ISSN 0020-4412, Instruments and Experimental Techniques, 2006, Vol. 49, No. 3, pp. 435–437. © Pleiades Publishing, Inc., 2006.
Original Russian Text © D.M. Edgorova, S.S. Dzhakhanov, A.V. Karimov, Sh.M. Kuliev, 2006, published in Pribory i Tekhnika Eksperimenta, 2006, No. 3, pp. 149–151.

LABORATORY TECHNIQUES

A Method for Determining the Thermal EMF and Thermal Conductivity

D. M. Edgorova, S. S. Dzhakhanov, A. V. Karimov, and Sh. M. Kuliev

Physicotechnical Institute NPO Fizika-Solntse, Academy of Sciences of Uzbekistan,
ul. Mavlyanova 2b, Tashkent, 700084 Uzbekistan
e-mail: karimov@uzsci.net

Received August 8, 2005

Abstract—A method for measuring the thermal emf and thermal conductivity of conducting samples is described. After the temperature and potential differences are measured between the sample's ends, on which metal contacts are deposited, at a specified direct current, the current is turned off, and instantaneous values of the integral thermal emf are measured directly at the metal contacts. Using the results from measuring the temperature and potential differences during passage of the direct current, the electrical and thermal conductivities of the sample are calculated. A specific feature of this technique is the use of additional thick metal layers being in contact with the surfaces of the metal contacts at the sample's ends, which are aimed at stabilizing the temperature gradient along the sample when the current source is switched off.

PACS numbers: 44.10.+i, 65.40.-b, 72.15.Jf

DOI: 10.1134/S0020441206030249

Thermoelectric materials are widely used in the development of independent electric-power sources [1]. Quality factor Z of thermoelectric materials is determined by the values of thermal emf α, thermal conductivity χ, and electrical conductivity σ:

$$Z = \alpha^2\sigma/\chi. \quad (1)$$

The known methods and devices for complex measurements of thermoelectric parameters of semiconductor and composite materials are fairly intricate [2–4]. In simpler techniques, e.g., such as that described in [5], one has to perform several measurements, each of which introduces its own errors into the final result, to determine one parameter.

In this study, we describe a modified version of this technique, which is suitable for measuring the thermal emf and thermal conductivity of conducting materials—semiconductors and semimetals—as well as composite materials [6]. A distinguishing feature of this technique is the use of additional thermal reservoirs—metal layers with a high thermal conductivity located at the ends of a long sample. The presence of such layers allows measurements of the thermal emf to be measured upon interruption of a Peltier current.

Figure 1 shows a sample prepared for such measurements. Rectangular sample *1* is manufactured from a current-conducting material. Metal contacts *2* applied to the sample's ends are in contact with a thick layer *3* of a high-conductivity (e.g., tin-based) material of volume $S_k\sqrt{S_k}$, where S_k is the area of the contact.

The electric circuit for performing measurements is shown in Fig. 2. Current lead-ins *2* connect the sample to current interrupter–switcher *3*, the circuit of which includes ammeter *4*. The temperature at the sample's ends is measured by thermocouples *5* and *6*. Using switches *7* and *8*, the ends are switched alternately to galvanometer *9*.

The measurement procedure is as follows. First, the initial values of temperatures T_1^0 and T_2^0 at the sample's ends are measured by thermocouples *5* and *6* at zero current (switch *3* in position II). A direct current is then fed to the sample from source *10* (switch *3* in position I) and a specified current value is set. After a

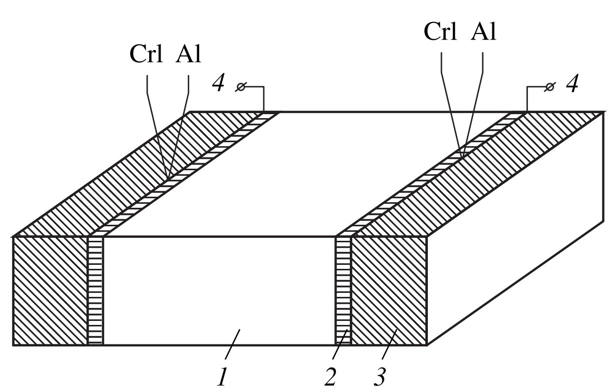

Fig. 1. Sample prepared for experiments: (*1*) sample of a current-conducting material, (*2*) metal contacts, (*3*) layers of a material with a high specific heat, and (*4*) current lead-ins.

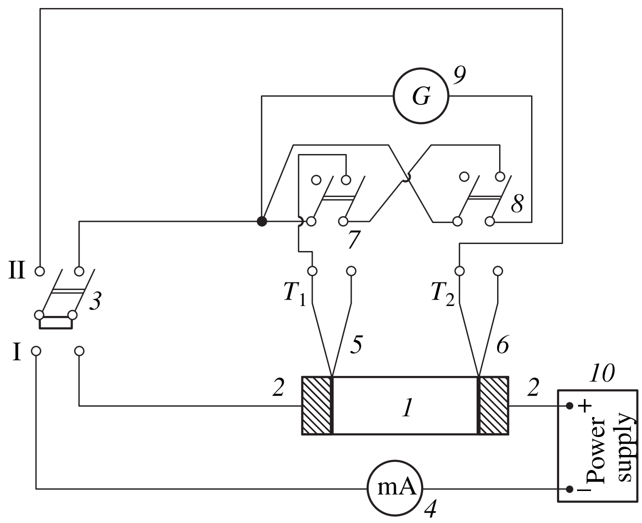

Fig. 2. Circuit diagram for determining the thermal emf and thermal conductivity of a sample: (*1*) sample prepared for experiments, (*2*) current lead-ins, (*3*) interrupting switch, (*4*) ammeter, (*5*, *6*) thermocouples, (*7*, *8*) switches, (*9*) galvanometer, (*10*) power supply.

steady-state regime is established, the current is measured. Subsequently, switches *7* and *8* are switched in turn to positions T_1 and T_2, and the temperature difference along the sample is measured:

$$\Delta T = |T_1| - |T_2|, \tag{2}$$

where $T_1 = |T_1^0| - |T_1^{\mathrm{I}}|$ and $T_2 = |T_2^0| - |T_2^{\mathrm{I}}|$. The current is then interrupted (switch *3* is set to position II), and the instantaneous values of potential difference U along the sample are measured at a zero current (the time constant of establishing the thermal equilibrium along the sample far exceeds the time constants of the thermocouples and galvanometer). From these data, integral thermal emf $\alpha = U/\Delta T$ can be found.

Using additional data obtained in measurements, the thermal conductivity of the sample can simultaneously be determined from the formula

$$\alpha I\bar{T} = \chi \Delta TS/l, \tag{3}$$

where α is the thermal emf, I is the direct current, $\bar{T}$ is the average temperature, χ is the thermal conductivity, ΔT is the temperature difference between the sample's ends, l is the length of the sample, and S is its cross section.

The table presents the results from measurements of the thermal emf and thermal conductivity of semiconductor samples based on gallium arsenide and silicon, as well as of a pressed sample and ingots of bismuth telluride and antimony, which were published in [7, 8]. The thermal emf values measured by our method are in satisfactory agreement with the data obtained by another method—the heating of one of the sample's ends [3].

The ambient temperature that was lower than the average temperature of the sample during measurements can explain the insignificant difference of our data from those obtained by the other method. As a result, the heat removal from the sample's center determined an additional contribution to the thermal emf measured.

Hence, additional metal layers with a high specific heat that serve to stabilize the temperature upon current interruption allow measurements of the thermal emf, the thermal conductivity, and the electrical conductivity of samples in a single experiment. The method proposed can be used in studies of thermoelectric and thermal characteristic of thermoelectric semiconductors and materials used in the semiconductor industry.

REFERENCES

1. Khvostikov, V.P., Khvostikova, O.A., Gazaryan, P.Yu., et al., *Fiz. Tekh. Poluprovodn.* (S.-Petersburg), 2004,

Table

Sample	Gradient ΔT, °C	Average temperature $\bar{T}$, °C	Thermal emf α, μV/°C	Thermal emf measured upon heating one sample's end [3]	Thermal conductivity, W/(°C · cm)
n-GaAs	0.8	30.6	210		1.6×10^{-2}
n-Si	1.5	30.3	300		1.74×10^{-2}
$(BiSb)_2Te_3$ (pressed)	1.0	30.1	297	295	2.6×10^{-2}
$(BiSb)_2Te_3$ (ingot)	1.0	30.1	200	190–200	1.4×10^{-2}

vol. 38, no. 8, p. 988 [*Semiconductors* (Engl. Transl.), vol. 38, no. 8, p. 950].

2. Glazov, E.I., Okhotin, A.S., Borovikova, R.P., and Pushkarskii, A.S., *Metody issledovaniya termoelektricheskikh svoistv poluprovodnikov* (Methods of Investigation of Thermoelectric Properties of Semiconductors), Moscow: Atomizdat, 1969.
3. *Teploprovodnost' tverdykh tel. Spravochnik* (Heat Conduction of Solids. Handbook) Okhotin, A.S., Ed., Moscow: Energoatomizdat, 1984.
4. Likalter, A.A., Abstracts of Papers, *XX Int. Conf. on Phenomena in Ionized Gases*, Pisa, Italy: Inst. of Atomic and Molecular. Phys., 1991, vol. 4, p. 883.
5. Harman, T.C., Cahn, J.H., and Logan, M.J., *Appl. Phys.*, 1959, vol. 30, no. 9, p. 1351.
6. Karimov, A.V., Resp. Uzbekistan Patent no. 5768, Kl. 6G01 no. 25/18 no. IAP 02666, Byull. Izobret., 2005, no. 2.
7. Karimov, A.V., Agzamova, M.Kh., Edgorova, D.M., and Nurkuziev, G., *Geliotekhnika*, 1992, no. 3, p. 12.
8. Karimov, A.V., Agzamova, M.Kh., Edgorova, D.M., and Nurkuziev, G., *Geliotekhnika*, 1993, no. 3, p. 75.