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ON CERTAIN PROPERTIES OF THE SEMICONDUCTOR $CdSnAs_2$–AN ELECTRONIC ANALOGUE OF INDIUM ARSENIDE

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A series of compounds of the type $A^{II}B^{IV}C_2^V$ has been obtained comparatively recently (^{1,2}). In accordance with the principles of electronic analogies, these compounds, in terms of the type of chemical bonding and consequently also in their physicochemical and electrical properties, should be close to compounds of the type $A^{III}B^V$ that are isoelectronic with them. On the basis of this assumption we carried out a study (^{3}), in which the existence of continuous substitutional solid solutions between $CdSnAs_2$ and InAs was established. Having obtained this indirect proof of the correctness of our assumption, we turned to a more detailed investigation of the compound $CdSnAs_2$ with the aim of obtaining direct evidence of the closeness of its electrical properties to those of InAs. In doing so, we were guided, as in earlier work, by the considerations that an increase in the number of dissimilar atoms (in the present case in the compound $CdSnAs_2$ as compared with InAs) cannot be the cause of a decrease in the mobility of current carriers, owing to the special features of the crystal chemistry of diamond-like semiconductors and the principal role of the electron lattice (^{4}). It should be noted that among the ternary compounds of the type $A^{II}B^{IV}C_2^V$, $CdSnAs_2$ is the "heaviest," since $CdSnSb_2$ does not exist (^{3}).

We assumed that in $CdSnAs_2$ the mobility of current carriers might be not only no smaller than in InAs, but even greater. This idea was suggested by the circumstance that the ratio of the forbidden-band width to the microhardness in $CdSnAs_2$ is such that, corresponding to a decrease in ionicity, it may indicate a greater covalency of the bond in this ternary compound than in InAs. (For InAs $\Delta E = 0.45$ eV, $H = 330$ kg/mm^2, and for $CdSnAs_2$ $\Delta E = 0.26$ eV, $H = 395$ kg/mm^2.)

These considerations led us to undertake the synthesis and purification of $CdSnAs_2$ with the application of certain improvements, as a result of which we succeeded in obtaining both monolithic polycrystalline (with grains of the order of several millimeters) and single-crystalline specimens of $CdSnAs_2$ several centimeters in length and with a cross section of ~ 0.25 cm^2.

It should be noted that Goodman (^{2}), having synthesized a whole series of

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

compounds of the type $A^{II}B^{IV}C_2^V$, was in general unable to obtain specimens suitable for electrical measurements; and Straus and Rosenberg, attempting to prepare $CdSnAs_2$ specimens by the Bridgman method, obtained alloys riddled with cracks and having a grain size of $\sim 20\,\mu$ (^{5}).

Microsections of the polycrystalline specimens we obtained had a polyhedral structure without any inclusions or inhomogeneities. In order to check the homogeneity of these specimens, the microhardness was measured; its value, as in (^{3}), proved to be 395 ± 5 kg/mm^2, and the small magnitude of the error indicated the homogeneity of the alloys obtained. Homogeneity was also checked along the length of the specimens (both polycrystalline and single-crystalline) by measuring the specific electrical conductivity at room temperature.

In this case the deviation from the mean value did not exceed 5%. Polycrystalline $CdSnAs_2$ samples, when studied by the Debye–Scherrer method, showed a chalcopyrite structure with $a_{CdSnAs_2} = 6.092 \pm 0.001$ Å and $c/a = 1.957 \pm 0.003$, which was in good agreement with the literature data (^{6}).

The single-crystal character of the samples was studied by the Laue method. The Laue patterns obtained from different areas along the crystal surface had the same arrangement of spots. The melting temperature of $CdSnAs_2$, determined by thermal analysis, proved to be 615° C.

The electrical properties of $CdSnAs_2$ have not yet been studied sufficiently. In (^{5}) results are given for measurements of the Hall effect and electrical conductivity on polycrystalline $CdSnAs_2$ samples only in the temperature range 85–350° K. The absence of data relating to single-crystal $CdSnAs_2$ samples is explained by the difficulty of obtaining them in a pure and perfect form.

Fig. 1. Temperature dependence of electrical conductivity.
1 –polycrystalline sample obtained by the usual synthesis method,
2 –polycrystalline monolithic sample,
3 –single crystal

Fig. 2. Temperature dependence of the electrical conductivity σ, concentration n, and mobility u for sample 3

Our task was to investigate the electrical properties of $CdSnAs_2$ single crystals over a wide temperature range. Measurements of the Hall effect and electrical conductivity were carried out by the compensation method in the temperature range 77–840° K. The Hall effect was measured in a constant magnetic field

$H = 6700$ oersteds.

For comparison of the values of electrical conductivity, measurements were carried out on three samples obtained by different methods and possessing different concentrations of current carriers (see Fig. 1).

It is seen from Fig. 1 that the electrical conductivity of all the samples studied in the low-temperature region (77—280° K) does not depend on temperature. With increasing temperature the electrical conductivity first decreases and then, passing through a minimum, increases exponentially. For samples 1, 2, and 3 the minimum of electrical conductivity is observed respectively at 550° K, 370° K, and 365° K.

Figure 2 presents the temperature dependence of the electrical conductivity, concentration, and mobility of current carriers for a $CdSnAs_2$ single crystal (sample 3). It is seen from Fig. 2 that, with increasing temperature up to the transition temperature, the decrease in electrical conductivity is caused by the decrease in mobility, since in this temperature interval the carrier concentration values remain almost constant. Beginning with the transition temperature, the electrical···

conductivity increases. The increase in electrical conductivity is due to an increase in the concentration of current carriers.

The mobility of carriers in the low-temperature region is practically independent of temperature. The constancy of the mobility may be due to scattering of the carriers both by neutral impurity atoms and (in the presence of degeneracy) by impurity ions. In the high-temperature region, scattering of the carriers by lattice vibrations predominates, which leads to a decrease in the mobility of current carriers and, at the same time, to a decrease in electrical conductivity.

The values of the electrical conductivity for all the investigated specimens at room temperature are given in Table 1.

Table 1

No.	Specimen	ΔE	σ, $\Omega^{-1} \cdot cm^{-1}$	u, $cm^2/V \cdot sec$	n, cm^{-3}
1	Polycrystal with cracks and cavities	–	$2.5 \cdot 10^2$	1000	$2 \cdot 10^{18}$
2	Monolithic polycrystal	0.26	$3.4 \cdot 10^2$	5800	$4.4 \cdot 10^{17}$
3	Single crystal	–	$4.1 \cdot 10^2$	18000	$1.7 \cdot 10^{17}$

Fig. 3. Temperature dependence of the Hall coefficient for specimens 1-3 (the specimen numbers are the same as in Fig. 1)

Figure 3: Fig. 3. Temperature dependence of the Hall coefficient for specimens 1-3 (the specimen numbers are the same as in Fig. 1)

No.	Specimen	ΔE	σ, $\Omega^{-1} \cdot \text{cm}^{-1}$	u, $\text{cm}^2/\text{V} \cdot \text{sec}$	n, cm^{-3}
4	Single crystal	–	$3.1 \cdot 10^2$	22000	$1 \cdot 10^{17}$

Figure 3 shows the dependence of the Hall coefficient on temperature. It is seen from this figure that in the low-temperature region the Hall coefficient does not depend on temperature, while in the high-temperature region, beginning approximately at 420° K, it falls exponentially with a further increase in temperature.

The mobility of current carriers, determined as the product of the Hall coefficient and the electrical conductivity ($R \cdot \sigma$), is given in Table 1. For comparison, Table 1 gives the results of intermediate experiments. It should be noted that the low value of the mobility in specimen 1, obtained by the usual method of synthesis, is due mainly to the high concentration of current carriers and to the imperfection of the specimen.

Fig. 3. Temperature dependence of the Hall coefficient for specimens 1-3 (the specimen numbers are the same as in Fig. 1)

For the single-crystal specimen (specimen 3) with a current-carrier concentration $n = 1.7 \cdot 10^{17}$ cm^{-3}, the electron mobility proved to be equal to 18000 cm^2/V·sec, and in specimen 4, with carrier concentration $n = 1 \cdot 10^{17}$ cm^{-3}, to 22000 cm^2/V·sec. The latter value is almost twice as great as the mobility in $CdSnAs_2$ obtained by Straus and Rosenberg (5).

The forbidden-band width for specimen 2, found from the high-temperature part of the curves $R(T)$ and $\sigma(T)$, was 0.26 eV. The forbidden-band width was also determined from the edge of the optical absorption band and likewise proved to be equal to 0.26 eV. Judging by the sign of the thermoelectric power and of the Hall coefficient, all specimens in the impurity-conduction region had electron conductivity.

Thus, it may be asserted that the compound $CdSnAs_2$ is a semiconductor possessing a mobility exceeding all values known up to now

values for ternary compounds. In addition, in terms of mobility the semiconductor $CdSnAs_2$ proved to be not inferior to InAs and even somewhat superior to it.

The investigations showed that the mobility of current carriers in $CdSnAs_2$ is limited by the presence of extraneous impurities and can be further increased by purification of the material.

A comparison of the mobility values in $CdSnAs_2$ and in InAs is given in Table 2.

Table 2

InAs	InAs	$CdSnAs_2$	$CdSnAs_2$	$CdSnAs_2$	$CdSnAs_2$
according to literature data	according to literature data	according to literature data	according to literature data	according to our data	according to our data
n, cm^{-3}	u, $cm^2/V \cdot sec$	n, cm^{-3}	u, $cm^2/V \cdot sec$	n, cm^{-3}	u, $cm^2/V \cdot sec$
$2.7 \cdot 10^{18}$	$0.9 \cdot 10^4$	$2.7 \cdot 10^{18}$	$5.6 \cdot 10^3$	$4.4 \cdot 10^{18}$	$5.8 \cdot 10^3$
$5.5 \cdot 10^{17}$	$1.3 \cdot 10^4$	$5 \cdot 10^{17}$	$1.2 \cdot 10^4$	$1.7 \cdot 10^{17}$	$1.8 \cdot 10^4$
$1.1 \cdot 10^{17}$	$2 \cdot 10^4$			$1 \cdot 10^{17}$	$2.2 \cdot 10^4$

Thus, the semiconductor $CdSnAs_2$, in comparison with its electronic analog $A^{IIIB}V$, possesses a new combination of properties and a mobility of the same order, which gives grounds for considering it promising for practical applications. The preparation of purer $CdSnAs_2$ samples is the subject of further work.

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Note: Figure translations are in progress. See original paper for figures.