THICKNESS DEPENDENCES OF KINETIC PROPERTIES OF QUANTUM WIRES OF PURE AND DOPED BISMUTH

P.P.Bodiul[a], A.N.Burchakov[a], D.V.Gitsu[a], A.A.Nikolaeva[a,b]

[a] Institute of Applied Physics, Kishinev, Moldova
[b] International Laboratory of High Magnetic Fields and Low Temperatures, Wroclav, Poland

INTRODUCTION

Last time a great number of researches is devoted to the investigation of quantum and classical size effects [1]. The problem is stimulated by the possibility to detect new effects having no analogues in bulk crystal and to find new applications. From this point of view the bismuth-type semimetals are of particular interest [2]. For instance, in thin monocrystalline bismuth wires, for the first time, the effect of the magnetic flux quantization on a single connected geometry was revealed at the investigation of longitudinal magnetoresistance. However, the influence of sizes on thermoelectric effects, particularly in thin wires, is studied only in a rather limited number of works. Nowadays this problem draws attention due to discovery of high-temperature superconducting materials with critical temperature T_c = 90-130 K. The solid state depth cooling by the Peltier effect employment is of interest in solving the problem of practical use of HTSC materials.

One of the best materials for the thermoelectric cooling is Bi_2Te_3 with $Z_{3D}T$= 0.67 at 300 K [3]. A number of theoretical works [4-6] has appeared showing the possibility to increase the material figure of merit ZT, in some complex two-dimensional quantum wells. Special attention is paid to the bismuth superlattice [6]. It was shown that Bi is a good thermoelectric material if the overlapping of the valence and conduction bands is removed. [7] The most important conclusion of [6] is that in order to improve ZT in comparison with the bulk material it is necessary to separate these two bands by size quantization and to obtain the one-band system. The ZT increase is determined also by the structure of 2D density of states. By using the superlattice with quantum wells, it is possible to obtain high $Z_{2D}T$ not only on materials with a large ZT in bulk (as Bi_2Te_3). Moreover it is better to use a material with low ZT in bulk (as Bi), but the one in which the condition of the size quantization effect is easier fulfilled.

The aim of our work was to study the thickness and temperature dependences of the resistance R(T) and thermo-e.m.f. S(T) of thin monocrystal wires of pure and Sn-doped bismuth. We were encouraged by the fact that in such thin d < 1μm wires of bismuth the effect of the magnetic flux quantization was observed, and the thermo-e.m.f. S changes its sign increasing in the positive region at the temperature decrease. This change significantly depends on the diameter d of Bi wires [8, 9].

SAMPLES, METHODS OF EXPERIMENT

The wires of pure and Sn-doped bismuth were obtained by the liquid phase casting in a glass coating [2].

With the aid of the X-ray analysis, angular diagrams of the transverse magnetoresistance and Shubnikov-de Haas oscillations was established that all the wires were monocrystals with the same orientation - the wire axis with the C_3 axis make up 19.5° angle in the bisector-trigonal plane. The sample diameter was varied from 0.1 up to 10 μm. The perfection of the crystal structure increases while the sample diameter d decreases. The doped wires were prepared by the method of the successive dissolution of the alloys Bi-0.3at%Sn and Bi-0.05at% Sn, obtained previously by the method of zone-melting recrystallization.

The resistance was measured by the two-contact method. At the measurements of the thermo-e.m.f. S in order to obtain good wetting and reliable electrical and thermal contacts with the bulk copper blocks the InGa eutectic was used. The measurement of the thermo-e.m.f. S in the region 300-80 K was made by the thermocouples copper-constantan, and in the region 80-4.2 K - by Cu-Cu/Fe ones.

The Shubnikov-de Haas oscillations were studied in the field of the Bitter magnet (up to 14T) and in the superconducting solenoid at the International Laboratory of Strong Magnetic Fields and Low Temperatures (Wroslaw, Poland).

RESULTS OF INVESTIGATIONS AND DISCUSSION

The temperature dependences of the resistance R(T) in the range 4.2-300 K, thermo-e.m.f. S(T) and Shubnikov-de Haas oscillations (H II I) in pure and Sn doped bismuth wires, (Bi-0.01 at%Sn; Bi-0.02 at%Sn; Bi-0.05 at%Sn and Bi-0.07 at%Sn) with the diameters from 0.1 up to 10 μm were studied.

Fig.1 shows the Shubnikov-de Haas oscillations of the thin wires of the above-mentioned compounds.

For pure Bi wires of the used orientation in the longitudinal field H II I the following periods of oscillations are observed: from the electron ellipsoid (a) pulled along the wire axis, from almost equivalent oriented two electron ellipsoids (b), as well as from close to the maximum cross-section of the hole ellipsoid in the T point of the Brillouin zone the difference is about.

$$\Delta^{e} = (3.8 \pm 0.4)10^{-5} Oe^{-1}; \Delta_{b}^{e} = (8.0 \pm 1)10^{-5} Oe^{-1}; \Delta_{T}^{h} = (0.6 \pm 0.1)10^{-5} Oe^{-1} \qquad [2]$$

The tin doping of bismuth leads to the shift of the Fermi level ε_F deep into the T valence band. As it was shown in [8] at $\varepsilon_{FL} \to 0$, the "rigid bands" model is justified, so the isoenergetic surfaces keep the "ellipsoidal" form, the anisotropy of the electron and hole Fermi surface in L and T is not changed. Taking into account this and the value of anisotropy of the hole Fermi surface in T : (S^{max}_{exp} / S^{min}_{exp} = 3.32), the position of $\varepsilon_F{}^T$ for all the above-mentioned alloys was estimated by the period of Shubnikov-de Haas oscillations from T holes and L electrons. In the alloys Bi-0.02 at% Sn only the oscillations from T holes are well