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ELECTRICAL PROPERTIES OF Sn-EXCESS SnTe SINGLE CRYSTAL AND METAL-SEMICONDUCTOR CONTACTS

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*The paper deals with the grown tin telluride (*SnTe*) single crystals containing extrinsic stacking faults (SFs) and their alloyed ohmic contacts of the* 57Bi–43Sn *eutectic alloy in the temperature range of 77–300 K. It is found that at a low concentration, SFs decrease the hole concentration and increase the electrical resistivity of specimens when they occupy vacancies in the Sn sublattice. At a high concentration, SFs create new current carriers, thereby decreasing the specific resistance of specimens. The ohmic contact resistance is rather low, and the current flows mainly through metallic shunts.*

Keywords: solid solution, electrical resistivity, contact resistance, metallic shunt, vacancies.

INTRODUCTION

Tin telluride (SnTe) and its solid solutions are used as topological insulators and medium-temperature thermoelectric materials [1]. These materials crystallize with the stoichiometric deviation, and the Sn sublattice contains a number of structural vacancies with the concentration reaching 10^{21} cm^{-3} [1–3]. Extrinsic stacking faults (SFs) can therefore vary the concentration of the current carriers, and the electrical parameters of SnTe single crystals and solid solution can be varied also.

On the other, the parameters of semiconducting electronic converters, thermal in particular, are also determined by the physical properties of metal-semiconductor contacts that are an integral part of these converters [4–7].

In this connection, the growth process of SnTe single crystals having the different concentration of vacancies in the Sn sublattice and the creation of metal-semiconductor contacts are of particular research and practice interest to researchers including a study of their electrical properties.

The aim of this work is to identify the importance of structural vacancies in the Sn sublattice to the electrical properties of SnTe single crystals and their contact with metal. With this view, Sn atoms are additionally introduced in the obtained SnTe single crystals in the amount of 1.0 at.%, and the metal (57Bi-43Sn eutectic alloy)-semiconductor (SnTe) contacts are synthesized. The electrical properties of the obtained metal-semiconductor contacts are examined in the temperature range of ~77–300 K.

MATERIALS AND METHODS

SnTe single crystals were synthesized by alloying the high pure tin (OSCh-000) and special-purpose tellurium (T-sCh) in the amount of 0; 0.01; 0.05; 0.10; 0.50 and 1.0 at.% Sn-excess. The synthesis of components was performed in quartz ampoules at ~1135 K and ~10^{-2} Pa vacuum pressure during 6 hours. The inner surface of quartz ampoules was

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graphitized. The melt mixing was performed by the mechanical vibration. The preliminary purification of high pure tin and special-purpose tellurium was provided by zone refining.

The Bridgman method was used to grow SnTe single crystals in a dual zone electrical heater. The upper zone was heated 50 degrees higher and 50 degrees lower than the SnTe melting temperature. The temperature gradient at the crystal-melt front was ~15 K/cm; the crystal growth velocity was ~2 cm/h.

The cone-shaped quartz ampoules with the inner diameter of ~7–8 mm and 170 mm length filled with the synthesized SnTe material were placed in the upper zone of the heater. The temperature was gradually risen up to approximately 1150 K, and SnTe material was then cured for 6 hours in the ampoule. Driven by the electric motor, the ampoules were vertically lowered at a ~2 cm/h velocity in the cool zone of the heater. Upon the completion of the crystallization process, the ampoules with SnTe material cooled down to room temperature together with the heater self-cooling. The X-ray diffraction analysis showed that the synthesized ingots are single phase and single crystal. After the refinement, the unit cell parameter of SnTe single crystal was determined to be 6.318(1) Å.

A method of electroerosion cutting was used to obtain the test specimens ~12 mm long from SnTe single crystal ingots. The disarrayed layer formed on the end surface after electroerosion cutting was removed by electrochemical etching. The test specimens for measuring the contact resistance represented two SnTe single crystals of the similar size joined with each other by the ends with the Bi–Sn eutectic solder. The electrical resistivity of the crystals and contacts was measured by an alternating current probe [8]. This method allowed us to avoid errors generated by the direct current induced by the Peltier effect.

Contact points with a 0.2–0.3 mm diameter are deposited on the lateral surface of the specimen along the generating line from both sides from the make-break contact. A distance between the contact points is ~2 mm. Copper wires used as measuring probes are soldered to these contact points. The power supply was provided by an audio frequency oscillator GZ-3. The input voltage control allows setting 0.1–0.5 A current in the circuit. The voltage drop between the contact points deposited on the lateral surface of the specimen along the generating line is recorded by the copper wires soldered to them. The specific transition resistance in the semiconductor-metal-semiconductor contact is determined by the relation

$$r_c = \frac{\Delta U_c \cdot S}{I},$$

where ΔU_c is the voltage drop on the make-break contact, V; S is the area of the make-break contact, cm^2; I is the circuit current, A. The voltage drop in the make-break contact ΔU_c is measured in the following way. The copper probes placed at the similar distance from the make-break contact, are connected by two to a microvoltmeter, and the voltage drop ΔU is then recorded at definite distances from the make-break contact.

During each measurement, the voltage drop ΔU between the probes situated at the same distance from the make-break contact, equals the sum of ΔU_c at the make-break contact and ΔU_l induced by the electrical resistance between the probes of the crystal with the length *l, i.e.* $\Delta U = \Delta U_\text{c} + \Delta U_\text{l}$. Here ΔU_c does not depend on the distance l between the probes, while ΔU_l linearly grows with the increasing distance l.

The $\Delta U/l$ dependence was constructed. The intercept $\Delta U = f(l)$ on the voltage axis corresponded to the voltage drop ΔU_c determined only by the make-break contact resistance. The copper probes were used to measure the electrical resistivity of SnTe single crystals. The measurement error was about 5%. The volt-ampere characteristic of the metal-semiconductor contact determined the ohmicity of contacts in all cases.

RESULTS AND DISCUSSION

The temperature dependencies between the electrical resistivity ρ of SnTe single crystals with the different SF concentration and the contact resistance r_c of 57Bi-43Sn eutectic alloy are plotted in Fig. 1. As can be seen from this figure, the contact resistance r_c increases in all cases with the increasing temperature. At ~77 K, the growth in the SF concentration is accompanied by the decrease in the electrical resistivity ρ from $2.61 \cdot 10^{-4}$ Ohm·cm^2 in the stoichiometric compound to $5.40 \cdot 10^{-5}$ Ohm·cm^2 in the 1 at.% Sn compound. At the same time, the electrical resistivity ρ