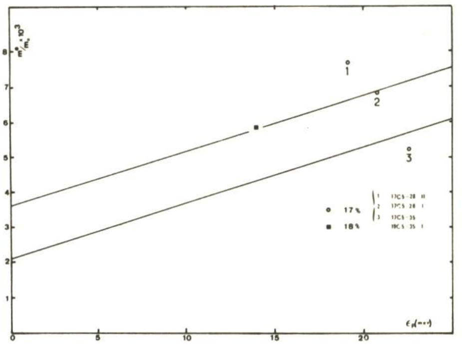

Fig.5 Electron effective mass $m^*(E_F)/m_0$ vs Fermi level; Straight lines are $m^*(E_F)=m_0(1+\frac{2E_F}{E_G})$ for x = 0.17 and 0.18.

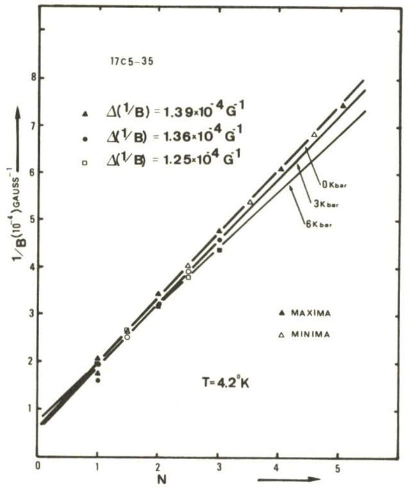

Fig.6 SdH oscillation periodicity as a function of the pressure

Samples	x(%)	ϵ_g(meV) à 4.2k	$\Delta(1/B)_{T^{-1}}$	n(Cm^{-3}) S.d.H.	$m^*(\epsilon_f)/m_0$	m^*/m_0	ϵ_F(meV)	n(Cm^{-3}) $_{R_h}$	|θ|
17C5-28-I	17	26±3	1.33	3.7×10^{15}	6.8×10^{-3}	2.1×10^{-3}	20.7	1.17×10^{15}	–
17C5-28-II	17	-	1.24	4.1×10^{15}	7.7×10^{-3}	-	19	1.6×10^{15}	–
17C5-35	17	-	1.39	3.5×10^{15}	5.3×10^{-3}	-	22.5	2×10^{15}	148
19C5-35-I	18	44±3	1.41	3.4×10^{15}	5.8×10^{-3}	3.6×10^{-3}	17.5	1.4×10^{15}	–
26C7-28-II	20	64±3	1.47	3.2×10^{15}	5×10^{-3}	6.6×10^{-3}	21	2×10^{15}	–

Table 1.

Fig.7 Longitudinal magnetoresistance vs magnetic field for 1 Bar and 6 KBar ⟶

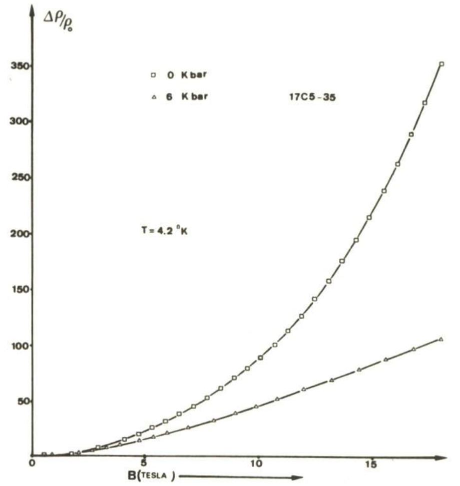

Figure 6 shows the evolution of the SdH oscillation as a function of the hydrostatic pressure at 4.2K. A change in the periodicity of the oscillations could be observed. If we take a pressure coefficient of 9meV/Kbar [13] , [14] for two different pressures P_1 and P_2, then

$$m^*_{d1} = m^*_{01}\,(1+\frac{E_{F1}}{Eg_1}) \text{ and } m^*_{d2} = m^*_{02}(1+\frac{E_{F2}}{Eg_2}) \quad \text{with} \qquad (1)$$

$$\frac{m^*_{01}}{m_0} = \frac{3}{2}\,\frac{Eg_1}{E_p}\,, \text{ and } \frac{m^*_{02}}{m_0} = \frac{3}{2}\,\frac{Eg_2}{E_p}\,. \qquad (2)$$

E_p is the Kane matrix element, m_0 the effective mass at the bottom of the conduction band. The oscillation periodicity could be written :

$$[\Delta(\frac{1}{B})]_1 = \frac{e\hbar}{m^*_{d1}E_{F1}} \quad \text{and} \quad [\Delta(\frac{1}{B})]_2 = \frac{e\hbar}{m^*_{d2}E_{F2}} \qquad (3)$$

Equation (3) becomes from equation (1)

$$\left.\begin{aligned}\left[\Delta\left(\tfrac{1}{B}\right)\right]_1 m_{d1}^{*2} - \alpha Eg_1\left[\Delta\left(\tfrac{1}{B}\right)\right]_1 m_{d1}^{*} - \alpha e\hbar = 0\\ \left[\Delta\left(\tfrac{1}{B}\right)\right]_2 m_{d2}^{*2} - \alpha Eg_2\left[\Delta\left(\tfrac{1}{B}\right)\right]_2 m_{d2}^{*} - \alpha e\hbar = 0\end{aligned}\right\} \text{ with } \alpha = \frac{3}{2}\frac{m_o}{E_p} .$$

One obtains for m_{d1}^* and m_{d2}^*

$$\left.\begin{aligned}m_{d1}^* = \frac{\alpha}{2} Eg_1 \pm \frac{1}{2}\left\{\left[\alpha Eg_1\right]^2 + \frac{4\alpha e\hbar}{\left[\Delta\left(\frac{1}{B}\right)\right]_1}\right\}^{1/2}\\ m_{d2}^* = \frac{\alpha}{2} Eg_2 \pm \frac{1}{2}\left\{\left[\alpha Eg_2\right]^2 + \frac{4\alpha e\hbar}{\left[\Delta\left(\frac{1}{B}\right)\right]_2}\right\}^{1/2}\end{aligned}\right\} \text{ with } E_p = 18.5\text{eV}.$$

TABLE II

P(Kbar)	$\Delta(1/B)_{T^{-1}}$	n(cm^{-3})	E_g meV	m_d^*/m_o	$E_F$meV
0	1.39	3.45×10^{15}	26	3.8×10^{-3}	21.6
3	1.36	3.58×10^{15}	53	5.5×10^{-3}	15.4
6	1.25	4.06×10^{15}	80	7.5×10^{-3}	12.4

The results are summarized in table II.

The analysis of these results shows that the Fermi level decreases linearly when an hydrostatic pressure is applied. This decreasing is due to the increasing of the effective mass. A weak increasing of the carrier concentration is seen since the oscillation periodicity decrease weakly.

Figure 7 shows the longitudinal magnetoresistance versus magnetic field for 1 bar and 6 Kbar. The change is due to a mobility effect (small change in carrier concentration). No freeze out has been observed at 18 Tesla and 6 Kbar. This is probably due to the presence of donor levels in the band.

By a set of transport measurements like resistivity, Hall effect and SdH versus T,B and P on $Hg_{1-x}Cd_xTe$ samples (x is the range 0.17-0.20) it has been shown that the E_2 anomaly is probably due to a resonant acceptor level. The conduction band perturbation, when E_F lies at the E_2 energy explains the discrepancy between carrier concentration obtained by Hall measurements and SdH ones . The change of the SdH oscillation periodicity under hydrostatic pressure is mainly due to an effective mass effect.

1) B.L. Gelmont and M.I. D'Yakonov: Sov. Phys. JETP21, (1972), 713.
2) L. Liu and D. Brust: Phys. Rev. 157, (1967), 627
3) A. Mauger and J. Friedel: Phys. Rev. B12, (1975), 2412
4) G. Bastard and P. Nozieres: Phys. Rev. B13, (1976), 2460
5) B. Joos, A.K. Das and P.R. Wallace: Phys. Rev. B18, (1978), 5693
6) C. Finck, S.Otmezguine, G. Weill and C. Verie: Proc. XIth Conf. on Phys. of Semi-cond. Warsaw, Poland 2, (1972), 944
7) C. Fau, J. Calas, M. Averous and B.A. Lombos: Proc. 3rd Int. Conf. of Small Gap, Warsaw, (1977), Poland.
8) W. Walukiewicz: J. Phys. C9 (1976), 1945.
9) L. Liu and C. Verie: Phys. Rev. Lett. 37, (1976), 453.
10) M. Avérous, J. Calas, S. Charar and C. Fau: Sol. state Com. 34, (1980),639
11) S. Charar: Thèse de Spécialité, Montpellier, France, Juillet 1979.
12) C. Weill, S. Otmezguine and C. Verie: Meeting of the European High Pressure Research Group, UMEA, Sweden (1971).
13) S. Otmezguine, F. Raymond, G. Weill and C. Verie: Phys. Semicond. S.P. Keller, J.C. Hensel and F. Stern eds. (USAEC) (1970).