TEMPERATURE DEPENDENCE OF THE CONCENTRATION OF CARRIERS IN $CdIn_2Te_4$ CRYSTALS

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UDC 621.315.592

The temperature dependences of electric conduction, the Hall coefficient, thermoelectric power, and the dimensionless field of the transverse Nernst—Ettingshausen effect in $CdIn_2Te_4$ crystals have been investigated in the region of mixed conduction (250—420 K). Using the experimental data on these kinetic coefficients, we determined the concentrations and mobilities of electrons and holes and the Fermi level energy in the interval of temperatures 350—420 K, where the scattering of charge carriers by optic polarization vibrations of the crystal lattice is dominant.

The complex defective compounds with stoichiometric vacancies which are formed in the $(A_2^3C_3^6)_x - (B_3^2C_3^6)_{1-x}$ systems attract the attention of researchers as perspective radiation-resistant materials for the electronic technique. One of such compounds is $CdIn_2Te_4$ which is realized in the $(In_2Te_3)_x$-$(Cd_3Te_3)_{1-x}$ system at x=0.75. Despite the available works concerning the possibility to design electronic-optical devices on the basis of $CdIn_2Te_4$ [1,2], the experimental studies of the fundamental physical properties are mainly concentrated on the phase diagram and crystallographic and optic properties [3—5]. From electric characteristics, the electric conduction and the Hall coefficient were investigated. In particular, it was shown [1] that crystals of $CdIn_2Te_4$ can possess the n- or p-type of conduction with a charge carrier concentration of $\sim 10^{15}$ cm^{-3} and a maximum mobility of 200 cm^2/(V·s) at room temperature.

The present work is devoted to the study of the transfer phenomena in crystals $CdIn_2Te_4$ grown by the Bridgman method. According to the data on the temperature behavior (Fig. 1) of the specific electric conduction σ (curve *4*), Hall coefficient R (curve *2*), differential thermoelectric power α (curve *1*), and the dimensionless field of the transverse Nernst—Ettingshausen effect ε_y (curve *3*), the majority carriers are electrons, whose Hall mobility [120—140 cm^2/(V·s)] varies weakly in the interval of temperatures 250—420 K. The conduction activation energy determined from the experimental data on $\lg R(T) = f(T)$ at T>300 K is E_a=0.45 eV, which is significantly less than a half of the energy gap for $CdIn_2Te_4$ determined from the optic measurements (E_g=1.23 eV at 300 K). This allows us to assume that the intrinsic conduction is not reached in the region of temperatures under study.

It turns out that the dimensionless field of the transverse Nernst—Ettingshausen effect ε_y grows by absolute value with decrease in temperature significantly more rapidly than the theoretically predicted value in the case of monopolar conduction [6]. By that work, the change in ε_y is caused by a change of the charge carrier mobility, which makes the Nernst—Ettingshausen effect to be very sensitive to the presence of carriers of the opposite sign. The negative and relatively large values of ε_y observed by us testify in favor of the mixed conduction when the electron component is dominant. With regard for this circumstance, we calculated the concentrations, charge carrier mobilities, and Fermi level energies with the use of relevant formulas for the mixed conduction in the relaxation time approximation for the isotropic parabolic law of dispersion and a weak magnetic field [7]:

$$\alpha = \frac{k}{e}\left[\frac{1-ab}{1+ab}(r+2) + \frac{1}{1+ab}\frac{E_g}{kT} - \ln\frac{eR(1+ab)^2N_c}{A(1-ab^2)a}\right],$$

$$\varepsilon_y = \frac{R\sigma}{2(1-ab^2)(1+ab)}\left[(1-2r)(1+a^2b^3) - \right.$$

$$\left. -ab(1+b)\left(6r+7+\frac{2E_g}{kT}\right)\right]H, \qquad (1)$$

$$n = \frac{A}{eR}\frac{(1-ab^2)a}{(1+ab)^2}, \qquad \mu_n = \frac{\sigma ab}{en(1+ab)},$$

$$F = kT\ln\left(\frac{n}{N_c}\right).$$

Here, $a = n/p$ and $b = \mu_n/\mu_p$ are, respectively, the ratios of concentrations and mobilities of electrons and holes, $E_g = (1.3 + \alpha T)$ eV is the energy gap ($\alpha = -2.5 \times 10^{-4}$ eV/K [4]), $N_c = BT^{3/2}$ is the effective density of states in the conduction band, r is the scattering parameter,

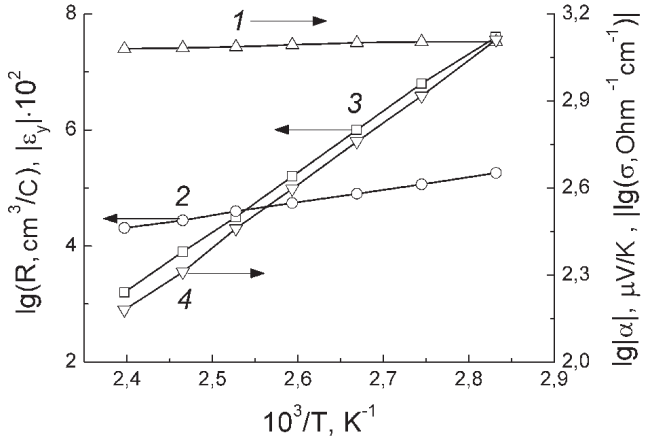

Fig. 1. Temperature dependences of thermoelectric power α (*1*), Hall coefficient R (*2*), the dimensionless field of the Nernst—Ettingshausen effect ε_y (*3*), and electric conductivity σ (*4*)

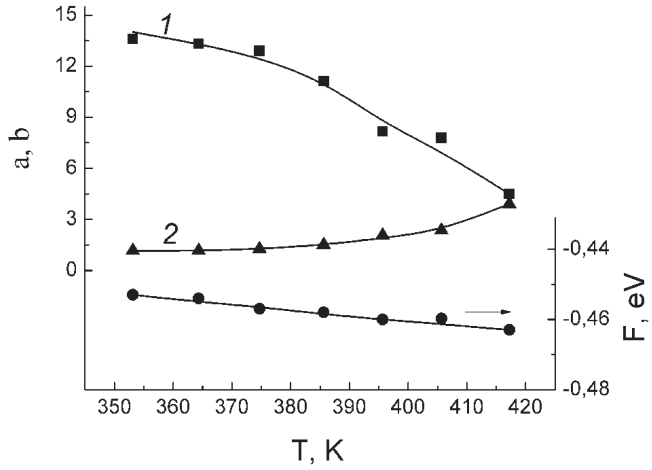

Fig. 2. Temperature dependences of the position of the Fermi level F relative to the bottom of the conduction band and the ratios of the concentrations and mobilities of electrons and holes $a = n/p$ (*1*), $b = \mu_n/\mu_p$ (*2*), respectively

and A is the Hall factor. At a fixed temperature, the unknown parameters are a, b, r, and B. The approximations accepted for the dispersion law and the statistics of carriers are based on the results given in [9].

The low concentration of charge carriers, $\sim 10^{11}$—10^{14} cm^{-3}, in the interval of temperatures 250—420 K under study testifies to that the role of extrinsic ions in the scattering of charge carriers is insignificant. Therefore, in our calculations, we consider the scattering of charge carriers by acoustic and optical vibrations of the lattice, as well as by the neutral centers which are the stoichiometric vacancies with the concentration $N_v \sim 10^{21}$ cm^{-3}.

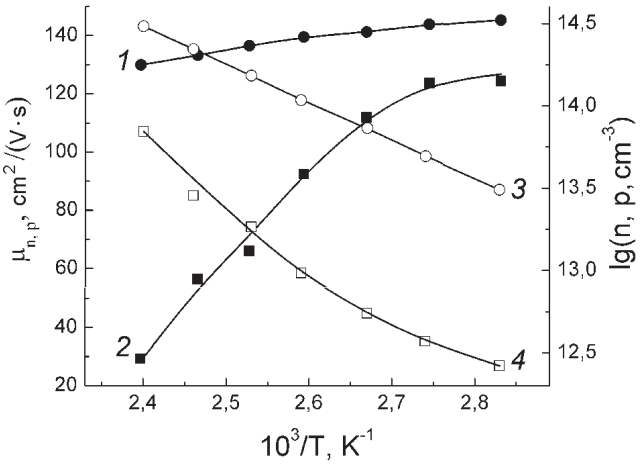

Fig. 3. Temperature dependences of the mobilities of electrons μ_n (*1*) and holes μ_p (*2*) and the concentrations of electrons n (*3*) and holes p (*4*)

As fitting parameters, we chose the quantities A, B, and r. It turns out that the best agreement of theory and experiment and the most correct results are derived at T>350 K with $B = 3.9 \times 10^{15}$cm^{-3}K$^{-3/2}$, $r = 1$, and $A = 1.1$. The value $r = 1$ indicates that the dominant mechanism at high temperatures (T>350 K) is the scattering of charge carriers by optic polarization phonons. At T<350 K, the used approximations [and thus formulas (1)] become unsuitable for the correct determination of $a(T)$ and. Therefore, in the discussion of the results, we restict ourselves by the temperature interval 350—420 K.

The temperature dependences $n(T)$, $\mu_n(T)$, $a(T)$, and $b(T)$ and the Fermi energy $F(T)$ are given in Figs. 2, 3. According to Fig. 2, the Fermi level is in the upper half of the energy gap and approaches its middle with increase in temperature. In the region of temperatures under study, the electron conduction exceeds the hole one ($\sigma_n/\sigma_p = ab$) by a factor of 14—20. Therefore, the experimental values of the electric conduction are satisfactorily described by the formula that is valid only for one type of the electron conduction [8]: $\sigma = \sigma_0 \exp\left(\frac{F}{kT}\right)$, where $\sigma_0 = eN_c\mu_n$, and $F(T)$ and $\mu_n(T)$ are the derived temperature dependences of the Fermi level energy (Fig. 2) and the mobility of electrons (Fig. 3), respectively.

We note that the Fermi level F (Fig. 2) varies linearly with temperature: $F = E_a + \gamma T$, where the activation energy of donor centers $E_a = 0.4$ eV, and the temperature coefficient $\gamma = 1.5 \times 10^{-4}$ eV/K. It is worth noting that the derived value E_a =

0.4 eV differs from $E_a = 0.45$ eV, that is estimated by the slope of the temperature dependence $\lg\sigma = f(10^3/T)$, but coincides practically with the activation energy derived from the dependence $\lg\left(\frac{1}{eR}T^{-3/2}\right) = f(10^3/T)$. Therefore, we may assert that, with regard for the accuracy of experimental measurements, the temperature dependence of the concentration of electrons in crystals $CdIn_2Te_4$ is mainly conditioned by the deep compensated level of intrinsic defects with the activation energy $E_a = (0.42 \pm 0.03)$ eV.

1. *Ou S.S., Eshraghi S.A., Stafsudd O.M., Gentile A.L.* // J. Appl. Phys. — 1985. — **57**, N2. — P. 355.
2. *Kianian S., Eshraghi S.A., Stafsudd O.M., Gentile A.L.* // J. Appl. Phys. —1987. —**62**, N4. — P. 1500.
3. *Weitze D., Leute V.* // J. of Alloys and Compounds. — 1996. — **236**. — P. 229.
4. *Koval L.S., Radautsan S.I., Sobolev V.V.* //Izv. AN SSSR. Neorg. Mater. — 1972. — **8**, N11. — P. 2021.
5. *Riede V., Neumann H.* // Solid State Communs. — 1991. — **78**, N3. — P. 211.
6. *Tsidil'kovsky I.M.* Thermomagnetic Phenomena in Semiconductors. — Moscow: GIFML, 1960 (in Russian).
7. *Askerov B.M.* Kinetic Effects in Semiconductors. — Leningrad: Nauka, 1970 (in Russian).
8. *Mott N.F., Davis E.A.* Electron Processes in Non-Crystalline Materials. — Oxford: Clarendon Press, 1979.
9. *Zhuze V.P., Sergeeva V.M., Shelykh A.I.*// Fiz. Tverd. Tela. — 1960. — **2**, N11. — P. 2858.

Received 21.02.05.
Translated from Ukrainian by V.V. Kukhtin

ТЕМПЕРАТУРНА ЗАЛЕЖНІСТЬ КОНЦЕНТРАЦІЇ НОСІЇВ У КРИСТАЛАХ $CdIn_2Te_4$

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Р е з ю м е

Досліджено температурні залежності електропровідності, коефіцієнта Холла, термо-ерс і безрозмірного поля поперечного ефекту Нернста—Еттінгсгаузена кристалів $CdIn_2Te_4$ в області змішаної провідності (250—420 K). Використовуючи експериментальні дані цих кінетичних коефіцієнтів, визначено концентрації та рухливості електронів і дірок, енергію рівня Фермі у діапазоні температур 350—420 K, де домінує розсіювання носіїв заряду на оптичних поляризаційних коливаннях ґратки.