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EXPERIMENTS CONCERNING THE MAGNETIC FIELD INDUCED WIGNER CONDENSATION

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Searching for the recently predicted magnetic field induced Wigner condensation a magneto-transport anomaly was discovered in different narrow-gap semiconductors. The anomaly bears all the features expected for an electron condensation. However, as standard magnetotransport experiments do not allow a final interpretation two crucial experiments are proposed.

Recently the magnetic field induced Wigner condensation was investigated by various authors [1-5]. One can conclude from all these different theoretical investigations [6], that a condensation of carriers in a semiconductor is expected to take place at temperatures of the order of 1K in the extreme magnetic quantum limit if the carrier density is low enough, e.g. $\lesssim 10^{22}$ electrons/m^3. Under these conditions the magnetotransport properties should differ widely from the one-electron behaviour we are used to. Quite recently a magnetotransport anomaly was discovered by Nimtz et al. [6-8], which in fact bears the predicted features of an electron condensation.

In the following we are going to introduce briefly the experimental results obtained so far. After comparing the properties of the transport anomaly with theoretical data we shall discuss experiments planned for the near future which represent more crucial tests for an electron condensation than the usual magnetotransport experiments.

The experiments were carried out with various n-$Hg_{0.8}Cd_{0.2}Te$ and $Pb_{1-x}Sn_xTe$ samples, their characteristics are given in the table.

Table: Sample identification, parameters are representative for T=4.2K

Semiconductor		Bandgap (eV)	m^*/m_o	n (10^{20} m^{-3})
1	$Hg_{.784}Cd_{.216}Te$	0.094	0.0071	4.5
2	$Hg_{.800}Cd_{.200}Te$	0.064	0.0049	6.4
N242	$Hg_{.804}Cd_{.196}Te$	0.057	0.0046	4.0
3	PbTe	0.189	0.05	60
4	PbTe	0.189	0.05	330
5	PbTe	0.189	0.05	530
6	$Pb_{.8}Sn_{.2}Te$	0.081	0.03	300
7	$Pb_{.8}Sn_{.2}Te$	0.081	0.03	400

In all investigated samples it was checked that neither thermal nor magnetic freeze-out of free carriers take place in the relevant range of magnetic field and temperature. The lack of carrier freeze-out is a special feature found in these narrow-gap semiconductors. Data of longitudinal ($\rho_\parallel$) and transverse ($\rho_\perp$) magnetoresistivity are shown in Fig.(1). It was observed that at temperatures near 4.2K both $\rho_\parallel$ and $\rho_\perp$ approximately show a power law above 0.3T as expected from the single-electron model [9]. The magnetic quantum limit is reached in this sample at a field of 0.3T. Cooling down below 2K, however, a strong increase of both $\rho_\parallel$ and $\rho_\perp$ was measured. The strong increase of resistivity was found to be most pronounced in $\rho_\parallel$ (1 to 2 orders of magnitude at 8T). There are three interesting features: 1) At fields near the magnetic quantum limit $\rho_\perp$ shows a small decay with decreasing temperature. This effect was also observed quite recently in two-dimensional systems by Tsui et al. [10].

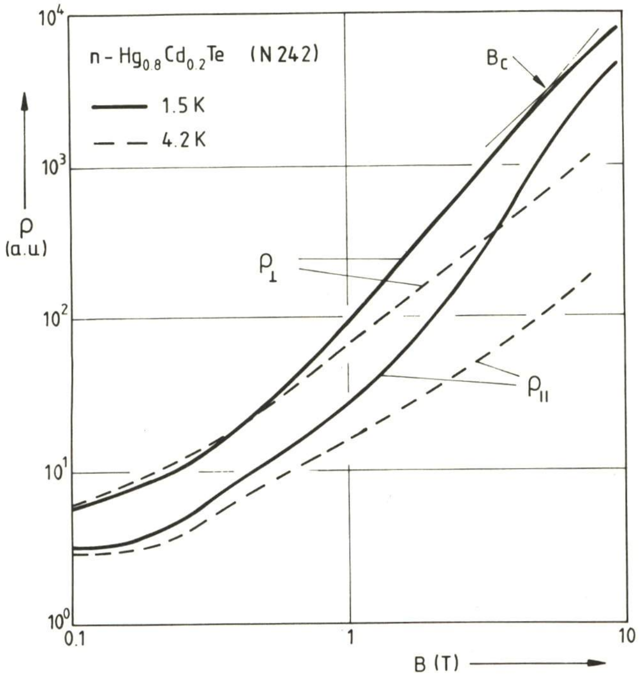

Fig. 1 Transverse and longitudinal magnetoresistivity above and below the critical temperature

Tentatively we relate this behaviour to the development of a charge density wave (CDW). It was pointed out by some theoreticians [3,5], that the transition from the homogeneous state to the strongly localized Wigner lattice might be interupted by a CDW phase. It would be very interesting to investigate $\rho_\perp$ in the two-dimensional systems also at fields far above the quantum limit, where the 3D-system shows the strong increase of $\rho_\perp$, as plotted in Fig.(1). 2) At fields far above the quantum limit both $\rho_\parallel$ and $\rho_\perp$ do show a point of inflection. We have defined the corresponding magnetic field as critical field B_C. Such a point of inflection was found in all the investigated sample below a critical temperature as shown in Fig.(2). 3) The strong anisotropy between $\rho_\parallel$ and $\rho_\perp$ vanishes above the critical field. Whereas the ratio of $\rho_\perp/\rho_\parallel$ is about 10 at 4.2K due to the quantization of k-space perpendicular to the magnetic field this drops to a factor of 2 or less near B_C below a critical temperature.

A critical field was found with all the investigated samples below a critical temperature as shown in Fig.(2). We correlate B_C to the existence of a Wigner lattice, which may be of only a short range order due to the interactions inherent with a real system. The critical field increases in the same semiconductor with increasing carrier density (see Table) in a way as expected from theory [2,6]. Also the reduction of the ratio of $\rho_\perp/\rho_\parallel$ was predicted for a localized state such as a Wigner lattice [2,4]. In agreement with the

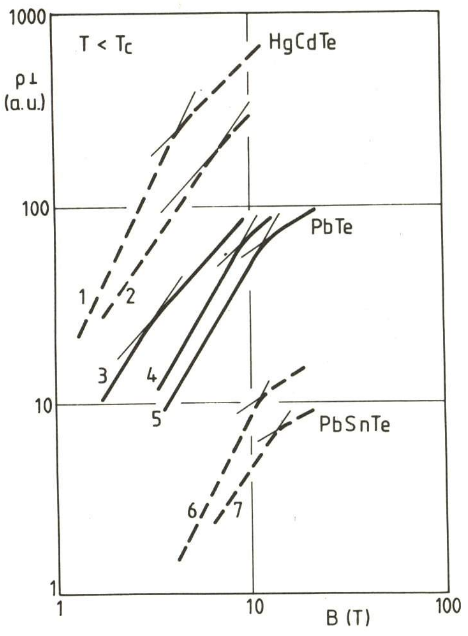

Fig. 2 Transverse magnetoresistivity of several samples as plotted below the critical temperature T_c

Hall-effect data we assume that the electron lattice is shifting as a whole in an electric field. The small anisotropy of ρ left above B_c is assumed to be due to the Wigner lattice, which becomes elongated parallel to the direction of the magnetic field [6].

The critical temperatures below which the deviations of the transport properties occur are about 2K in the $Hg_{1-x}Cd_xTe$ crystals and about 20K in the $Pb_{1-x}Sn_xTe$ samples. The various theoretical models yield a transition temperature of the order of 1K [6].

In a hot carrier experiment it was proved that the observed magnetotransport anomaly is only a function of the electron temperature. As shown in Fig.(3) the state of high resistivity was annihilated within 10^{-7} s in electric fields of 400 V/m which cause an electron temperature of about 4K. The strong dependence of the resistivity on electron temperature near B_c of the anomaly is idealy suited for microwave heterodyne detection. The construction and test of such a hot carrier bolometer was reported recently [8].

A crucial experiment for the existence of a solid electron state would be the detection of a shear mode propagating in the electron system. The long-wavelength excitations in an ideal Wigner crystal in strong magnetic fields were theoretically investigated by Kuramoto[11]. Due to the electric charge a shear mode may easily be excited by a linearly polarized electric wave at one end of the sample and detected by electric probes at the other end. The success of the planned experiment will only depend on the damping of the propaga-

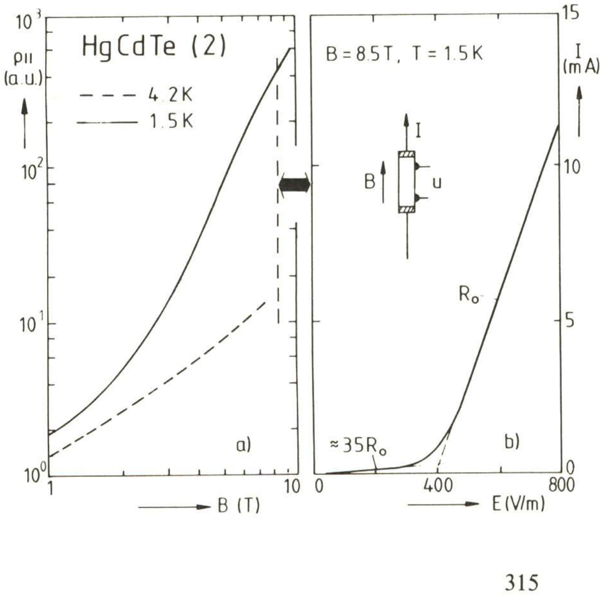

Fig. 3 a) Longitudinal magnetoresistivity above and below the critical temperature b) IE-characteristic measured at a lattice temperature of 1.5K showing the transition from the high to the low resistivity state near 400 V/m tion of such an excitation, which is not known particularly since it is assumed, that the Wigner condensation in a real semiconductor is characterized by a short range order only.

The Hartree-Fock calculations suggest, that there are precursors to the crystallized phase [3,5]. That is the inhomogeneous charge distribution starts with the evolution of a simple charge density wave. On the other hand a piezoelectric active acoustic mode of the ion lattice in a semiconductor is always accompanied by a CDW caused by it's piezoelectric potential. Accordingly one can amplify a destinct acoustoelectric mode if a magnetic field induced CDW exists by applying an electric ac-field.

The first experiments concerning the magnetic field induced Wigner condensation have revealed a magnetotransport anomaly bearing all the predicted features. The experiments have definitively shown that the one-electron model is not adequate to describe the magnetotransport at low temperatures and high fields. Some further experiments are necessary to get more quantitative informations about the new anomaly which is presumably caused by an electron condensation.

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