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MAGNETOTRANSPORT CHARACTERIZATION OF HgCdTe SOLID SOLUTIONS STRUCTURAL QUALITY

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It has been demonstrated that variable-magnetic-field Hall measurements for n-$Hg_{1-x}Cd_xTe$ samples in the extrinsic and intrinsic conductivity regions permit to identify and to evaluate semiqualitatively electrical activity of extended defects in this material.

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The variable-magnetic-field Hall $R_H(B)$ technique is used routinely in the electrical characterization of multicarrier systems, connected with either mixed conductivity or with multilayer structures appearing during the devices fabrication process.

But, as it has been shown in Ref. [1], the $R_H(B)$ measurements in the region of extrinsic conductivity of n-HgCdTe samples, i.e. under the conditions when effects connected with several carriers types are absent, permit also to characterize the extended defects in this material. Here the possibilities of this technique have also been generalized for the region of intrinsic conductivity, where, as in case of extrinsic conductivity, the effects connected with many carriers types, are absent because of electron mobility in HgCdTe being much higher than that of holes.

The measurements were performed on melt-grown bulk $Hg_{1-x}Cd_xTe$ single crystals with composition x from 0.19 to 0.25. After growth the HgCdTe boules were sliced into thick wafers which were annealed to convert the material to n-type. The high purity of the material is confirmed by the low electron concentration ($0.9\times10^{14} \leq n \leq 8\times10^{14}$ cm^{-3}), their high mobility ($\mu \geq 1.5\times10^5$ cm$^2\cdot$ V$^{-1}\cdot$ s^{-1}) and the bulk lifetime of the order of 0.8–3 μs, all measured at 77 K. Crystallographic defects were revealed using selective chemical etching [2].

Magnetic-field-dependent Hall data $R_H(B)$ were taken at 77 K in the range of 0.02–2 T with constant magnetic fields and up to 10 T with pulsed magnetic fields. During the measurements great attention was paid to elimination of all of the spurious effects which might simulate peculiarities of $R_H(B)$. It regards, first of all, a sharp step-function discontinuity in carrier concentration near the Hall probes, because such inhomogeneities result in anomalous $R_H(B)$ dependencies [3]. In case of HgCdTe such uniformities can occur owing to the material overheating while soldering the contacts. Therefore, at first the measurements were performed using the Van der Pauw method on massive samples with uniform structural perfection on entire area according to the selective etching data. After that the wafers were cut into small rectangular Hall bars and measurements were repeated on one of them. The complete coincidence of the $R_H(B)$ shapes for the measurements by these two methods demonstrated the absence of any additional disturbances.

The results obtained for a great number of samples of the different technological origin permit us to single out three main groups of samples with different magnetic field dependencies of the Hall coefficient. The first group has a classical $R_H(B)$ dependence consisting of two plateaux in weak and strong magnetic fields with the Hall factor $r \approx 1.09 \pm 0.02$ (Fig. 1, curve 1). To the same group we attribute the samples with $n \geq 5 \times 10^{14}$ cm^{-3}, for which R_H did not at all depend on magnetic field within the limits of experimental error ($\pm 1\%$). In this case electron gas at 77 K is degenerate and $r = 1$. For all of those samples fairly uniform dislocations density not exceeding 10^5 cm^{-2} and without the subgrain boundaries are characteristic.

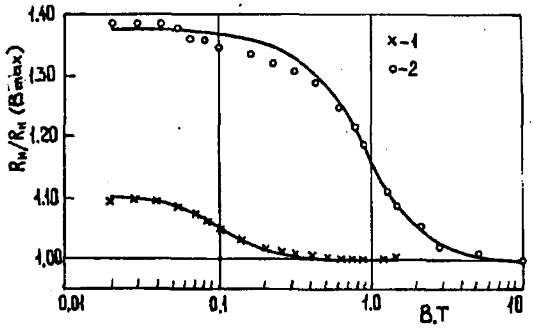

Fig. 1. The normalized Hall coefficient versus magnetic field at 77 K for two regions of the same slice with $x \approx 0.2$ (1 — classical dependence for the region without the subgrain boundaries, 2 — dependence for the region with subgrains, leading to the formation of the electron percolation channels).

The distinctive feature of the $R_H(B)$ curves of the samples belonging to the second group is a large decrease in R_H in fields up to 1 T, as in p-type samples with mixed conductivity. But in high magnetic fields R_H saturates without changing its sign (Fig. 1, curve 2). Analysis, performed using model of Petritz [4], shows that in these crystals two sets of electrons with different parameters coexist (n_1, n_2, μ_1, μ_2).

A special program permits to define these parameters by analyzing $R_H(B)$. The density of additional electrons, obtained by such a procedure, varies from sample to sample within the limits of $(0.8\text{–}11) \times 10^{12}$ cm^{-2}, and their mobilities are $(0.6\text{–}3.0) \times 10^4$ cm$^2 \cdot$V$^{-1} \cdot$s^{-1}. For the samples of this group the presence of a continuous subgrain boundary network is characteristic. Therefore we attribute the second-set electron conductivity to the electron channels, appearing when the constituent dislocation density exceeds some critical level corresponding to the percolation threshold at a certain critical misorientation across the boundaries. It is confirmed by the local measurements of $R_H(B)$, performed on the slice, different parts of which possessed different structural perfection. And if $R_H(B)$ for regions without the subgrain boundaries had classical character (curve 1, Fig. 1), then for other regions in proportion as with the increasing of the subgrain boundaries density the form of $R_H(B)$ gradually approaches to the form of curve 2 in Fig. 1, which confirms the increase in electron channel density. It should be also noted that for regions with subgrain boundaries the electron concentration was always lower (up to 40%) than that of the regions without subgrains. It may be explained by the purifying effect of boundaries acting as drains for impurities.

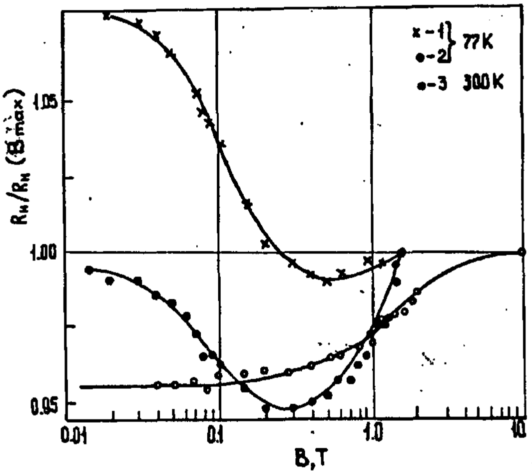

Fig. 2. The normalized Hall coefficient versus magnetic field at 77 K and at 300 K for the samples with $x \approx 0.2$ (curve 1, 2) and 0.25 (curve 3) with different relative volume of conducting inclusions. The fraction of the volume occupied by the inclusions $f \approx 0.001$ and 0.013 for the curves 1 and 2 and $f \approx 0.004$ for the curve 3, given at 77 K and at 300 K accordingly. Equation (1) and the Hall scattering factor $r = 1.09$ for 77 K and $r = 1.00$ for 300 K were used in fitting.

The distinctive feature of the third group of samples was the occurrence at 77 K of a minimum on $R_H(B)$, whose magnitude varies from slice to slice (Fig. 2). Qualitatively and semiquantitatively the curves in Fig. 2 could be explained in accordance with the model of Wolfe and Stillman [5] by the presence of multiple isolated inhomo geneities with a conductivity σ_0, much higher than the surrounding medium conductivity σ. Under this condition in the low-magnetic-field limits the Hall constant measurements give an average value for the inhomogeneities and the surrounding medium, and R_H will be lower than the Hall constant of the surrounding medium. When magnetic field is increased, the current flowing into the inhomogeneities decreases because of the boundary conditions at the inhomogeneity–medium interface. In the high-magnetic-field limit there is no current flow into the inhomogeneities, and the measured Hall constant is that of the medium surrounding the inhomogeneities. In the case of inclusions having the spherical form the Hall coefficient is given in the form [5]

$$R(f,B)=\frac{\mu_n}{\sigma}\left(1-\frac{9f}{1+\mu_n^2B^2}\right), \tag{1}$$

where $f=N(V_0/V)$ is the fraction of the volume occupied by the inclusions and N is the total number of inclusions of volume V_0 in the sample volume V, all inclusions are assumed to have the same volume. The real curves reflect contributions both from inclusions and from the Hall factor. Analysis of the experimental data on the basis of this model yields f equal to 0.013 and 0.001, though the precision of such a determination is not known.

It was found that the effect can also be observed at 300 K ($f = 0.04$ for curve 3 in Fig. 2), though for most of the samples this effect was significantly smaller than the precision of the experiment. The comparison of the ratio of this effect magnitudes at 300 K and at 77 K for different samples permit to judge about the nature of those inclusions. At 300 K, i.e. in the intrinsic conductivity region they can be connected only with the solid solution composition fluctuations. But for the sample with the largest value of the effect at 77 K (curve 2 in Fig. 2) the increase in R_H versus B was absent at 300 K, therefore we can suppose that in this case the impurities fluctuations are the source of the inclusions.

In general, the performed investigations demonstrate the effectiveness of the Hall effect using for the extended defects determination in HgCdTe and in other solid solutions on the base of mercury chalcogenides.

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