ELECTRICAL CHARACTERISTICS OF $Zn_xIn_2S_{3+x}$ SINGLE CRYSTALS

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Abstract

The electrophysical characteristics, including the Hall effect, of the family of layered $Zn_xIn_2S_{3+x}$ (x = 1, 2, and 3) compounds were studied in a temperature range of 250–500 K ($\vec{E} \perp C$). They were interpreted taking into account an exponential distribution of traps near the conduction band. The main parameters of the material were determined, and the way was shown how they can be varied.

1. Introduction

Wide gap semiconductors, such as sulphides and oxides, are promising for application as luminophores and in various fields of electronics [1, 2]. According to [3], $CdGa_2(Se)S_4$ can be used for manufacturing photoconvertors of optical radiation in a wide spectral range. Sulphides are especially promising for the creation of UV detectors and solar cells [4]. Among them we can name the family of $ZnIn_2S_{3+x}$ sulphides (x = 1–5) with a layered crystal structure. In particular, effective photoelectrical UV and X-ray radiation sensors and photochemical solar cells were developed on the basis of single crystalline platelets of these compounds [5, 6]. However, there are only few data published about their electrical characteristics. The aim of this work was to study the electrical properties of $ZnIn_2S_{3+x}$ sulphides.

2. Experimental

Single crystalline samples of the layered $ZnIn_2S_{3+x}$ (x = 1, 2, 3, and 5) were grown using the method of chemical transport reactions with iodine as a transportation agent. The load consisted of especially pure chemical elements. The technological regimes were previously studied and summarized in [7].

We used the experimental scheme intended for measurements of high-resistance materials. An electrometric amplifier TR-1501 was used in the scheme. The indium ohmic contacts were prepared by thermal evaporation in high vacuum on the (0001) faces of the platelets. The *C* axis was perpendicular to this face. The method of measurements of galvanomagnetic properties was described in [8]. The range of maximal sensitivity of the mobility μ was found in the crystals with resistance $R = 10^6 – 10^7$ Ohm.

3. Results and discussion

The electrical conductivity of undoped layered $ZnIn_2S_{3+x}$ single crystals in the fields with the electric field strength of 10^2–10^4 V/m obeyed the Ohm law. For the compound with x = 1 with a lower resistivity the measurements were performed in a wider temperature range. This allowed us to observe the curves with two slopes. It can be seen in Fig. 1 that curves 1 and 2 were measured in the range of temperatures higher than 400 K. For lower temperatures the conductivity diminishes to the level below the sensitivity of the experimental setup. Figure 2 shows the typical dependences of the concentration of electrons *n* on temperature T. The n-type conductivity was observed for all used temperatures. The main parameters are summarized in the table. Here the following notations were used: E_d is the activation energy of donors, N_d and N_a are the concentrations of donors and acceptors, respectively.

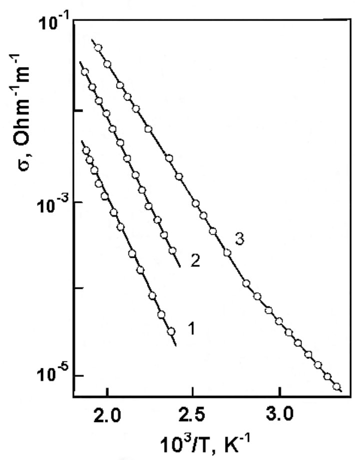

Fig. 1. Dependence of the conductivity of $Zn_xIn_2S_{3+x}$ single crystals versus temperature: x = (1) 3, (2) 2, and (3) 1.

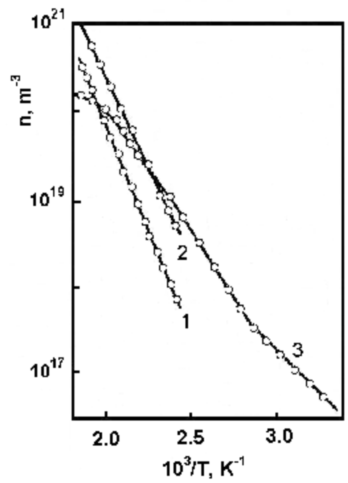

Fig. 2. Dependence of the electron concen-tration of $Zn_xIn_2S_{3+x}$ related layered compounds versus temperature: x = (1) 3, (2) 2, and (3) 1.

Table

x	Compound	Galvanomagnetic effect						Thermo-e.m.f.	
		n, m^{-3}	10^4□ , m^2/Vs	E_d, eV	N_d, m^{-3}	N_a, m^{-3}	N_a/N_d, %	$10^6\alpha$, V/K	m^*/m_o
1	$ZnIn_2S_4$	10^{18}-10^{19}	25-30	0.4-0.5	2.6 x 10^{23}	7.8 x 10^{21}	3	320	0.22
2	$Zn_2In_2S_5$	10^{17}-10^{18}	4-8	0.7-0.8	9 x 10^{24}	3.5 x 10^{23}	39	160	0.19
3	$Zn_3In_2S_6$	10^{17}-10^{18}	2-4	1.0-1.2	2 x 10^{24}	1.1 x 10^{24}	55	110	0.18

The effects of charge transport, in particular, dependences of conductivity σ, and Hall mobility μ_H as a function of temperature and dependences of magnetoresistance ΔR/R on the magnetic field strength H in $ZnIn_2S_4$ samples with a dark resistivity of 10^{-2} -1 Ω·m were studied by Italian researchers [9]. It should be noted that the dependences of the conductivity and mobility found experimentally in a temperature range of 120–300 K follow the exponential law

$$\sigma \sim \exp(-E_1/kT) \text{ and } \mu_H \sim \exp(-E_2/kT),$$

where $E_1 = 0.045$ eV and $E_2 = 0.02$ eV.

The electronic type of conductivity was observed in the entire range of temperatures of 250-500 K. The mobility of electrons at room temperature amounted to $\mu_H \sim 2 \times 10^{-3}\ m^2V^{-1}s^{-1}$. The observed dependences (T < 70 K) were elucidated taking into account the formation of local states near the conduction band.

The measurements were performed for the case $\vec{E} \perp C$. The parameters of the materials can be varied using doping with various elements. This was demonstrated for the crystals doped with Ni [10] and Cu [11]. Later we obtained $Zn_5In_2S_8$ compound which exhibits an intensive cathodoluminescence in the orange-red region (T = 300 K) [12]. Note that a unique multilayered structure ZnO/In_2O_3, which consists of ultrathin ZnO and In_2S_3 layers, was prepared on the basis of these layered compounds [13].

4. Conclusions

Several electrophysical characteristics of the layered $Zn_xIn_2S_{3+x}$ (x = 1, 2, and 3) compounds were studied ($\vec{E} \perp C$). Their possible interpretation was proposed. The main parameters of the material were determined, and the way was shown how they can be varied.

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