POSSIBILITY OF CONTROLLING THE TEMPERATURE DEPENDENCE OF THERMOELECTRIC-CONVERTER PARAMETERS

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The possibility of controlling the temperature dependence of thermoelectric-converter parameters by selection of the doping-impurity concentration of thermocouple material is discussed. Fundamental parameters are presented for semiconductor thermoelectric converters.

Thermoelectric converters, which check processes accompanied by the liberation of heat and radiant energy, for example, heat converters to measure the fundamental electrical ac quantities in a frequency range from several hertz to hundreds of megahertz, are used extensively in metrology and measuring technique.

Converters fabricated on the basis of metal thermocouples are most widespread [1]. However, the low sensitivity of metal thermocouples specifies a low loading capacity for such converters, that their volt—ampere characteristics will be significantly not quadratic, and a low value of the thermal emf at the nominal current, etc.

An essential improvement in the properties of thermoconverters can be achieved by using thermocouples of semiconducting materials that possess a significantly higher coefficient of thermal emf.; the low thermal conductivity of the semiconductors permits us to realize the needed temperature drops easily.

However, a sharp temperature dependence of the parameters is inherent to the majority of semiconducting materials [2], which is, in our opinion, the main reason for the rejection of semiconductor thermocouple utilization in heat converters [3]. A heat converter with semiconductor thermocouples, produced in the USA [4], is known. In this case the use of bismuth telluride semiconductor thermocouples significantly raised the reliability and squareness of the conversion, as regards the temperature dependence of the conversion coefficient. By analyzing the properties of bismuth telluride [5], it can be seen that it does not satisfy the rigid requirements of measurement technique. The purpose of this paper is to develop a method which would permit the control of the temperature dependence of the fundamental heat-converter parameters by changing the temperature dependence of the thermal emf coefficient, the thermal conductivity, and the electrical conductivity of the semiconducting material.

The investigations were conducted on cadmium antimonide single crystals doped with silver and zinc impurities. There were two reasons for the selection of the material: on the one hand, the high thermal emf coefficient assures the needed output signal at a negligible temperature drop, which improves the squareness of the transformation, as is known [6]; on the other hand, cadmium antimonide is a material studied sufficiently well, and its band spectrum affords a possibility of performing optimization computations at the necessary level.

The idea of controlling the temperature dependence of heat-converter parameters is that the temperature dependence of the fundamental thermoelectrical parameters can be reduced to a minimum by selecting the doping-impurity concentration in such a way that two competing carrier relaxation mechanisms, for example, scattering by acoustical phonons and by an ionized impurity, would simultaneously act in a given temperature band. Then according to the model of nonequivalent valleys [7], the tensor components of the thermoelectrical parameters of a material in a semiconductor can be represented at almost-room-temperatures in the form

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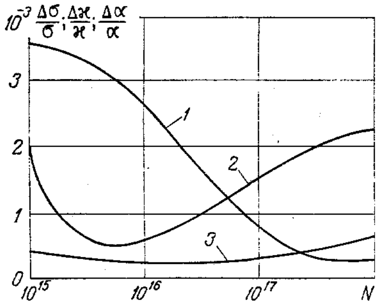

Fig. 1

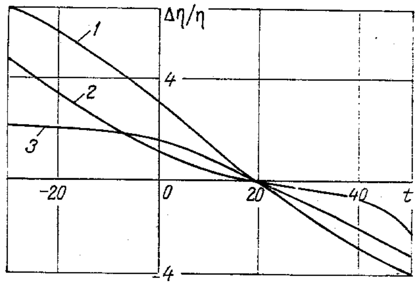

Fig. 2

Fig. 1. Concentration dependences: 1) electrical conductivity; 2) thermal conductivity; 3) thermal emf in CdSb single crystals doped with Ag and Zn in the 300-330°K temperature interval. $\Delta\sigma/\sigma$, $\Delta\varkappa/\varkappa$, $\Delta\alpha/\alpha$ $\deg^{-1}$; N, cm^{-3}.

Fig. 2. Temperature dependence of the volt — watt response of thermoelectric converters: 1) TVB-type thermal converter; 2) semiconductor converters with CdSb thermocouples; 3) multielement TEM thermal converters. $\Delta\eta/\eta$, %; t, °C.

$$\sigma_{ii} = \sum_{n=1}^{3} \sigma_{ii}^{(n)} = e^2 \left(\frac{\rho^{(1)} \langle \tau_{ii}^{(1)} \rangle}{m_{ii}^{(1)}} + \frac{\rho^{(2)} \langle \tau_{ii}^{(2)} \rangle}{m_{ii}^{(2)}} + \frac{\rho^{(3)} \langle \tau_{ii}^{(3)} \rangle}{m_{ii}^{(3)}} \right), \tag{1}$$

$$\alpha_{ii} = \frac{\alpha^{(1)}\sigma_{ii}^{(1)} + \alpha^2 \sigma_{ii}^{(2)} + \alpha^{(3)}\sigma_{ii}^{(3)}}{\sigma_{ii}}, \tag{2}$$

$$\varkappa_{ii} = \varkappa_{ii}^{(0)} + \frac{T}{2} \frac{\sum\limits_{\substack{s,\,t=1 \\ s\neq t}}^{3} \sigma_{ii}^{(s)} \sigma_{ii}^{(t)} (\alpha^{(s)} - \alpha^{(t)})^2}{\sigma_{ii}}. \tag{3}$$

The concentrations of the doping impurities are selected in such a way that the equality

$$\langle \tau_{ii}^{(n)\Phi} \rangle = \langle \tau_{ii}^{(n)I} \rangle$$

is satisfied at the temperature $T = T_0$. In this case (1), (2), and (3) become

$$\sigma_{ii} = \frac{e^2}{k_0 m_{ii}^{(1)} m_{ii}^{(2)} m_{ii}^{(3)}} \left\langle \frac{E^{\frac{3}{2}}}{6k_0^2 T_0^3 + TE^2} \right\rangle [m_{ii}^{(2)} m_{ii}^{(3)} \tau_{ii}^{0L(1)} \rho^{(1)} + m_{ii}^{(1)} m_{ii}^{(3)} \tau_{ii}^{0L(2)} \rho^{(2)} + m_{ii}^{(1)} m_{ii}^{(2)} \tau_{ii}^{0L(3)} \rho^{(3)}],$$

$$\alpha_{ii} = \frac{\alpha^{(1)}\rho^{(1)} m_{ii}^{(2)} m_{ii}^{(3)} \tau_{ii}^{0L(1)} + \alpha^{(2)}\rho^{(2)} m_{ii}^{(1)} m_{ii}^{(3)} \tau_{ii}^{0L(2)} + \alpha^{(3)}\rho^{(3)} m_{ii}^{(1)} m_{ii}^{(2)} \tau_{ii}^{0L(3)}}{\rho^{(1)} m_{ii}^{(2)} m_{ii}^{(3)} \tau_{ii}^{0L(1)} + \rho^{(2)} m_{ii}^{(1)} m_{ii}^{(3)} \tau_{ii}^{0L(2)} + \rho^{(3)} m_{ii}^{(1)} m_{ii}^{(2)} \tau_{ii}^{0L(3)}},$$

$$\varkappa = \varkappa_{ii}^{(0)} + T \frac{e^2}{k_0} \frac{\left\langle \frac{E^{3/2}}{6k_0^2 T_0^3 + TE^2} \right\rangle m_{ii}^{(1)} m_{ii}^{(2)} m_{ii}^{(3)}}{[\rho^{(1)} m_{ii}^{(2)} m_{ii}^{(3)} \tau_{ii}^{0L(1)} + \rho^{(2)} m_{ii}^{(1)} m_{ii}^{(3)} \tau_{ii}^{0L(2)} + \rho^{(3)} m_{ii}^{(1)} m_{ii}^{(2)} \tau_{ii}^{0L(3)}]} \times$$

$$\times \left[\left((\alpha^{(1)} - \alpha^{(2)})^2 \rho^{(1)} \rho^{(2)} \frac{\tau_{ii}^{0L(1)} \tau_{ii}^{0L(2)}}{m_{ii}^{(1)} m_{ii}^{(2)}} + (\alpha^{(1)} - \alpha^{(3)})^2 \rho^{(1)} \rho^{(3)} \frac{\tau_{ii}^{0L(1)} \tau_{ii}^{0L(3)}}{m_{ii}^{(1)} m_{ii}^{(3)}} + (\alpha^{(2)} - \alpha^{(3)})^2 \rho^{(2)} \rho^{(3)} \frac{\tau_{ii}^{0L(2)} \tau_{ii}^{0L(3)}}{m_{ii}^{(2)} m_{ii}^{(3)}} \right] .$$

The values of $\tau_{ii}^{0L(n)}$ are determined from the quantities $\langle \tau_{ii}^{F} \rangle$ [8]. The temperature dependences of σ_{ii}, α_{ii}, and $\varkappa_{ii}$ were computed for the nondegenerate case according to (1)-(3). The impurity concentrations varied between 10^{15}-10^{18} cm^{-3} in the 300-330°K temperature range. The Fermi levels were found from the equation of electrical neutrality taking into account that all the impurities are ionized at these temperatures.

It follows from Fig. 1 that the minimal temperature dependence of the thermoelectric parameters σ_{ii} and α_{ii} is observed in the 10^{17}-10^{18} cm^{-3} concentration range. As regards the thermal conductivity, according to computations the contribution of the hole component to it is an order of magnitude less than the contribution of the lattice component. Therefore, limiting ourselves to just the first term in the thermal-conductivity equation, we can show that the change in the lattice component of the thermal conductivity is $\Delta\varkappa/\varkappa \approx 3 \cdot 10^{-4}$ $\deg^{-1}$

TABLE 1. Fundamental Parameters of Thermal Converters with Metal and Semiconductor Thermocouples

No.	Type of thermal converter, factory-fabricator or firm	Nominal current, mA	Value of the emf at the nominal current, mV	Response (sensitivity) V/W	Admissible loading (%) of the nominal current value	Reference
1	Experimental thermal converters (All-Union Sci.-Res. Inst. Metrology)	0,1	0,38	2,3	—	[11]
2	Semiconductor thermal converter (Chernovtsy State Univ.)	0,1	2,5	100	500	—
3	Inst. Phys. Geography	0,5	5	2,8	—	[11]
4	Semiconductor thermal converter (Chernovtsy State Univ.)	0,5	10	50	450	—
5	EAB	0,6	5	3,4	—	[11]
6	Semiconductor thermal converter (USA)	0,72	10	0,806	450	[4]
7	TVB-1 (Moscow Electric Light-Bulb Factory)	1	2,5	4,1	150	[1]
8	Hartman–Brown	1	7	0,38	150	[1]
9	Semiconductor thermal converter (Chernavtsy State Univ.)	1	15	50	450	—
10	TVB-2 (Moscow Electric Light-Bulb Factory)	3	5	2,8	150	[1]
11	TVB-3 (Moscow Electric Light-Bulb Factory)	5	10	2,6	150	[1]
12	Semiconductor thermal converter (Chernovtsy State Univ.)	3	20	30	450	—
13	Siemens	5	10	2,6	200	[1]
14	Semiconductor thermal converter (USA)	4,39	10	0,96	450	[4]
15	Semiconductor thermal converter (Chernovtsy State Univ.)	5	25	10	400	—

for the temperature interval mentioned. Changes of the same magnitude are obtained for the electrical conductivity and thermal emf.

Comparing the results obtained with the change in the fundamental thermoelectrical parameters of alloys used to fabricate the thermocouple, for example, Chromel — Copel, shows that the alloys possess considerably greater temperature dependences of the thermoelectrical parameters:

$$\frac{\Delta\sigma}{\sigma_{\text{Chromel}}} \approx 4\cdot 10^{-4}\ \text{deg}^{-1},\quad \frac{\Delta\alpha}{\alpha_{\text{Chromel}-\text{Copel}}} \approx 1.6\cdot 10^{-3}\ \text{deg}^{-1},\quad \frac{\Delta\varkappa}{\varkappa_{\text{Chromel}}} \approx 10^{-3}\ \text{deg}^{-1}.$$

The fundamental parameters of semiconductor thermal converters with optimized cadmium antimonide thermocouples and of thermal converters based on metal thermocouples are presented in Table 1, and the change in the volt — watt response of thermal converters with the change in temperature of the ambient medium in the −30 to +50°C range is presented in Fig. 2.

It is seen from the results presented that the use of semiconductor materials assures a number of advantages to the semiconductor thermal converters as compared with the metallic. Thus, for instance, a three- to fourfold increase in the loading capacity of the semiconductor thermal converters as compared with the loading capacity of the metallic thermal converters in a number of cases affords the possibility of disposing of special protective circuits [9], which complicate the apparatus and introduce additional errors into the measurement.

The possibility of producing highly responsive semiconductor converters without a significant increase in the number of thermocouples simplifies the problem of measuring low alternating currents both by extending the range of the quantities being measured toward the low values and by increasing the output emf at the nominal current. Moreover, the high response of semiconductor thermocouples permits a substantial reduction in the heater resistance, which improves the frequency applicability of the thermal converter, as is known [10].

An increase in the output thermal emf of semiconductor thermal converters raises the accuracy and interference-immunity of ac measuring apparatus in the general case.

NOTATION

σ_{ii}, electrical conductivity tensor components; α_{ii}, thermal emf coefficient tensor components; $\varkappa_{ii}$, thermal conductivity tensor components; e, charge on an electron; $\rho^{(n)}$, carrier concentration of the n-th extremum; $\langle\tau_{ii}^{n}\rangle$, components of the average relaxation time of the n-th extremum; $m_{ii}^{(n)}$, tensor components of the effective carrier mass of the n-th extremum; $\alpha^{(n)}$, isotropic thermal emf due to carriers of the n-th extremum; $\varkappa_{ii}^{(0)}$, lattice component of the thermal conductivity; T, absolute temperature; $\langle\tau_{ii}^{(n)F}\rangle$ average carrier relaxation time for scattering by acoustic phonons; $\langle\tau_{ii}^{(n)I}\rangle$, average relaxation time for scattering by ionized impurities; k_0, Boltzmann constant; E, energy.

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SOLUTION OF A PROBLEM ABOUT EVAPORATION OF SPHERICAL METAL PARTICLES IN AN ARC FLAME BY AN INTEGRAL EQUATIONS METHOD

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The problem about the evaporation of metal particles in a plasma is reduced to a single-phase nonstationary Stefan problem, whose solution is obtained by an integral equations method. Computations are performed for spherical lead particles with an initial radius of $R = 7\cdot 10^{-3}$ cm.

Plasma interaction with solid particles is of great interest in plasma physics. The processes occuring here can be modeled by the following problem.

A globular metal particle with initial radius R_0 enters a plasma whereupon it starts to evaporate. Our problem is to find the law of the time change in the particle radius $r_1(t)$. Experiments on the evaporation of lead and tin particles are elucidated in [1].

The problem under consideration is treated in this paper as a Stefan problem and its theoretical solution by an integral equations method is proposed [2, 3]. The temperature at any point of the particle can be found from the expression

$$T(r,\ t)=\int_0^t T(\rho,\ \tau)\, G|_{\rho=r_1(\tau)}\frac{dr_1}{d\tau}d\tau + a\int_0^t\left(G\frac{\partial T(\rho,\ \tau)}{\partial\rho}-T(\rho,\ \tau)\frac{\partial G}{\partial\rho}\right)\Bigg|_{\rho=r_1(\tau)}d\tau, \qquad (1)$$

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