BOLOMETER FOR RECEPTION OF INFRA-RED RADIATION IN A WIDE DYNAMIC RANGE

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Abstract

Results of the measurements of galvanomagnetic properties of thin monocrystal wires of PbTe<Tl> in the temperature region 0,4÷300 K are presented. Monocrystal wires (with diameters d = 5÷100 μm) were obtained from solution melt by the filling of quartz capillary with the following crystallization of material. The structural perfection of investigated samples was tested by X-ray diffraction and LAMMA analysis. It is revealed, that at low temperatures in monocrystal wires of PbTe<Tl> transition in a superconducting condition is observed. Moreover, starting with T = 30÷40 K samples exhibited negative temperature coefficients of resistance down to T = 0,4 K. The temperature of transition correlates with concentration of an impurity (for monocrystal wires of PbTe<Tl> at thallium concentration 2% Tc = 2,1 K).

Such unusual behaviour of temperature dependence of resistance in the region of low temperatures has been used by us for creation a bolometer for detection of infra-red radiations in a wide dynamic region, which can be used in spectroscopy, geophysics, astrophysics and also in other domains of science and technology, which needs measuring of weak infra-red radiation.

Introduction. Today for detection radiation with wavelengths from far infra-red radiation to near infra-red radiation (between 200 μm and 3 mm) widely are used bolometers [1]. Unique materials for creation of such type of bolometers are compound A4B6 doped by elements of the third group.

Doping of semiconductor compounds of type A4B6 by elements of III group leads to a number of features in their electro physical and optical properties [2,3]. By that is explained the interest to such materials and, in particular, to semiconductor compound Pb1-xTlxTe as to the most striking example in which a lot of unique properties have been observed. Dramatic influence of Tl content on superconducting properties is the main feature of Pb1-xTlxTe semiconductor [4]. Specific action of thallium consists in the following: the thallium impurity generates on the range of the permitted band states of a valence band an impurity band that leads to essential change of density of band states. It leads to essential change of transport coefficients which are determined by density of states, by the form of the impurity band and by the relative position of the Fermi level [2,3].

On the other hand starting with T = 30÷40 K samples exhibited negative temperature coefficients of resistance down to T = 0,4 K [5].

Such unusual behaviour of temperature dependence of resistance in the region of low temperatures – a semiconductor form and transition in a superconducting state – has been used by us for creation a bolometer for detection of infra-red radiations in a wide dynamic region.

Experimental results and discussion. Monocrystal microwires of Pb1-xTlxTe (diameter d = 5÷100 μm, length l ~ 20 sm) with thallium average concentration x = 0.001÷0.02 were grown in the following way [6] (Fig. 1). In the quartz tube (diameter – 15 mm) initial material with corresponding chemical composition was placed. The bulk material was prepared in the following way. Since pure Tl oxidizes in the air quickly and greatly, it is necessary for a preparation of initial mixtures to use compounds of thallium – in our case TlTe. Syntheses of polycrystalline materials (PbTe)1-x(TlTe)x of corresponding compounds were made in the quartz tube in the hydrogen atmosphere. Over the material the bunch of quartz capillary is situated. The choice of quartz as the material for capillaries is limited by the high temperature of softening one, what must be higher than the melting temperature of material. The tube was evacuated up to residual pressure 10–2 ÷ 10–3 Pa and placed in vertical zone furnace, in which the temperature on the whole length of the capillary is the same and higher than the melt temperature of material (Tmelt < T < Tsoft). After melting of material the capillary with open lower ends were put down in the melt material. Afterwards in the tube rise pressure under which capillary were filled by the melting material. Crystallization of melting material was realized directly beginning from soldered ends to open one at the of move of furnace (rate of move may be changed and make up several centimeters per hour). Given method of obtaining of monocrystal microwires allows to produce samples with different diameters under the same grown conditions with high structural perfection. The structural quality was tested by X-ray diffraction and Laser Microprobe Mass Analyzer (LAMMA).

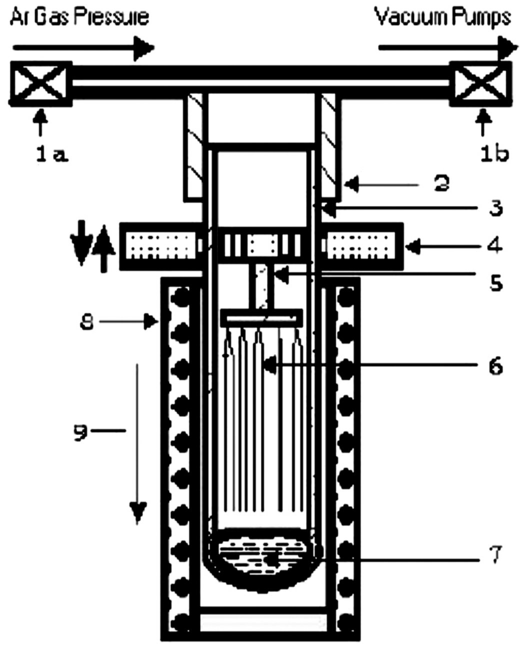

Fig.1. Sketch of the laboratory-scale apparatus for fabrication of thin glass-coated semiconducting wires using the high-pressure injection and directional crystallization method.

1a, 1b – vacuum valves; 2 – metallic tube; 3 – quartz tube; 4 – permanent-magnet system to move capillaries; 5 – support for capillaries; 6 – glass capillaries; 7 – molten material; 8 – electric furnace; 9 – direction of furnace movement during wire crystallization.

The samples for the measurements were prepared in the following mode. The sample of the corresponding diameter was choused from the set of crystals obtained in that way for carrying out of measurements. As the initial sample has glass isolation, it was preliminary subjected to selective etching in a solution of acid HF. Reliable electrical contact was made using eutectic In-Ga. Measurements have been executed both on samples with different diameters, and on samples of the same diameters. Measurements of temperature were carried out by means of thermocouple Cu – (Cu + 0,04 at % Fe). Such thermocouple make possible to carry out experiments with high precision in low temperature region.

In the Fig. 2–4 temperature dependences of resistivity vs temperature of monocrystals microwires of Pb1-xTlxTe are shown. The analysis of temperature dependences of resistivity shows, that in the doped samples the superconductivity with Tc > 0.4 K appears at x > 0.01. Specimens with lover thallium concentration starting with T = 30÷40 K exhibited negative temperature coefficients of resistance down to T = 0.4 K. Typical temperature dependencies of resistance are brought in Fig. 2–4.

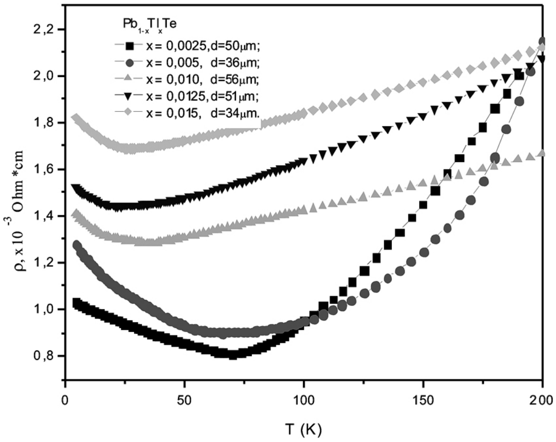

Fig. 2. Low-temperature resistivity of monocrystal wires of Pb1-xTlxTe.

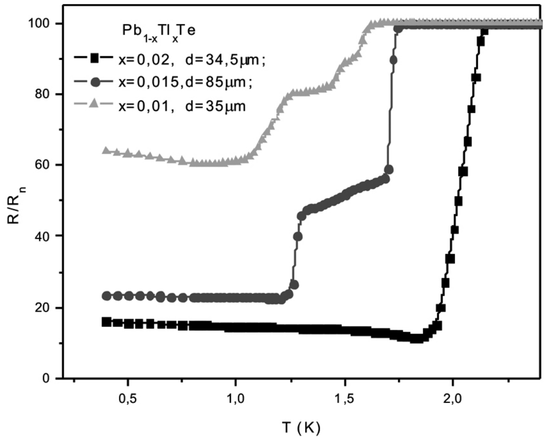

Fig. 3. Low-temperature resistivity of monocrystal wires of Pb1-xTlxTe.

Not going into details discussion on the mechanism of superconducting properties of this materials, we shall note that. From the moment of discovery of superconductivity in system PbTe <Tl> traditionally the mechanism of explanation of the superconductivity was based on the bases that the resonant states of an impurity play thus a decisive role [2,3].

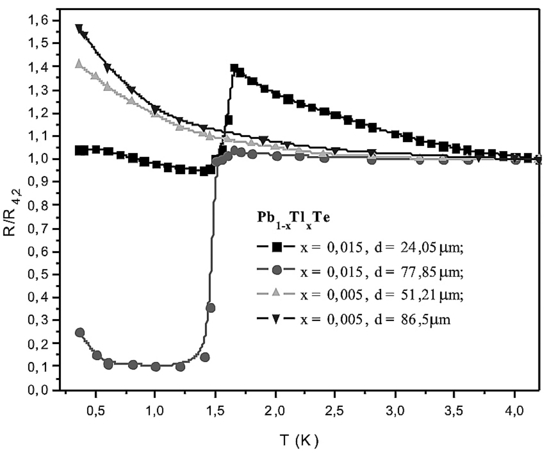

Fig. 4. Low-temperature resistivity of monocrystal wires of Pb1-xTlxTe.

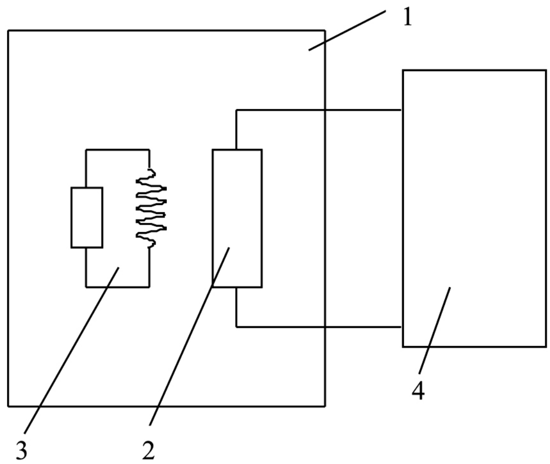

Fig. 5. Flow diagram of the bolometer.

Working of the detector is based on use of this dependence of resistance from temperature, namely for detection signals of the big capacity the interval of a semiconductor course (working temperature T > Tc) is used. For fixing signals of low power (T ≈ 2 K < Tc) the area of superconducting transition is used. Thus, in the proposed device for expanding of dynamic range of infra-red radiation detection is used the specific interior quality of Pb1-xTlxTe (x = 0,01÷0,0225) – the temperature coefficient of resistance dR/dT is different for different temperature: dR/dT < 0 at T > Tc and dR/dT > 0 at T ≈ Tc (T – operating temperature, Tc – critical temperature of the material), that leads to a sharp change of sensibility at transition of sensitive element from the state with dR/dT < 0 in other state with dR/dT > 0.

In the Fig. 5 is presented a flow diagram of the proposed bolometer. In the cryostat with helium 1 is plased the sensitive element 2 (sensing element are produced from lead telluride doped with thallium), connected with registration apparatus 4. The sensitive element is placed in the system 3, that allows changing and controlling his operating temperature.

The operation of bolometer is based on electric resistance dependence vs temperature of sensitive element, namely the conditions “wide band” is reached during the work in semiconductor state, that means at the temperature of work T > Tc. Transition in “narrow band” state is achieved by temperature decreasing till to T ≈ 2 K < Tc, that means in superconducting state, when dR/dT is one hundred times more than the value of dR/dT in semiconductor state of sensitive element and as a result, the sensibility of sensor increases one hundred times.

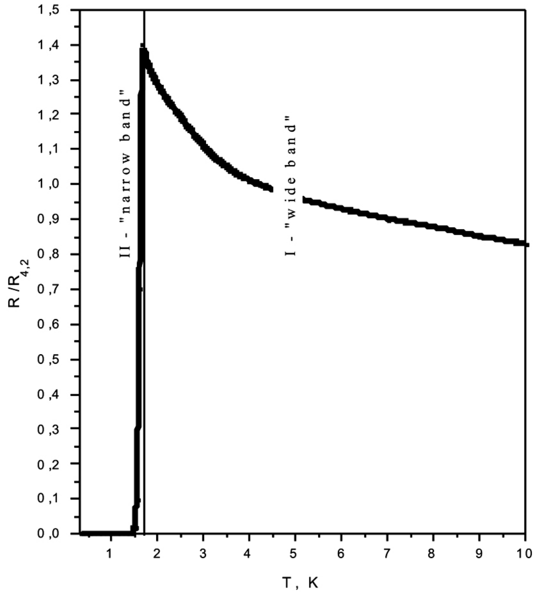

Fig. 6. Characteristivc dependence of normalized resistance from temperature of the sensitive element (monocrystal wires of Pb1-xTlxTe).

Transition from the superconductor state into normal one of the sensitive element can be used as a signal about exceeding of the radiation power over critical value. In the region of normal state of the sensitive element the bolometer can be also used for measuring radiation, because his resistance depends on the temperature (dependence dR/dT characteristic for the semiconductors).

In the Fig.6 is presented the characteristic dependence of normalized resistance vs temperature R(T)/R4,2 (R4,2 – the resistance of sensitive element at the temperature of 4,2K) of the sensitive element fabricated from Pb1-xTlxTe with indication of temperature regions corresponding to conditions of operation: I – “wide band”; II – “narrow band”.

Conclusions

In the present work the results on research of resistive properties of monocrystal wires of Pb1-xTlxTe (x=0.001 ÷ 0.02, d = 5 ÷ 100 μm) in a wide range of temperatures are presented. The principal task of research was the analysis of the experimentally established features of resistive properties of these systems in the range of low temperature and elaboration on the base of these results of the sensor of infra-red radiation with a wide dynamic range for reception of radiation.

It has been shown, that on the basis of thin monocrystal wires of PbTe<Tl> it is possible to fabricate the sensor of infra-red radiation with a reconstructed band of reception of radiation. Due to essential expending of dynamic range of bolometer with wide dynamic band of infra-red radiation is possible to use it for registration of infra-red signals with a large variation of intensity, for example, for topographical survey of the surface of land, water, etc.

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