Magnetic-field-induced metal–insulator transition in n-$Hg_{0.8}Cd_{0.2}Te$

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In magnetic fields higher than the threshold field H_0^{xy} a metal-insulator transition is found to occur in strongly doped, compensated semiconductors n-$Hg_{0.8}Cd_{0.2}Te$. The dependence of H_0^{xy} on the electron density is discussed.

Several papers in which the particular features of the kinetic coefficients of n-$Hg_{0.8}Cd_{0.2}Te$ at low temperatures $0.01 \leqslant T \leqslant 30$ K are interpreted as evidence of the Wigner crystallization have recently been published (see, e.g., Refs. 1–3). Elsewhere[4,5] these characteristic features are explained by the localization of electrons in fluctuational wells of the potential relief formed by randomly distributed impurities. After studying certain transport phenomena in $Hg_{0.8}Cd_{0.2}Te$ crystals with a compensation factor $K = 0.4 - 0.5$, Gebhardt *et al.*[1] concluded that the electron density n is constant but the electron mobility in strong magnetic fields increases exponentially with increasing temperature. This conclusion is consistent with the qualitative proposition of a flow of viscous fluid of correlated electrons.[6] Rosenbaum *et al.*[2] attributed the sharp increase in the Hall resistance $\rho_{xy}(H)$ of n-$Hg_{0.8}Cd_{0.2}Te$ samples with $K = 0.4 - 0.6$

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in magnetic fields H above a certain threshold field H_0^{xy} to the Wigner crystallization. In another study[3] the authors asserted that the Mott transition is responsible for the increase in $\rho_{xy}(H)$. In fields $H<H_0^{xy}$, a small dip on the $\rho_{xy}(H)$ curves can be explained on the basis of the viscous-fluid model.[6]

Interpretation of the experimental data in Refs. 1–3 raises some serious objections which we will discuss in another paper. Here we note, however, that at $K=0.4-0.6$ the fluctuating impurity electric field destroys the electronic ordering.

We studied the behavior of the Hall coefficient $R(H)$ and of the longitudinal magnetoresistance $\rho_{zz}(H)$ and transverse magnetoresistance $\rho_{xx}(H)$ over the temperature interval $1.7\leqslant T\leqslant 300$ K in strongly doped ($N_D a_B^3 \sim 10$, where N_D is the donor density, and a_B is the Bohr radius) and strongly compensated ($0.6\leqslant K\leqslant 0.8$) $\mathrm{Hg_{0.8}Cd_{0.2}Te}$ semiconductors with $1.1\times 10^{14}\leqslant n\leqslant 1.2\times 10^{15}$ cm^{-3}. The degree of compensation (K) of the samples was estimated from the electron mobility. In quantizing magnetic fields the following features of the kinetic coefficients can be observed. 1) With increasing magnetic field and temperature, the change in ρ_{zz} and ρ_{xx} is much more pronounced than that predicted by the theory for scattering by impurity ions. Here $\rho_{zz}(H)$ and $\rho_{xx}(H)$ increase in essentially the same manner. 2) At temperatures $1.7\leqslant T\leqslant 30$ K, $|R(H)|$ decreases in fields $H>H_0^{xy}$, and the slope at which the curve falls off increases with decreasing temperature.

A decrease in $|R(H)|$ occurs typically when there is an appreciable difference in the mobilities of the charge carriers in the conductivity, $\mu_1\gg\mu_2$. Analysis of the $R(H)$ and $\rho_{xx}(H)$ curves carried out on the basis of a two-band model shows that in magnetic fields the density of light electrons, n_1, decreases and the density of heavy electrons, n_2, increases (the sum n_1+n_2 remains constant). The decrease in $n_1(H)$ resembles the cold-trapping of electrons into the ionized donors. However, an estimate of the threshold field of the Mott transition, H_M, with the help of the relation $2\lambda^2 a_B N_D/\ln(a_B/\lambda)\simeq(0.25)^3$ [$\lambda=(c\hbar/eH)^{1/2}$ is the magnetic length] for the samples with $N_D=4.8\times 10^{14}$–3.1×10^{15} cm^{-3} gives $H_M=60$–130 kOe, which is greater than the experimental values of H_0^{xy} by two orders of magnitude.

The $R(H)$ and $n_1(H)$ dependences can be accounted for well by the theory of electron localization in strongly doped and strongly compensated semiconductors.[7] In strong magnetic fields ($\hbar\omega_c\gg\epsilon_F$) the Fermi level falls below the percolation level ϵ_p and the electrons are trapped in the fluctuation wells: a metal-insulator transition occurs. The critical localization field H_0 is given by the relation $\epsilon_F(H)=\epsilon_p(H)$.

In magnetic fields $H\gg H_0^{xy}$ the screening length for our samples is several factors smaller than the electron wavelength and, according to Ref. 7, for a nonlinear screening we have

$$H_0 \simeq \frac{9\pi^2}{2}\frac{c\hbar}{e}a_B n\frac{1-K}{1+K} \quad (1)$$

Expression (1) differs from the expression in Ref. 7 in that it contains the coefficient $9\pi^2/2$.

The values of H_0^{xy} determined experimentally and the values of H_0 calculated according to (1) for the $\mathrm{Hg_{1-x}Cd_xTe}$ samples with $0.19\leqslant x\leqslant 0.22$

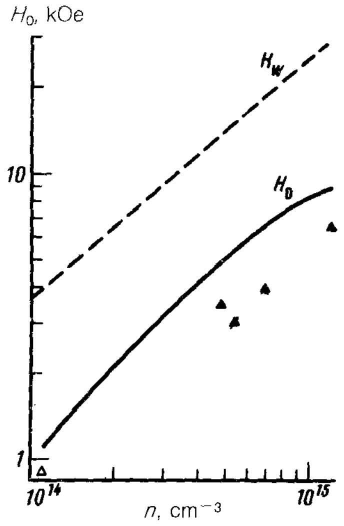

FIG. 1. The critical field H_0^{xy}(▲) versus the electron density.

($1.2\times10^{-5}\leqslant a_B\leqslant2.6\times10^{-5}$ cm) and $K=0.6$–0.8 are plotted as functions of n in Fig. 1. The experimental data are in satisfactory agreement with the results of calculations. The n dependence of the Wigner-transition field H_W, calculated for $T=0$ according to the equations in Ref. 8, is shown, for comparison, in Fig. 1. We see that the fields H_W are several times higher than the experimental values of H_0^{xy}. According to the calculations of Ref. 9, the electronic ordering of the n-$\mathrm{Hg_{0.8}Cd_{0.2}Te}$ crystals with $10^{14}\leqslant n\leqslant10^{15}$ cm^{-3} should set in at $T<1$ K and $H\sim10^4$ Oe, an additional evidence which contradicts the conclusion of Gebhardt *et al.*[1] that electronic crystallization occurs at $T>1.5$ K.

Since the samples which we studied differ slightly in Cd content and the degree of compensation, we have constructed the n dependences of the reduced threshold fields

$$H_0^{xy}\frac{a_B(x=0.2)}{a_B(x)}\,\frac{1+K}{1-K}$$

and

$$H_{\text{ot}}=H_0\frac{a_B(x=0.2)}{a_B(x)}\,\frac{1+K}{1-K}$$

(Fig. 2). The dependence $H_{\text{ot}}^{xy}(n)$ is nearly linear, in complete agreement with the theoretical predictions of Ref. 7 for strongly doped and strongly compensated semiconductors.

There are also other data which are at variance with the explanation of the features of the $\rho_{zz}(H,T)$ $\rho_{xx}(H,T)$, and $R(H,T)$ curves in terms of the electronic crystallization. For exmaple, analysis of the $n_1(H)$ and $R(H)$ shows that at $H>H_0^{xy}$ the density $n_1(T)$ increases. Consequently, the light electrons are electrons that are activated above the ϵ_p level. Another point is worth noting: Even in a narrow tempera-

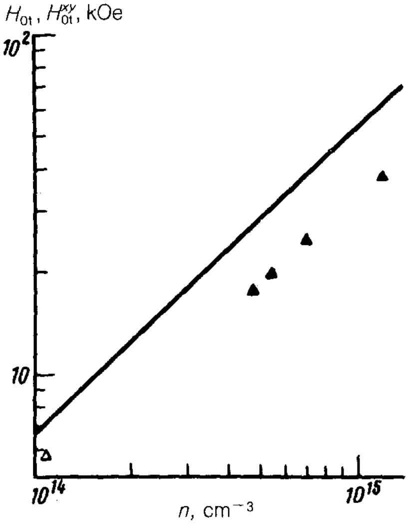

FIG. 2. The critical fields H_{0t}^{xy}(▲) and H_{0t} (solid line) versus the electron density.

ture interval $1.7 \leqslant T \leqslant 10$ K, $\rho_{zz}(T^{-1})$ cannot be described by a single exponential function which is required by the viscous-fluid theory. This experimental result is characteristic of a situation in which the conductivity involves both the delocalized electrons from the conduction band and the strongly scattered electrons of the impurity states for which[10] $(\hbar/\tau) \gtrsim \epsilon_F$ (τ is the relaxation time).

In summary, all the particular features of the kinetic effects for n-$Hg_{0.8}Cd_{0.2}Te$ which we observed can be accounted for by the magnetic-field-induced electron localization in the fluctuation wells of the potential relief.

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