THERMOELECTRIC EFFECTS IN ALLOYS Bi-Sn

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Changes of thermopower temperature changes (77-300 K) in bulk Bi-Sn crystals and thermopower of wire crystals Bi-0,07 at%Sn and Bi-0,05at%Sn were measured from the liquid helium temperature to the room one. The dependence $\alpha^2\sigma$ on temperature for both bulk and wire samples is given.

Introduction

Wide possibilities of practical use of thin (with the thickness $10^{-4}\div10^{-5}$ cm) wire crystals in various devices and apparatus favour their comprehensive experimental and theoretical research. In thin wire crystals there appears a number of specific effects, which are not observed in bulk samples and even in films. These effects are determined by the electron movement limitation in two directions of wire crystal. The electron state in the wire crystal due to the limitation of the latter in two directions is determined by two discrete and one continuous quantum numbers. Therefore, quantum size effects in a sense are analogous to the phenomena characteristic of bulk crystal located in the magnetic field.

Experiment and Discussion of Results

Single crystal samples of alloys Bi-Sn were grown by the multiple zone recrystallization. Homogeneity of the impurity distribution along the sample was controlled by the microroentgen phase analysis. Maximal deviation of the sample composition from the set one does not exceed 10%. Samples of rectangular form (10x3x4 mm) were placed into a cryostat for measurements between two bulk copper blocks, with a furnace wound on one of them for creation of the temperature gradient ΔT. The temperature gradient along the sample is determined with the help of copper constantan thermocouples soldered to butt-ends of the blocks.

We measured the thermopower on glass insulated Bi-Sn whiskers with diameter of ≥0,3μm in the temperature range 80-300K. The crystals were obtained by liquid phase casting by the Ulitovsky method [5]. The crystal diameter was measured by the optical microscope MIM-8 (1350 x) with precision of about 0,1μm. The crystal length was 4-5 μm, it was measured by a MI-1 microscope with precision of about 20μm.

Electrical and thermal contacts were formed by In-Ga eutectics. The X-ray analysis proved the monocrystallinity of all the whiskers with preferential <4041> orientation (in hexagonal peaking) along a whisker axis. The third order axis (C_3) is inclined to the whisker axis at the angle of about 80º, and one of the second order axes (C_2) is at right angle to the whisker axis. With respect to the orientation of crystallographic axes such whiskers are similar to bulk crystals of the second type (the crystal axis coincides with the bisector axis C_s).

Fig. 1 shows the concentration dependence α_{11} and α_{33} for bulk Bi-Sn samples at 80 K. When the doping degree increases both components of the thermopower tensor decrease in the absolute value, pass through zero and achieve maximal positive value $\alpha_{11}=\alpha_{33}=40$ μV/degree. In this region the thermopower is approximately isotropic, however when concentration of the impurity atoms grows the thermopower anisotropy is shown again.

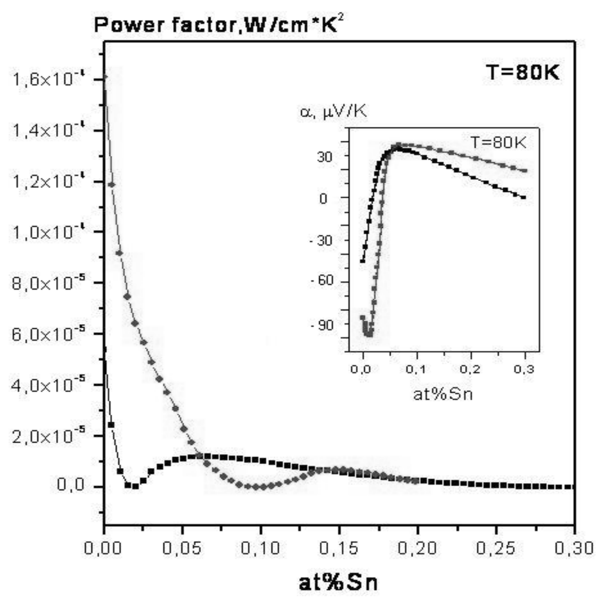

Fig. 1. Power factor and Thermo-e.m.f. in Bi-Sn alloys at 80K. The upper scale represents the (p-n) disbalance obtained by Hall measurements at strong magnetic field.

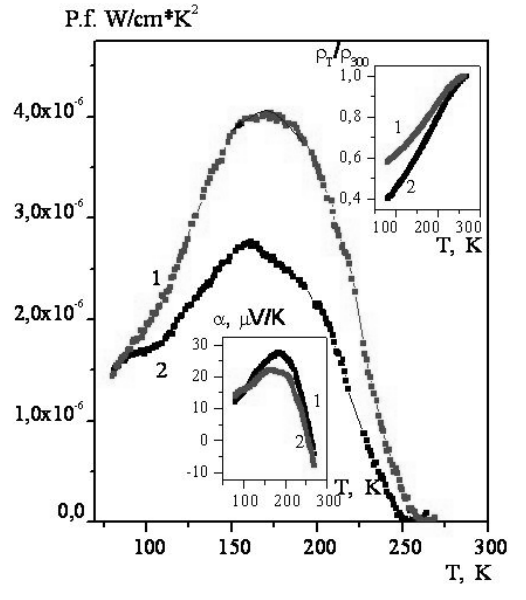

Fig. 2 Temperature dependences of the Power factor ρ_T/ρ_{300} and thermopower $\alpha_{ii}(T)$ of wire Bi-0.07at% Sn.
1. d=0,3μm; 2. d=0,2μm.

Further doping leads to the thermopower sign inversion and disappearance of the thermopower (at the carrier concentration $1{,}7\bullet10^{19}$ cm^{-3}). At the carrier concentration $2{,}5\bullet10^{19}$ cm^{-3} the thermopower component α_{33} achieves its maximal negative value, and the thermopower anisotropy appears again.

Fig. 2 shows temperature dependences of thermopower α(T) for different concentrations of Sn in the wire and fig. 1 shows the temperature dependence of Power factor in the Bi-0,07at%Sn wire with different diameter: 1. d=0,3μm; 2. d=0,2μm.

For explanation of thermopower behavior in weakly doped alloys Bi-Sn the thermopower was theoretically calculated taking into account the phonon drag effect,

This effect was taken into account due to peculiarities of the thermopower temperature change. They are shown at low temperatures, when as it is known favourable conditions for the phonon drag effect manifestation are created [1]. The phonon component in the thermopower in both non-degenerated semiconductors and semimetals may exceed the diffusion component by hundreds and even thousands times. In [2] it is shown that these results are true for space-limited crystals too.

Numerical calculation of the thermopower dependences on temperature and diameter in bismuth wire crystals shows that all the peculiarities of behaviour of α(T) and α(d) at low temperatures are determined by the phonon drag effect. At low temperatures (T<30 K) the phonon drag effect contribution to the thermopower is significant. At the presence of the temperature gradient in the sample the phonon drift from the hot end to the cold one takes place. Existence of this drift leads to the fact that electrons and holes being scattered on phonons obtain additional energy along the phonon drift. The energy of the current carriers obtained from the directed flow of phonons is considerably higher than their diffusion energy along the wire.

For a valuable analysis of thermoelectric efficiency $Z = \frac{\alpha^2\sigma}{\xi}$ it is necessary to know heat conductivity ξ. However, measurement of heat conductivity in wires of bismuth and its alloys is a complicated and labour-consuming problem, which is not solved yet. Available data for bulk crystals of various sizes show that heat conductivity decreases with size reduction [6].

Peculiarities of the temperature dependence $\alpha_{ii}(T)$ in thin wires can be qualitatively understood in the frames of simplified classical approximations. As it is known, when two types of the charge carriers are available for bulk bismuth crystal:

$$\alpha_{ii}(T) = \frac{\alpha_0^h \sigma_{ii}^h + \alpha_0^e \sigma_{ii}^e}{\sigma_{ii}^e + \sigma_{ii}^h} \quad ,$$

where $\alpha_0^{h,e}$ are partial thermopowers of electrons and holes, and $\sigma_{ii}^{e,h}$ are their partial electric conductivities.

As it is seen from the Figure, single crystal wires of bismuth doped with tin at the temperatures below 200 K may be used as a material for p-branch with the parameters close to those of bulk bismuth.

Changing the wire diameter and the doping degree one can shift the interval of maximal value of $\frac{\alpha^2\sigma}{\xi}$ from (30-50) K in pure bismuth wires to (130-220) K in alloys Bi-0,07at%Sn.

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