and shows only a small magnetic field dependence. At low pressures and zero magnetic field the conductivity is much higher because of the electronic contribution. With applied magnetic field, oscillatory behavior is first observed as the Landau levels pass through the Fermi energy. The rapid fall in conductivity at higher fields (over more than three orders of magnitude for sample 7B) we attribute to the fall in electron concentration and electron mobility as the last Landau level approaches and passes through the Fermi energy. Kubo, Miyake, and Hashitsume[35] have obtained expressions for the transport coefficients in the quantum limit. The following expression for the longitudinal magnetoconductivity, for the case of the Fermi energy independent of magnetic field, is derived from Eqs. 13–34 of Ref. 35 using Eqs. 8-14 and 12-7 of the same reference (the expression is valid for parabolic bands, and we neglect collision broadening):

$$\sigma_{zz}^{e}=\frac{2e^2\hbar}{\pi W m^*}\left(\phi-\tfrac{1}{2}\hbar\omega\right) \quad , \qquad (7)$$

where ϕ is the Fermi energy measured from the conduction-band edge and ω is the cyclotron frequency eB/m^*c. W is a constant defined as $W = n_s[(2\pi\hbar^2/m^*)f\,]^2$, where n_s is the number of scattering centers and f is the scattering amplitude.

We assume that the spin splitting can be included by rewriting Eq. (7) as

$$\sigma_{zz}^{e}=\frac{2e^2\hbar}{\pi W m^*}\left[\phi-\tfrac{1}{2}\hbar\omega(1-\delta)\right] \quad , \qquad (8)$$

where δ is the ratio of the spin splitting to the Landau-level separation.

This equation may be used to describe approximately the linear part of the falling conductivity plots in Fig. 9, but will fail at higher magnetic fields because of the neglect of nonparabolicity and collision broadening. If δ is known as a function of pressure or energy gap, the Fermi energy could be determined as a function of pressure by extrapolating the linear region of the plots to the field B_0 at which $\sigma_{zz}^{e}=0$, since $\phi=(\hbar eB_0/2m^*c)(1-\delta)$. Approximate values for ϕ at zero pressure have been obtained by taking $\delta=0.6$ from the data of Groves, Harman, and Pidgeon,[5] for a sample with $x=0.16$, and taking m^* as the band-edge effective mass, which is given by $m^*\simeq 3\hbar^2E_g/4P_K^2$.[1] Using the empirical relation[8] for E_g, the values for ϕ in samples 7B, 7B1, and 8B are, respectively, 9, 16, and 18 meV, which are consistent with values of E_F obtained above.

A similar magnetoresistance effect has been reported for BiSb alloys,[36] but in that case the electronic δ is greater than 1 and a semiconductor-to-semimetal transition is induced by a magnetic field.

The non-Ohmic effects (shown in Fig. 10) are similar to effects reported for n-type InSb, in which the carriers are "frozen out" onto donor impurities by the application of magnetic field.[37,38] We speculate that in our case the non-Ohmic effects involve the impact ionization of electrons from the acceptor level to the lowest-conduction-band Landau level.

The band-gap deformation potential D_G is related to the pressure coefficient by $D_G=\beta^{-1}dE_g/dP$, where β is the compressibility, $\beta=3/(c_{11}+2c_{12})$. Taking the value for dE_g/dP at 77 °K of 7×10^{-6} eV/bar, and values for the elastic constants interpolated between those for HgTe[39] and CdTe,[39] a value of 3.3 eV is obtained for the deformation potential.

SUMMARY

The dependence of the carrier concentration on pressure at 77 and 4.2 °K has been measured for p-type samples of $Hg_{1-x}Cd_xTe$ with x close to 0.14.

The results obtained at 77 °K for an annealed sample with low hole concentration can be described satisfactorily by the band model for the material and $\vec{k}\cdot\vec{p}$ theory. As-grown samples with high hole densities yielded values of np, too high to account for in this way, both at 77 and 4.2 °K. Analysis of the electron concentration as a function of pressure indicates that the Fermi-level position at 4.2 °K is situated at 20 and 16 meV above the valence band in the two as-grown samples, and 9 meV above the valence band in the annealed sample. In all cases, its position is independent of pressure. A model is proposed which required an acceptor level 9 meV above the valence-band edge in the annealed sample, with the Fermi level pinned by compensating donors. In the as-grown samples a band of levels at approximately 20 meV above the valence band is proposed, "metallic"-type impurity-band conduction taking place within this band.

A sharp transition is observed in the pressure dependence of both R and σ, which, according to our model, occurs at the pressure at which the conduction band passes through the acceptor level.

Magnetic freeze-out effects have been observed and attributed to the lowest-energy, spin-split, zero-order Landau level passing through the Fermi energy. Approximate values obtained for the Fermi energy agree with those given above.

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APPENDIX: METHOD OF OBTAINING CARRIER DENSITIES AND MOBILITIES

Assuming a value of unity for the Hall scattering factor, the low-field Hall coefficient can be expressed as[26]

$$R(0) = -\frac{1}{e}\frac{nb^2 - p}{(nb+p)^2} \quad , \tag{A1}$$

where n and p are the electron and hole concentrations, respectively, and b is the electron-to-hole mobility ratio. Since b is greater than 100, $nb^2 \gg p$ for very low values of n/p and

$$R(0) \simeq -\frac{1}{e}\frac{nb^2}{(nb+p)^2} \quad . \tag{A2}$$

Expressing $R(0)$ in terms of the electron and hole contributions to the conductivity and rearranging gives

$$n = -\frac{1}{R(0)e}\left(1 + \frac{\sigma_p(0)}{\sigma_n(0)}\right)^{-2} \quad . \tag{A3}$$

The electron mobility can be expressed as

$$\mu_n = R(0)\,\sigma(0)\left(1 + \frac{\sigma_p(0)}{\sigma_n(0)}\right) \quad . \tag{A4}$$

The conductivity, in a magnetic field, can be expressed as

$$\sigma(B) = \frac{\sigma_n(B)\,\sigma_p(B)[R_n(B) + R_p(B)]^2}{\sigma_n(B)R_n(B)^2 + \sigma_p(B)R_p(B)^2} \quad , \tag{A5}$$

where $R_n(B)$ and $R_p(B)$ are the Hall coefficients which would be obtained if only the electrons or only the holes were present, and similarly $\sigma_n(B)$ and $\sigma_p(B)$ are the hole and electron transverse magnetoconductivities.

Because of the high values of b in $Hg_{1-x}Cd_xTe$, a range of fields exists for which $\mu B \gg 1$ and $\mu_p B \ll 1$. In this range, we can replace the coefficients for electrons in Eq. (A-5) by their saturation values and the coefficients for holes by their low-field values. Then

$$\sigma(B) = \frac{\sigma_n(\infty)\sigma_p(0)[R_n(\infty) + R_p(0)]^2}{\sigma_n(\infty)R_n(\infty)^2 + \sigma_p(0)R_p(0)^2} \simeq \sigma_p(0) \quad . \tag{A6}$$

The approximation is valid for our samples where $n \ll p$ and $b \gg 1$. Thus, $\sigma_p(0)$ can be obtained from the "saturation" value of $\sigma(B)$ (see Fig. 4). $\sigma_n(0)$ can be obtained from the conductivity in zero field, since

$$\sigma_n(0) = \sigma(0) - \sigma_p(0) \quad . \tag{A7}$$

Having determined $\sigma_p(0)$ and $\sigma_n(0)$, n may be obtained from Eq. (A3) and μ_n from Eq. (A4). When $\sigma_n(0) \gg \sigma_p(0)$, the method reduces to obtaining n directly as $1/R(0)e$ and μ_n as $R(0)\sigma(0)$. When $\sigma_n(0) \ll \sigma_p(0)$, the determination of n and μ_n becomes inaccurate.

p is obtained from the high-field Hall coefficient, since

$$p = 1/R(\infty)e + n \quad . \tag{A8}$$

For $n \ll p$

$$p \simeq 1/R(\infty)e \quad . \tag{A9}$$

The hole mobility μ_p is determined from

$$\mu_p = \sigma_p(0)/pe \quad . \tag{A10}$$

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