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RESEARCH OF DOUBLE-LAYER THERMOELEMENTS WITH PERIODICALLY PROFILED SURFACE

In the work the results of computer simulation and experimental research of a new type of transverse thermoelements, i.e. a double-layer thermoelement with a periodically profiled surface are presented . It is shown that the deviation of the computed and experimentally obtained values of power and transverse thermoEMF in relation to temperature gradient is no more than 6%. It has been established that the application of the double-layer thermoelements with the periodically profiled surface makes it possible to obtain big values the transverse thermoEMF, power and efficiency in comparison with anisotropic and short-circuited thermoelements.

Key words: thermoelectric generator, micro-CHP, cogeneration

Introduction

Interest to transverse type thermal converters arose in 1970s due to their attractive properties, i.e. the dependence of transverse thermoEMF on geometric dimensions of thermoelements and the absence of commutations with the search of constructions with low-inertia detectors. These circumstances for example give the possibility to increase high-speed performance of the thermoelements with the decrease of their thickness without losses of volt-watt sensitivity. Thus, the transverse type thermal converters are promising to create high-speed thermoelectric devices. However, semiconducting materials for which thermoEMF anisotropy is typical and which are used for making anisotropic thermoelements have relatively low thermoelectric figure of merit. [1-3]. Although it is possible to create high-voltage thermoelements, whose emf is defined by the correlation of geometric dimensions of the oriented single crystals, the power generated by the volume units is less than the standard Seebeck generators possess.

The problem of the new type thermoelements search is topical that would allow to improve the working characteristics of the thermoelectric devices by optimizing the construction and operation modes of the thermoelements. Modern computer technologies make it possible to perform optimization of the new thermoelements constructions and determine their advantages in comparison with other types of thermoelements.

The aim of the present work is the experimental research of the new type thermoelements, i.e. the double-layer thermoelements with the periodically profiled surface, and the comparison of the experimental research result with the computer simulation results.

Simulation of the double-layer thermoelement with the periodically profiled surface

The physical model of the double-layer thermoelement with the periodically profiled surface is shown in Fig. 1.

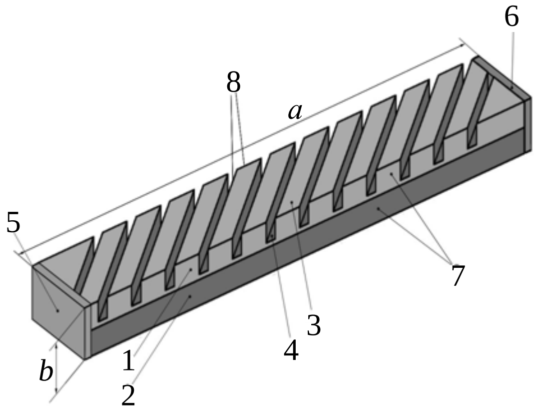


Fig. 1.Double-layer thermoelement with periodically profiled surface [4-5]. 1 – material of p-type conductivity; 2 – material of n-type conductivity; 3 –fins p-type material; 4 – grooved in p-type material; 5, 6 – electrical contacts; 7, 8 –thermoelement sides where sources and heat sinks are located; a, b – thermoelement geometrical dimensions.

The thermoelement consists of the materials of *n*- and *p*-type of conductivity. One of the thermoelement layers has the periodically profiled outer surface with the system of fins and hollows oriented angle wise towards the bar sides 7 and 8, which are thermostated at different temperatures T_1 and T_2. Other outer sides of the thermoelement are in thermal insulation. Electrical contacts are thin metal layers with high electrical conductivity and therefore are practically equipotential within the limits of one contact.

The layered structure with the layers with different thermoelectric properties can be regarded as artificially anisotropic media. Thus, the presence of temperature drop between the corresponding side planes 7 and 8 (Fig. 1) of the double-layer thermoelement with the periodically profiled surface lead to the appearance of electrical current and thermoEMF in the direction perpendicular to the heat flow. This phenomenon is analogous to the transverse Seebeck in the anisotropic medium [3]. Like in the anisotropic thermoelement, the transverse emf value depends on the relation of the thermoelement geometrical dimensions *a/b*. However, in this case the EMF value will not also depend on the thermoelement profiled layers parameters. Therefore, the transverse thermoEMF value $E_\perp$ can be presented in the following way:

$$E_\perp = \Delta\alpha\Delta T \frac{a}{b} f\left(\varphi, n\right), \qquad (1)$$

where ΔT is the thermoelement temperature difference, $\Delta\alpha$ is the Seebeck coefficients difference of the working body layers material, $f(\varphi, n)$ is the function of the angle of slope of the locking elements (fins) φ towards the thermoelement hot plane and a number of periods of the profiled layers profile *n* per the thermoelement length unit *a*; *b* is the distance between the hot and cold thermoelement planes.

In works [4-5] there are presented the results of the multidimensional optimization of the given thermoelement by computer simulation. At the bottom of this model there lies the method of finite elements where the thermoelement working body is divided into a big number of finite elements, and in each of them the function value is searched which satisfies the set differential equations with corresponding boundary conditions.

The calculations were carried out for the thermoelement from Bi_2Te_3 material [4]. Ftom the computer simulation results it is established that for every geometry and thermoelectric parameters of the thermoelement layers the less the value is d_1/d_2 (Fig. 2), the more the transverse thermoelement thermoEMF is, and correspondingly its efficiency. The transverse thermoEMF is a non-monotonic function and reaches the maximum at the specific 'porosity' values δ_1/δ_2 (Fig. 2) of the profiled layer.

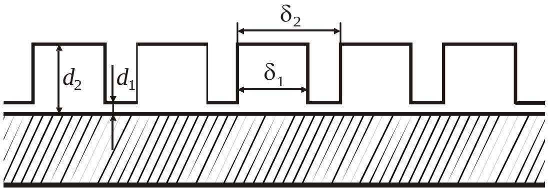


Fig. 2.Geometrical parameters of the thermoelement profiled layer.

In works [4-5] it was shown that for any 'porosity' of the profiled surface the transverse thermoEMF reaches its maximum value when the electrical conductivity value of the profiled layer is twice as much as the lower layer electrical conductivity of the thermoelement.

It was established that the EMF and power values increase with the increase of the relation between the thicknesses of the profiled and non-profiled thermoelement layers. Dependences of emf and the thermoelement electrical power on the relation of geometrical dimensions are monotonic functions that increase with the value growth a/b (Fig. 1).

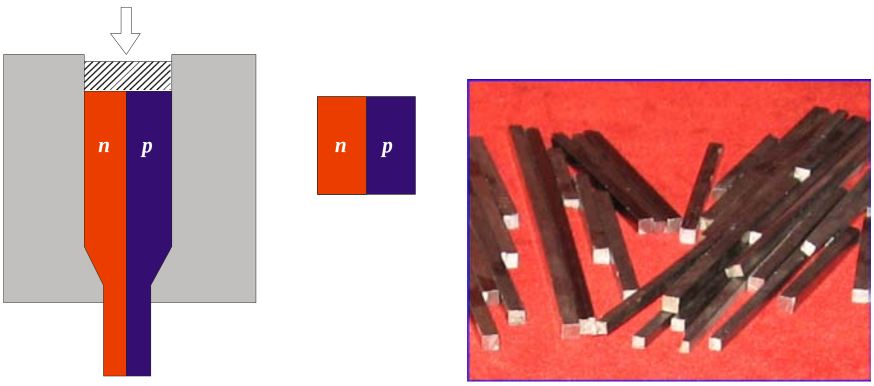
In order to check the computer simulation results and practical confirmation of the effectiveness of the double-layer thermoelement with the periodically profiled surface the experimental researches were performed. The fulfilled work contained the following stages: synthesis of thermoelectric materials, measurement of the temperature dependences of kinetic parameters of the given materials, obtainment of the double-layer pivots by extrusion methods, manufacturing of samples of the double-layer thermoelement with the periodically profiled surface, emf and power measurements of the obtained double-layer thermoelements.

Manufacturing of double-layer thermoelements with the periodically profiled surface

Thermoelectric materials were synthesized Bi_2Te_3 (75%) + Bi_2Se_3 (25%) and Bi_2Te_3 (30%) + Sb_2Te_3 (70%) (*n*- and *p*-type, correspondingly) in order to produce the samples of artificially anisotropic thermoelements

The following step was to obtain the double-layer pivots of the thermoelectric material, i.e. preforms for future profiled thermoelements by thermomechanic treatment of the synthesized material. The thermomechanic treatment presupposes the plastic deformation (extrusion) of the preforms through the filament extrusion device with the set profile and the following pivot annealing. Such method allows obtaining the calibrated pivots of different cuttings and a profile with the uniform distribution of material properties along its length.

Thus, the double-layer pivots with the transverse cutting 4.1×4.1 mm^2 were obtained by the preform extrusion that consisted of two equal parts of *n*- and *p*-type conductivity (Fig. 3, *a*). The appearance of ready double-layer pivots of the thermoelectric material is shown in Fig. 3, *b*).

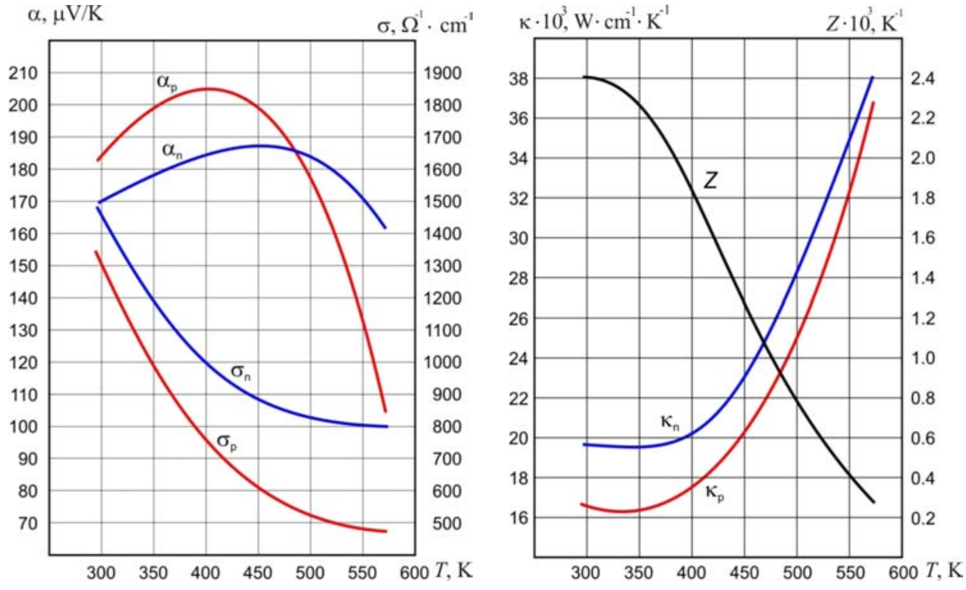


а) *б)*

Fig. 3.Scheme to obtain a double-layer pivot of a thermoelectric material by extrusion (a) and appearance of pivots (b).

In order to define the temperature dependences of the kinetic parameters of the thermoelectric material areas, the samples have been cut out of the obtained pivots that contained the material of only one of the areas. Temperature dependences of the kinetic parameters in the temperature range of 290 ÷ 580 K have been measured for the obtained samples of *n*- and *p*-types of conductivity. The appearance of these dependences and the material thermoelectric figure of merit are presented in Fig. 4.

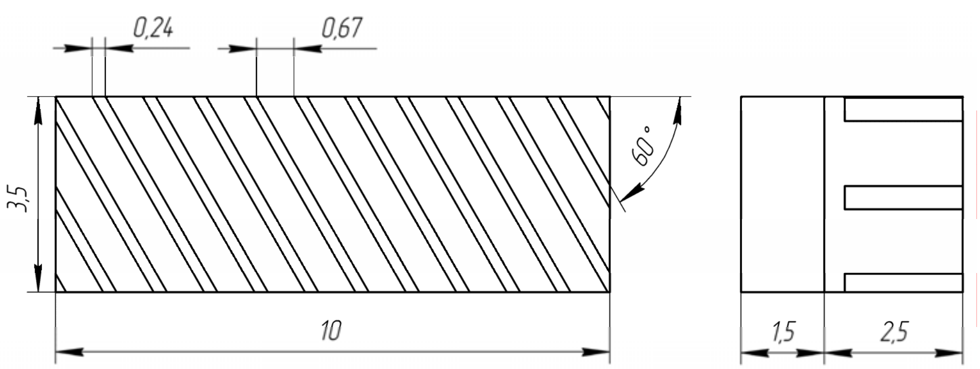
Further preparation for the production of the thermoelement working body included the cutting of double-layer pivots into the samples of the definite length, profiling of one of the layers and samples polishing.



a) *b)*

Fig. 4. Temperature dependences of a thermoEMF coefficient, specific electrical conductivity, specific thermal conductivity of the areas and thermoelectric material figure of merit.

In order to carry out the experimental researches of the double-layer thermoelements with the periodically profiled surface, the samples with the transverse cutting of 4×3.5 мм^2 and the length of 10 mm were produced. The thickness of the solid non-profiled layer is δ_1 = 1.5mm, thickness of the profiled layer is δ_2 = 0.2mm, δ_3 = 2.3mm (Fig. 5). The profiled layer fin is 0.24mm, the groove width is 0.67mm.



a) *б)*

Fig.5. Front (a)and side (b)projections of the profiled thermoelement.

Appearance of the ready double-layer thermoelement with the periodically profiled surface is shown in Fig. 6.

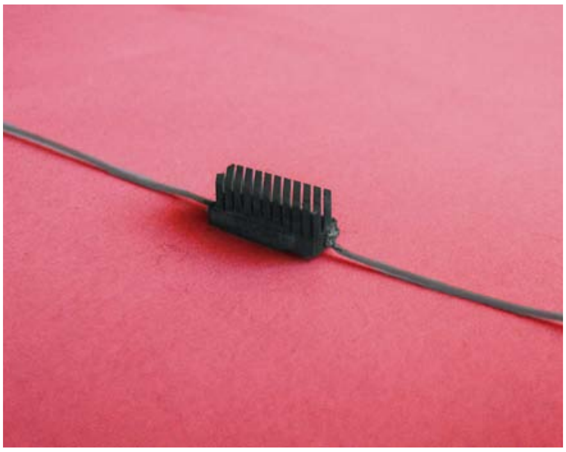


Fig. 6. Double-layer thermoelement with the periodically profiled surface.

Experiment scheme the profiled thermoelements emf and and power measurements

The scheme of the experimental assembly for measuring emf and power of the layered thermoelements is shown in Fig. 7.

The measurements have been carried out for the double-layer thermoelements with the periodically profiled surface 1, which are included into the electrical circuit in series. The hot planes temperature is set by the heater 5 and controlled by the thermocouple 3. The cold planes temperature is controlled by the thermocouples 2 and is set by heat sinks 4, through which the water of the set temperature circulates along the pipe 6. All measurements are carried out in the vacuum conditions of 10^{-5}mm.mercury column.

In Fig. 8 the assembly during the experiment process is shown.

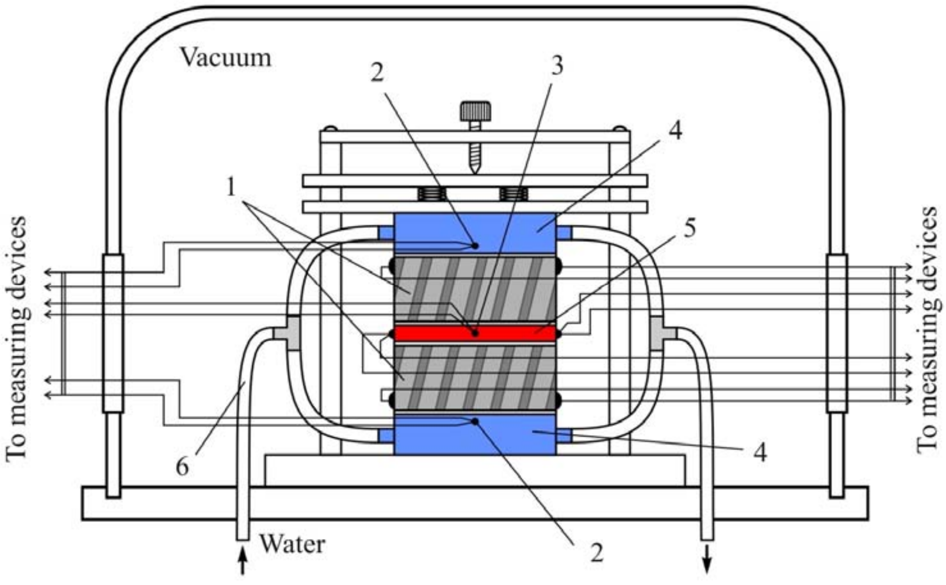


Fig.7. Scheme of the experimental assembly for studying the double-layer thermoelements with the periodically profiled surface: 1 – double-layer thermoelements, 2 –thermocouples for temperature control of cold planes, 3 – thermocouple for temperature control of hot planes, 4 – heat sinks, 5 -heater, 6 – pipe for water supply to heat sinks.

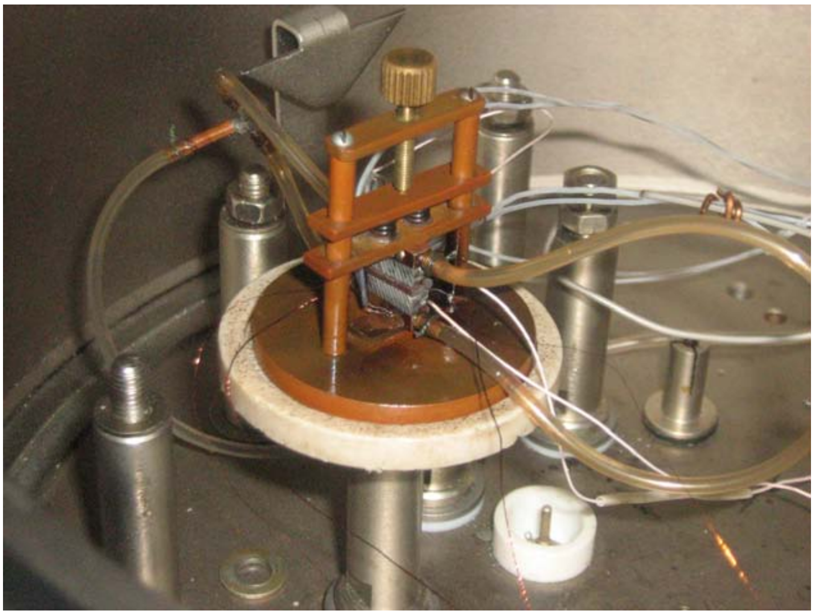


Fig.8.Assembly for emf and power measurements of the double-layer thermoelements with the periodically profiled surface.

Dependences of emf and power of the double-layer thermoelements with the periodically profiled surface on the hot plane temperature were measured during the researches. The cold plane temperature of the thermoelement was 290 К. ThermoEMF of the thermoelements couple was measured in the unloaded circuit.

Results of the experimental researches of the double-layer thermoelements with the periodically profiled surface

In order to define the resistances of the thermoelements and the maximum power *W* the loading characteristics were taken. The electrical power was fixed at the optimal load of the thermoelements, which is brought to the heater and through the electrical conductors and the thermocouple taking into account the heat losses, and also by the radiation from the side surfaces the heat flow was defined *Q*, passing through the thermoelements.

In Fig. 9 the appearance of the loading characteristics of the couple of the double-layer thermoelements with the periodically profiled surface connected in series was given obtained during the experiment. As it is seen from the figure the maximum power with the growing temperature drop on the thermoelements is shifted to the side of big resistances that is connected with the electrical conductivity drop of the thermoelement material with the temperature increase.

The measurement results of the transverse thermoEMF dependence on the temperature drop at the thermoelement and the corresponding computer experiments are presented in Fig. 10.

The graphs of dependence of electrical power of the double-layer thermoelement with the periodically profiled surface on temperature drop at the thermoelement are shown in Fig. 11. Deviation from the computed computer simulation and the experimentally defined power values are not more than 6% and are within the limits of the experiment error.

Thus, the double-layer thermoelements with the periodically profiled surface broaden the element thermoelectricity basis and are promising for using as thermal sensitive elements of different heat metric devices.

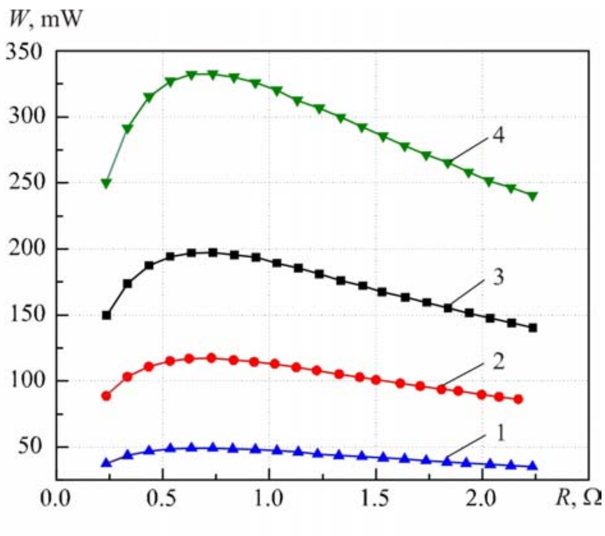


Fig.9.Loading characteristics of the couple of the double-layer thermoelements with the periodically profiled surface connected in series at different temperature drops: 1 - ΔT=84 K; 2 - ΔT=130 K; 3 - ΔT=185 K; 4 - ΔT=285 K.

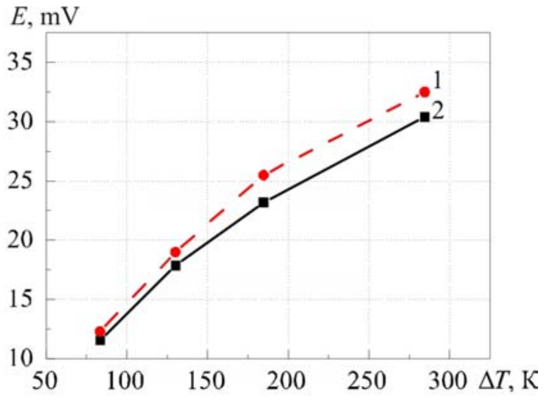


Fig. 10.Dependence of transverse thermoEMF of the double-layer thermoelement with the periodically profiled surface on temperature drop at the thermoelement:
1 – computer experiment,
2 –physical experiment

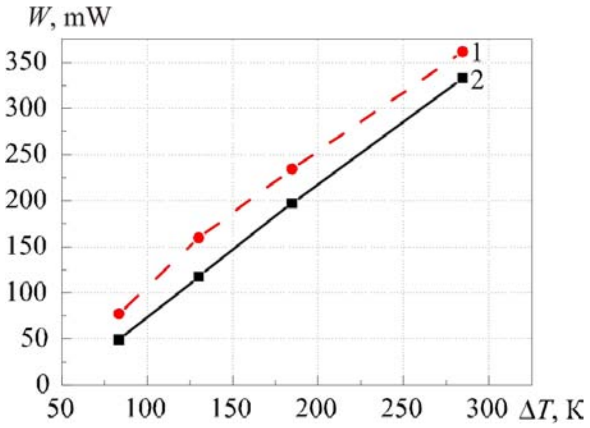


Рис. 11. Dependence of electrical power of the double-layer thermoelement with the periodically profiled surface on temperature drop at the thermoelement:
1 – computer experiment,
2 –physical experiment

They promote the development and creation of the low inertia radiation detectors, heat flow detectors, microcalorimeters and heat meters.

Conclusions

1. There has been produced the double-layer thermoelement with the periodically profiled surface that generated the transverse thermoEMF of 30.4 mV at the temperature drop of 285 K and the power of 332 mV.
2. There have been experimentally confirmed the computer simulation results of the double-layer thermoelement with the periodically profiled surface. It is shown that deviation from the computed and the experimentally defined thermoEMF values are not more than 6%.
3. The application of the double-layer thermoelement with the periodically profiled surface makes it

possible to obtain the greater values of the transverse thermoEMF, power and the efficiency in comparison with the anisotropic and short-circuited thermoelements. This broadens the possibilities of the practical application of the transverse thermoEMFs.

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