Analysis of formula (3.2) shows that \( a_{n,j}(0) = 0; a_{n,j}(\kappa_{\text{max}}) = -(j + 1/2) \) and \( a_{n,j}(\kappa) < 0; (\kappa/a_{n,j}) < 0 \) for \( \kappa \) from the interval \( 0 < \kappa < \kappa_{\text{max}} \). This means that the pole lies on the negative real \( \alpha \) axis and as \( \kappa \) decreases from \( \kappa_{\text{max}} \) to 0 it moves to the right along this axis from the point \( -(j + 1/2) \) to 0. The origin in the \( \alpha \) plane is a point of accumulation of poles. If for some \( \kappa \) the pole passes through the physical value \( \alpha (z < 137 \) is a negative integer), then a bound state of energy
\[
E_{n,j} = m/\left(1 + \alpha^2/(n' + \sqrt{1 + (j + 1/2)^2 - \alpha^2})\right)^2
\]
arises in a hydrogenlike ion of atomic number \( z \).

Bound states \( n/j \) of all hydrogenlike ions thus lie on the trajectory \( a_{n,j}(\kappa), \kappa_{\text{max}} > \kappa > 0 \). For \( k > 0 \) the pole passes onto the positive imaginary \( \alpha \) axis and moves upward along this axis as \( k \) increases.

Thus, resonances do not exist for the Coulomb potential and if the potential is attractive (\( \alpha < 0 \)) an infinite number of bound states exists.

LITERATURE CITED


CURRENT CARRIER MOBILITY IN MANGANESE-DOPED CADMIUM TELLURIDE

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The possibility of substantial influence of a manganese impurity on the magnetic and optical properties of CdTe, which is explained by the state and interaction of the Mn 3d5-electron spins in the CdTe crystal lattice, is shown in [1-3]. An investigation of the influence of the Mn impurity on current carrier scattering in this material is of interest. To this end, the temperature dependence of the Hall mobility of electrons in CdTe-Mn single crystals is investigated in this paper in the temperature range 77-435°K.

1. Experimental Part

The investigations were performed on specimens cut from single-crystal CdTe:Mn ingots obtained by a modified Bridgman method. The material was doped by insertion of an appropriate quantity of Mn in the CdTe melt. Special investigations were performed using an impurity tagged by a radioactive isotope* to determine the concentration of the Mn impurity dissolved in the CdTe lattice.

The value of the effective distribution factor for Mn in CdTe (\( k_{\text{eff}} = 0.75-0.95 \)) was determined from the data of these investigations, and the distribution of the doping impurity along the ingot was computed. The concentration of the Mn impurity was \( 10^{20} \text{ cm}^{-3} \) in the specimens investigated.

Freshly fabricated CdTe:Mn single crystals were semiinsulating (\( \rho \approx 10^5-10^{10} \Omega \cdot \text{cm at 300\,K} \)), and had electron conductivity. This material was used to measure the electrical conductivity \( \sigma \) and the Hall coefficient \( R_H \) in the 293-435°K band. Low-temperature (77-293°K) investigations were performed on specimens with the specific resistivity \( \rho \approx 10^{-10} \Omega \cdot \text{cm at 300\,K} \), obtained by annealing the semiinsulating crystals at 900°C and a cadmium vapor pressure of \( P_{\text{Cd}} = 2.34 \text{ atm for 260 h} \). The type of specimen conductivity did not alter during annealing.

*Results of the investigations of Mn solubility in CdTe will be published separately.
Fig. 1. Temperature dependence of the Hall coefficient for initial (preannealing) CdTe : Mn specimens.

Fig. 2. Temperature dependence of the Hall coefficient for postannealing CdTe : Mn specimens.

Fig. 3. Temperature dependence of the electron mobility for CdTe : Mn: 1) experimental results for annealed specimens; 2) theoretically calculated values for doped specimens ($N_{\text{Mn}} \approx 10^{20} \text{ cm}^{-3}$); 3) theoretically calculated values for specimens not doped; 4) experimental values for a CdTe specimen not doped [5].

Let us note that with the exception of the 150-200 $\mu$m thick near-surface domain which had been ground, the annealed specimens were sufficiently electrically homogeneous.

Measurements of the quantities $\sigma$ and $R_H$ were performed by the usual compensation method by using the U1-2 electrical amplifier in the case of the seminsulating specimens. Ohmic contacts were produced on the n-type low-resistance specimens by fusion of In in a $H_2$ atmosphere, and in the high-resistance material by deposition of Cu from a CuSO$_4$ solution [4].

Results of the measurements are presented in Figs. 1-3 for specimens with a $10^{20} \text{ cm}^{-3}$ manganese impurity concentration. For the seminsulating specimens the current carrier concentration and mobility at 300$^\circ$K were, respectively, $4.1 \cdot 10^5 \text{ cm}^{-2} \text{ V}^{-1} \text{ sec}$ and $740 \text{ cm}^2/\text{V} \cdot \text{sec}$.

The electrophysical properties of the material were determined by the depth of an impurity center with the ionization energy $E_C \approx (0.73 \pm 0.02) \text{ eV}$, determined from the rectilinear sections of the dependence $\log R_H = f(1/T)$. A low-resistance material with electron concentration $n = 7.1 \cdot 10^{15} \text{ cm}^{-3}$ at 300$^\circ$K was obtained by controlled annealing. The value of the Hall electron mobility in the bulk of the specimens hardly changed during the annealing and was $720 \text{ cm}^2/\text{V} \cdot \text{sec}$ (at 300$^\circ$K). The depth at which the impurity level lay for the annealed material was $E_C \approx 0.05-0.06 \text{ eV}$. Let us note that the CdTe - Mn specimens investigated has good reproducibility of the electrophysical properties in the temperature range being investigated.

The electron mobility increased as the temperature was lowered, and reached a maximum value at $T \approx 110$ (Fig. 3, curves 1 and 2). It is characteristic that the value of $\mu_H$ is substantially less for the Mn-doped specimens, and reaches the maximum value at higher temperatures than for the pure nondoped material (Fig. 3, curve 3), for which the maximal value of the electron mobility was reached at 20$^\circ$K and equaled $1.1 \cdot 10^5 \text{ cm}^2/\text{V} \cdot \text{sec}$ [5].

A theoretical analysis of the dependence $\mu(T)$ was performed for CdTe - Mn with electron scattering by magnetic impurities taken into account in order to explain the results obtained.

2. Theoretical Part

If a uniform impurity distribution over the crystal volume and no mutual interaction are assumed, then the Hamiltonian system can be written in the form

$$H = H_0 + H_m + H_{e1-Im} + H_{e1-p}$$

(1)