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The method of measuring the thermoelectric power in the thin films of the semimetals and narrow-gap semiconductors formed on the thin substrates

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Abstract. In our paper we propose the method for measuring the thermoelectric power of thin semimetals films and narrow-gap semiconductors on the thin substrates. This method eliminates the occurrence of mechanical stresses due to different thermal expansion coefficients of the substrate material and the gradient plates. We compared the thermopowers' temperature dependences obtained by the new method of measuring and by the standard method for thin films $Bi_{1-x}Sb_x$ on a substrate of mica. With the help of our method it is possible to get more reliable results for thin films of semimetals and narrow-gap semiconductors formed on thin substrates.

1. Introduction

Currently, studies are being conducted actively to increase the efficiency of thermoelectric materials suitable for the creation the thermoelectric converters. One way to improve the efficiency of such converters is the use of thermoelectric thin films [1–2]. When conducting research in this area there are a number of difficulties, especially in the measuring the thermopower.

Studying low-dimensional systems' thermoelectric power is a difficult task, since it is necessary to create and accurately measure the temperature difference between "cold" and "hot" contacts for miniature objects. The complexity of these investigations increases when study the thin films on the thin substrates (5–40 μm) in a wide temperature range. The classical method of creating the controlled temperature gradient along the film is placing it on a sufficiently thick metal plate, along which there is measured temperature gradient. To improve the thermal contact of the substrate with film and plates liquid lubricant are used. However, this method gives satisfactory results only in the temperature range in which the plasticity of thermally conductive grease is stored. When measuring the thermopower at temperatures less than 200 K, especially for narrow-gap semiconductors and semimetals films, can be obtained substantially distorted results. It is known that the properties of these materials are heavily influenced by mechanical deformation [3–7]. The solidified lubricant is rigidly connected the substrate with film and the "gradient" plate that, due to different coefficients of thermal expansion (CTE) of the used materials give a rise to the deformation in the system, and thus in the film. So when using the gradient plates, we study not the film on the substrate, but the film on the substrate fixed on a gradient plate.

2. The basic idea of the new method of measuring the thermopower

The main idea of our method is to create an additional film structure on the back side of the substrate with respect to the film. This structure contains a copper resistance thermometer with four probe resistance measurement method and film heater (figure 1). The resistance thermometer located just below the hot contacts to the film. The film heater is located close to the resistance thermometer. Take into account the small thickness of the substrate, a resistance thermometer's temperature and the temperature of the film in the contact area equal.

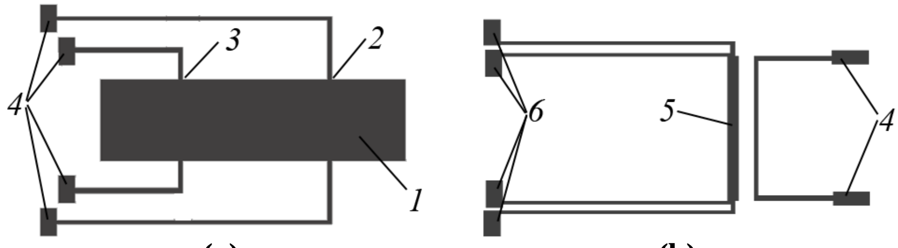

Figure 1. The topology of the object. Front side **(a)**: *1* – studied thin film; *2* – "hot" contact; *3* – "cold" contact; *4* – contacts for measuring the thermopower. Back side **(b)**: *4* – film heater; *5* – thermistor; *6* – lead contacts to the thermistor.

As the material for the film resistance thermometer is selected a copper as it has close to a linear temperature dependence of the resistance in a wide temperature range. The contacts and film heater are made of manganin, which has a low value of the thermoelectric power combined with copper and a small temperature coefficient of resistance. Additional thin film structure is produced by thermal evaporation in a vacuum.

The holder's flat surface on which is mounted the film has a ledge with the height of 0.5–1 mm. Film is installed on this surface so that over the ledge is only "hot" contact of the film, resistance thermometer and heater. Installing the substrate with the film to the holder is either weak mechanical pressure in the region of the contact pads, or a small drop of glue also in the contact area. The process of measuring the thermopower's temperature dependence with the help of our method is carried out according to the algorithm presented below.

1. The film heater is turned off; 2. The holder's temperature is stabilized in accordance with the studying temperature point; 3. The resistance of the resistance thermometer is measured; 4. The studied film's value of the thermopower is measured at the heater off; 5. Turns film heater, pausing to reach steady state (~ 5 s); 6. The current and the voltage drop are measured by the resistance thermometer; 7. The studied film's value of the thermopower is measured at the heater on; 8. The film heater is turned off; 9. The holder's temperature is stabilized in accordance with the next studying temperature point. Next, the algorithm is repeated.

If we study the influence of the magnetic field on the thermopower, points 6 and 7 are repeated with each value of the magnetic field. At the end we process the obtained results.

We calculate the resistance value of the resistance thermometer (RT). Using the values of the holder's temperature at the temperature points and resistance values of RT at these points, we construct the dependence of resistance RT via temperature (figure 2). We find the temperature coefficient of resistance RT by approximating the dependence into the line.

At each temperature point we find the difference of the resistance RT when the heater is on and off and then using the temperature coefficient RT, we calculate the temperature difference formed when the heater is turning on (figure 2). After that we calculate the difference in the thermopower of the film sample with and without a heater and using the temperature difference, we determine the value of the differential thermopower.

The measurement error of the thermoelectric power of the polyimide film on mica substrates with thickness 5–40 μm when the temperature difference across the sample 5–8 K is ~ 5%.

We used this method while studying the temperature dependence of the thermopower of the bismuth and bismuth-antimony films on substrates of mica (muscovite) and polyimide films.

3. Results and discussion

For example, figure 3 shows the dependence of the thermoelectric power via temperature for films $Bi_{92}Sb_8$ $Bi_{95}Sb_5$ on mica. There is the curve obtained with the help of the gradient plate and vacuum oil as a heat contact and the curve obtained when using the proposed method of measurement. For comparison there are results at the increasing and at the decreasing temperature. As it can be seen from figure 3, the thermoelectric power's temperature dependences obtained by the forward and reverse temperature during are almost the same. But when we use the gradient plate the direct and inverse temperature dependence vary considerably. You can see that there is an abrupt increase in absolute value of the thermoelectric power at the area of 150 K on the graph obtained at the decreasing of the temperature. It is connected with exfoliation of the substrate with film from the gradient plate because of the high mechanical stresses caused by the differences in CTE of the substrate material and the gradient plate.

On the graph obtained in the reverse temperature during also there is the sharp changing of the thermoelectric power's value, but at the temperature of 230–250 K. This temperature corresponds to the melting temperature of the vacuum oil and to the recovering of the heat contact between the substrate and the gradient plate.

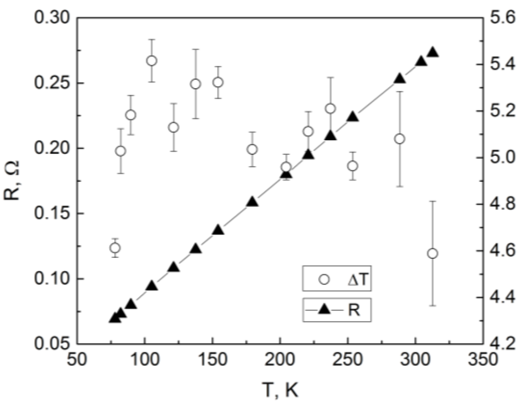

Figure 2. The temperature dependence of the film copper TR's resistance (R) and the temperature difference (ΔT) along the sample at the constant current of the film heater at the studying the thermopower's temperature dependence.

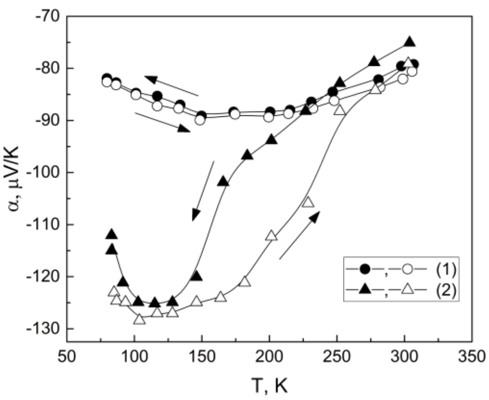

Figure 3: The thermopower's temperature dependence of the thin film $Bi_{92}Sb_8$ with thickness 0.75 μm on mica. This dependence obtained by the proposed method (1). The thermopower's temperature dependence of the thin film $Bi_{95}Sb_5$ with thickness 0.75 μm on mica (2). This dependence obtained with the help of the gradient plate.

4. Conclusions

On the basis of our research we can conclude that the proposed method of measuring the thermoelectric power's temperature dependences of the thin films on thin substrates provides reliable, repeatable results without additional mechanical strains in the sample.

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References

[1] Dresselhaus M S, Dresselhaus G, Sun X, Zhang Z, Cronin S B and Koga T 1999 *Phys. Solid State* **41** 679–82
[2] Hicks L D and Dresselhaus M S 1993 *Physical review* B **47** 16631

[3] Kusagaya K, Hagino H, Tanaka S, Miyazaki K and Takashiri M 2015 *Journal of Electronic Materials* **44** 1632–6
[4] Kusagaya K and Takashiri M 2015 *Journal of Alloys and Compounds* **653** 480–5
[5] Komarov V A 2002 *Proc. Int. Conf. Thermoelectrics and their Applications (St. Petersburg)* (Saint Petersburg: Ioffe Institute) p 237
[6] Kablukova N S, Komarov V A, Demidov E V and Khristich E E 2012 *Izvestia: Herzen University Journal of Humanities & Sciences* **153** 13–9
[7] Grabov V M, Komarov V A and Kablukova N S 2016 *Phys. Solid State* **58** 622–8