

**R.R. Kobylianskyi, Cand.Sc.(Phys-Math)** <sup>1,2</sup>  
**V.V. Lysko, Cand. Sc (Phys-Math)** <sup>1,2</sup>  
**A.V. Prybyla, Cand. Sc (Phys-Math)** <sup>1,2</sup>  
**I.A. Konstantynovych, Cand. Sc. (Phys-Math)** <sup>1,2</sup>  
**A.K. Kobylianska, Cand. Sc (Phys-Math)** <sup>1</sup>  
**N.R. Bukharayeva,** <sup>1</sup>  
**V.V. Boychuk** <sup>2</sup>

<sup>1</sup> Institute of Thermoelectricity of the NAS and MES of Ukraine,  
1 Nauky str., Chernivtsi, 58029, Ukraine;

<sup>2</sup> Yuriy Fedkovych Chernivtsi National University, 2 Kotsiubynskyi str.,  
Chernivtsi, 58000, Ukraine  
*e-mail: anatykh@gmail.com*

## TECHNOLOGICAL MODES OF MANUFACTURING MEDICAL PURPOSE THERMOELECTRIC SENSORS

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*This work presents technological modes of manufacturing thermoelectric heat flux converters. It has been established that the optimal thermoelectric material for a thermopile is low-temperature materials based on  $Bi_2Te_3$ . The effectiveness of using such technological modes for manufacturing thermoelectric microthermopiles capable of recording laser radiation with an improved conversion coefficient of 1 – 1.5 orders of magnitude compared to existing measuring transducers has been experimentally confirmed. The specified technological modes significantly simplify and mechanize the method of manufacturing medical purpose thermoelectric heat flux sensors and microgenerators for powering low-power medical equipment.*

**Key words:** technological mode, thermoelectric converter, medical purpose thermoelectric heat flux sensor.

### Introduction

*General characterization of the problem.* Thermoelectric heat flux sensors are widely used in medicine due to their ability to accurately measure changes in the heat release of the human body [1 – 20]. This allows them to be used for diagnostics and monitoring of the condition of patients, especially in cases where it is important to detect local changes in body temperature [21 – 40]. The main aspects of thermoelectric sensors [1 – 40]:

1. Operating principle:

- is based on the thermoelectric Seebeck effect, where a temperature difference between two points causes an electric voltage to arise;
- the sensor responds to the heat flux that occurs due to the temperature difference between the two sides of the sensor.

2. Medical applications:

- blood flow distribution: heat flux measurement can be used to assess blood microcirculation, which is useful in diagnosing diabetic foot or for studying skin pathologies;

- monitoring of wound conditions: in wounds or postoperative sutures, changes in heat flux may indicate inflammation or healing;
  - tumor diagnosis: tumors are usually accompanied by a local increase in heat flux due to intense blood circulation in the affected area;
  - neurophysiology: sensors help in measuring thermal changes caused by neural activity.
3. Sensor types:
- disposable or reusable devices;
  - high-sensitivity sensors for localized measurement, for example in dermatology.
4. Advantages:
- high accuracy;
  - small size, which allows them to be integrated into wearable devices;
  - rapid response to changes in heat flux.
5. Production technologies:
- use of biocompatible materials;
  - micromechanical design (MEMS) to ensure compactness and accuracy.

The prospects for the development of such sensors in medicine include their integration into multifunctional diagnostic and rehabilitation systems, which contributes to more accurate and comfortable monitoring of patients' health.

*The purpose of this work* is to develop special technological modes for the production of improved thermoelectric microthermopiles for medical purpose heat flux sensors.

## 1. Selection of thermoelectric material for manufacturing microthermopile

Thermoelectric semiconductor materials (TEM) must satisfy a number of requirements: maintain a high figure of merit in a wide temperature range, have significant mechanical strength, be easy to process when manufacturing samples of the required sizes, not be subject to the oxidizing action of the atmosphere, not sublime or decompose at elevated temperatures, etc. The most important of these requirements is to achieve high values of the thermoelectric figure of merit, on which in most cases the possibility of using a thermoelectric material depends [1 – 3].

Thermoelectric materials are classified according to their operating temperature range: low-, medium-, and high-temperature. Low-temperature materials are semiconductors with the operating temperature of 0 – 350 °C, medium-temperature materials are semiconductors with the operating temperature of 350 °C – 650 °C, and high-temperature materials are semiconductors with the operating temperature of 700 °C – 1000 °C.

In this case, low-temperature materials are used to manufacture thermoelectric sensors.

As mentioned, the TEM is characterized by the figure of merit:

$$Z = \frac{\alpha^2 \sigma}{\chi} \quad (1)$$

where  $\alpha$  is the Seebeck coefficient,  $\sigma$  is electrical conductivity,  $\chi$  is the thermal conductivity.

$$\alpha = \frac{E}{\Delta T}, \quad (2)$$

$$\sigma = \frac{I}{Us}, \quad (3)$$

$$\chi = \frac{I^2 R l}{\Delta T_s} . \quad (4)$$

The most effective low-temperature materials are solid solutions based on  $Bi_2Te_3$ .

In the process of selecting the material for manufacturing the thermopile legs, low-temperature materials based on  $Bi_2Te_3$  obtained by different methods were tested: single crystals (the Bridgman, Czochralski, zone melting), extrusion and pressing. Fig. 1 shows samples of n- and p-type thermoelectric material obtained by extrusion.



Fig. 1. Extruded bars of thermoelectric material of n- and p-type conductivity.

In the process of manufacturing a thermopile, such bars are cut into thin plates (Fig. 2), which are then glued together in pairs.

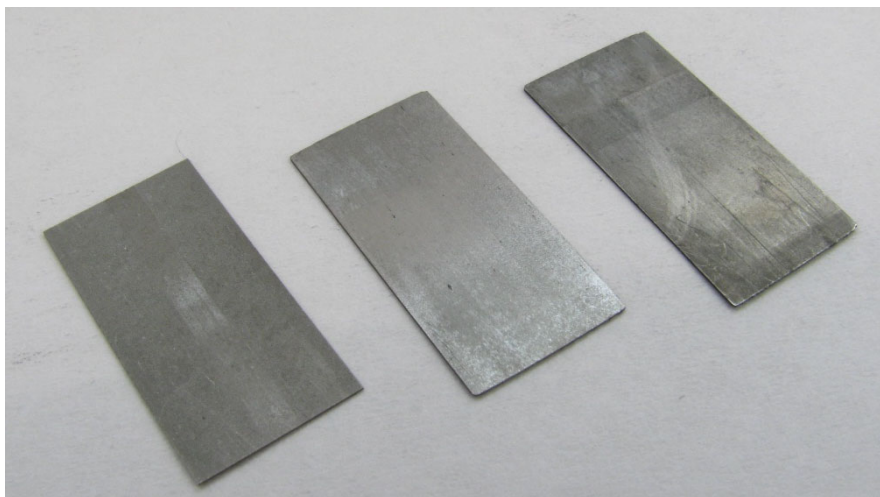


Fig. 2. Plates of thermoelectric material of n- and p-type conductivity.

Unlike single crystals grown by the Bridgman, Czochralski, and zone melting methods, the extruded material has high mechanical and technological properties; uniformity along the length of the rods, high mechanical strength, which is especially important in the manufacture of small-sized legs [1 – 3].

In the process of obtaining thermoelectric material, internal stress occurs as a result of various thermal and mechanical loads. The presence of final stresses, reaching ultimate strength values, can lead to the occurrence of micro- and macrocracks, which significantly weaken the strength of the material and can worsen its thermoelectric properties. The best strength is demonstrated by samples obtained by

extrusion. The high mechanical strength of the extruded material is explained by its relatively high homogeneity.

The thermopile legs were made of semiconductor material obtained by the extrusion method.

Of great importance for the materials used in thermoelements is the degree of their homogeneity. Inhomogeneities create closed thermoelectric currents in the middle of the leg, which reduce the efficiency of thermoelements.

TEMs obtained from powders by hot or cold pressing are currently the most widely used due to their technological simplicity and the possibility of manufacturing thermoelements of the required sizes [1 – 3].

In the simplest case, when the material of all grains is homogeneous and isotropic, the contact between grains is ideal and the influence of various microscopic defects (cracks, holes, various types of inclusions and cavities) is so small that it can be neglected, the expressions for describing the electrical and thermal conductivity of pistons are isomorphic, therefore, regardless of the configuration of the grains, their sizes, mutual orientation and contact area, the ratio  $\sigma/\chi$  should remain constant. The Seebeck coefficient should also not depend on the listed factors, so the values of powder and single-crystal materials should coincide. In most cases, the figure of merit of powder materials is somewhat lower than that of single crystals, due to additional scattering of phonons and current carriers at grain boundaries, dislocations, vacancies, microcracks; due to the presence of oxide films, etc.

When using powders from anisotropic materials, the figure of merit of pressed powders may be significantly lower than that of single crystals. The anisotropy of thermoelectric power during grain misorientation leads to the appearance of eddy currents, which also deteriorates the properties of the material.

To achieve maximum figure of merit, it is necessary to perform grain orientation. In layered materials (in low-temperature TEMs operating in the temperature range of  $0 \div 300$  °C), represented by  $Bi_2Te_3$ -based alloys, such orientation is achieved during hot pressing [1 – 3] – the grains are arranged with cleavage planes perpendicular to the pressing direction. Orientation is also achieved when manufacturing samples by extrusion. When using such techniques, the powder material becomes anisotropic and approaches single crystals in the figure of merit.

## 2. Design of a thermoelectric microthermopile

The disadvantage of the above-mentioned technology for manufacturing thermoelectric microthermopiles is a significant percentage of defective plates of thermoelectric material due to microcracks that may occur during their grinding.

The operating principle of a semiconductor thermopile is based on the direct thermal into electrical energy conversion in accordance with the Seebeck effect, which states that in a closed circuit consisting of two dissimilar conductors, the junctions of which are at different temperatures, a thermoelectric power arises.

The thermopile design is a monolithic block with dimensions not exceeding  $(22 \times 22 \times 20)$  mm<sup>3</sup>. The block consists of 1600 *p*- and *n*-type semiconductor legs of square cross-section and insulated from each other. The *p*- and *n*-type legs are connected in pairs in a series electrical circuit (Fig. 3) and are arranged parallel to the heat flux, i.e. the heat flux passes along the thermopile legs (along the height). The extreme *p*- and *n*-type legs in the electrical circuit are connected to nickel buses, which are glued to two opposite side surfaces of the semiconductor thermopile [1 – 3].

The dimensions of the manufactured thermocouple leg are:  $(20 \times 0.5 \times 0.5)$  mm<sup>3</sup>. The thermopile legs are made of extruded thermoelectric semiconductor material based on  $Bi_2Te_3$  alloys. The average values of the electrical parameters of this material are:  $\alpha_{av} = 190$   $\mu\text{V K}^{-1}$ ,  $\sigma_{av} = 900$  Ohm<sup>-1</sup>cm<sup>-1</sup>.

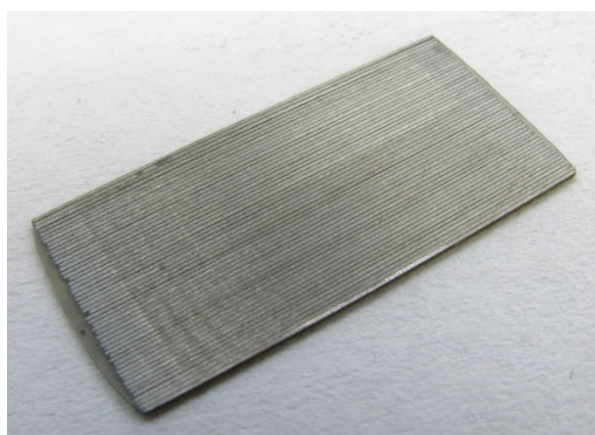


Fig. 3. Glued thermopile legs made of extruded thermoelectric material.

### 3. Technological modes of manufacturing thermoelectric microthermopile

Micromodules are, as a rule, single-stage thermopiles made of low-temperature thermoelectric materials based on ternary alloys of bismuth telluride [1 – 3], which acquire *p*- or *n*-type conductivity depending on their doping. The process flow chart of micromodules includes the following stages: synthesis of low-temperature thermoelectric alloys of *p*- and *n*-type conductivity; crushing of alloy ingots into powder with the required grain size with its subsequent extrusion through dies measuring  $7 \times 7 \text{ mm}^2$  or  $5 \times 10 \text{ mm}^2$ . The obtained thermoelectric legs with the appropriate cross-section are characterized by high parameter values in the temperature range of  $200 \div 600 \text{ K}$  and good mechanical properties, which allows them to be used in production conditions. From these legs, bars of the required length and an average value of  $180 \div 200 \mu\text{V/K}$  and  $900 \div 1200 \text{ Ohm}^{-1}\text{cm}^{-1}$  are cut with a diamond disk. Then the bars are cut using a mechanical wire cutting into 0.7 mm thick plates and after appropriate chemical treatment, the plates are glued together, maintaining the sequence of alternating *p*- and *n*-conductivity. The electrical insulation between the plates is a polyamide film with a thickness of 10 microns, the adhesive chosen is epoxy compound K-400 with a plasticizer. The blocks obtained after drying were cut into rows of legs of the required thickness (in our case – 0.7 mm). After chemical etching, the ends of the rows of glued legs were covered with an anti-diffusion layer, followed by the creation of interconnect coating. After these operations, we obtain the required number of micromodule units, each of which contains a selected number of half-elements (legs) connected electrochemically.

The structure of micromodule fragment is shown in Fig. 4.

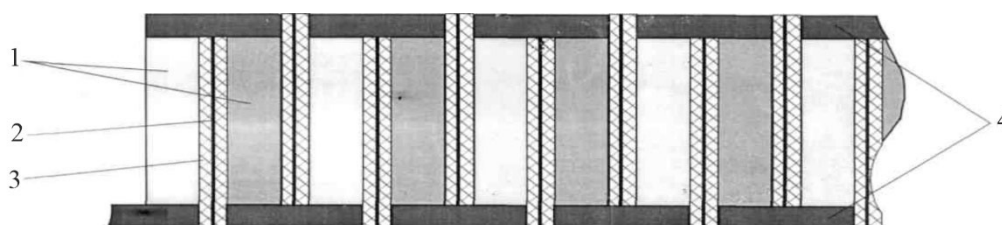


Fig. 4. Fragment of thermopile micromodule: 1 – half-elements of *p*- and *n*- type conductivity, 2 – polyamide film, 3 – epoxide compound, 4 – interconnects.

According to the above-mentioned process flow chart, 4 units of micromodules were assembled, which were glued into a block through a polyamide film and connected to each other from the heat-generating side. Fig. 5 shows the assembled and connected micromodule.

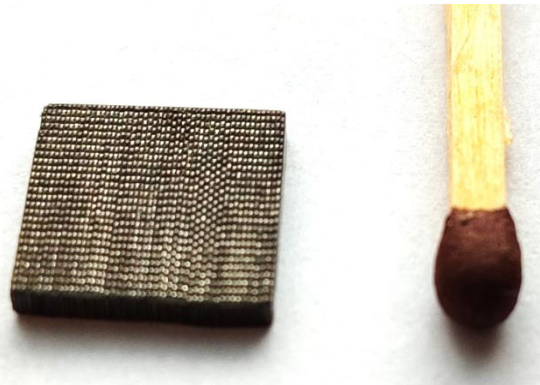


Fig. 5. Assembled and connected thermopile micromodule.

Electrical leads were soldered to the micromodule block, which is actually a thermopile, and its heat-exchange sides were covered with a heat-conducting protective layer containing boron nitride.

In general, the technological chain for manufacturing a thermopile can be reduced to the following diagram (Fig. 6):

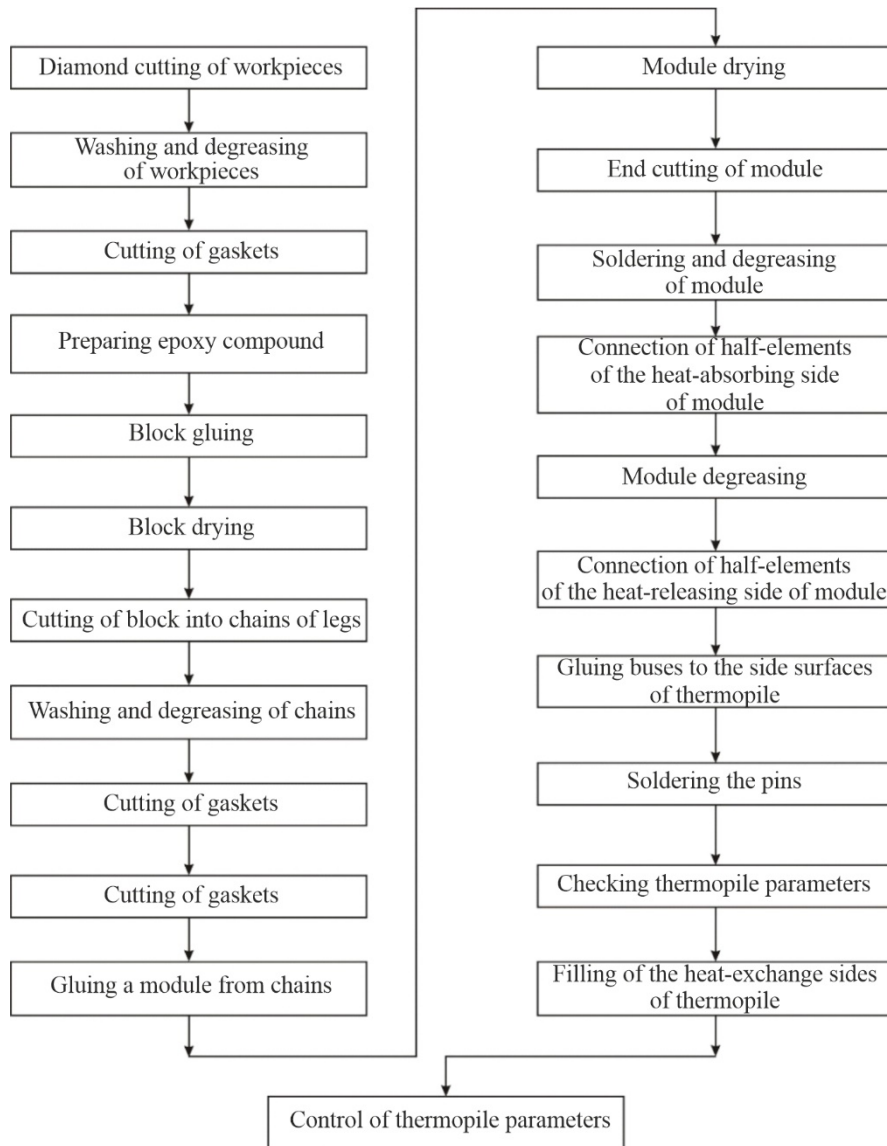


Fig. 6. Process flow chart for the production of thermopile.

### 3.1. Anti-diffusion layers and interconnects of thermoelectric micromodules

To create thermopiles, highly efficient low-temperature thermoelectric materials are used, which are ternary alloys based on bismuth telluride  $Bi_2Te_3$  [1 – 3] and which acquire  $p$ - or  $n$ -type conductivity depending on their doping.

The relatively high operating temperature of the hot junctions of the micromodule half-elements requires the use of anti-diffusion layers on the surfaces of the contact half-elements. Various technologies and methods for sputtering anti-diffusion metal layers are known: chemical, electrochemical, melt immersion, mechanical deposition, vacuum sputtering, vapor phase deposition, cathodic sputtering, plasma spraying. Each of the above methods has negative and positive features. Cathode sputtering provides the best results. However, the extremely slow deposition rate and high energy consumption of the process do not allow this method to be used. Plasma spraying allows for a significant increase in the rate of coating deposition, but requires the use of rather complex and energy-intensive technological equipment. At the same time, galvanic methods are not characterized by low cost of the technological process, relative simplicity of equipment and sufficiently high quality of metal layers. The choice of materials for galvanic anti-diffusion layers is quite limited. The point is that it is necessary to ensure, in addition to significant adhesion, also a small contact resistance  $r_0$ , which significantly affects the thermoelectric figure of merit  $Z_{TE}$  of the thermoelement [1 – 3]:

$$Z_{TE} = Z_{TEM} \frac{1}{1 + \frac{2r_0}{r}}, \quad (5)$$

where  $Z_{TEM}$  is the figure of merit of thermoelectric material,  $r$  is half-element resistance.

Nickel  $Ni$  is considered one of the most suitable for creating anti-diffusion contact layers. It provides contact resistance at the level of  $1 \div 5 \cdot 10^{-6}$  Ohm·cm<sup>2</sup>.

The reliability of  $Ni$  antidiffusion layers is determined by the existence of internal stresses in the metal coatings. Classical Watts sulfuric acid electrolytes are characterized by rather large values of internal stresses, therefore they cannot be used to create antidiffusion layers and interconnects of highly reliable thermoelectric microbatteries.

$Ni$  coatings with zero internal stress values can be obtained using modern electrolytes: fluoroborate, sulfanate, sulfamate, fluoroborate, and sulfamate sulfate.

The most promising is the sulfamic acid electrolyte, which allows, by changing the electrodeposition modes, to regulate the values of stresses from tensile to compressive. The work investigated the influence of the concentration of  $Ni$  sulfamic acid on the values of stresses in the deposited layers obtained in electrolytes of the following composition

1. Nickel sulfamic acid, g/l	100 – 800
2. Nickel chloride, g/l	20
3. Boric acid, g/l	30
pH	4.0
$t_e$ , °C	40 – 60
$I_K$ , A/dm <sup>2</sup>	3.10

The obtained results indicate that with an increase in the concentration of *Ni* sulfamic acid from 100 to 800 g/l, the tensile stress in the deposited layers decreases and reaches zero values at 650 g/l ( $t_e = 40\text{ }^\circ\text{C}$ ). If the concentration of *Ni* sulfamic acid is further increased, the tensile stresses are transformed into compressive stresses.

For the application of anti-diffusion layers and interconnects in micromodules, nickel sulfamic acid electrolyte was used. The thickness of the *Ni* layer was 100 – 120  $\mu\text{m}$ . To ensure minimal internal stress values, deposition was carried out at reduced cathodic current density values. Also, in order to reduce stresses, immediately after the nickel plating, the thermopile was annealed at a temperature of 150  $^\circ\text{C}$  for 4 hours. As a result, a high-quality protective interconnect coating with adhesion of at least 120  $\text{kg}/\text{cm}^2$  and high cyclic stability was obtained.

### 3.2. Improving the reliability of thermoelectric microthermopile

One of the effective methods of increasing the reliability of multi-element systems is the use of redundant elements, which, in the event of a system element failure, take over the functions of the failed element in whole or in part. In this work, the so-called passive redundancy method was used. It consists of the fact that the legs of a multi-element thermopile are shunted by passive resistors, which, in the event of a leg failure, prevent the opening of the thermopile electrical circuit, and therefore the failure only entails a decrease in the thermopile power, but not a complete failure of the thermopile (Fig. 7).

This method is economical and effective with the optimal choice of the ratio of resistances of the redundant legs and redundant shunts, which depends on the failure criterion of the thermopile. Such a criterion for passive redundancy is the permissible percentage of decrease in the output power of the thermopile for the guaranteed operating time.

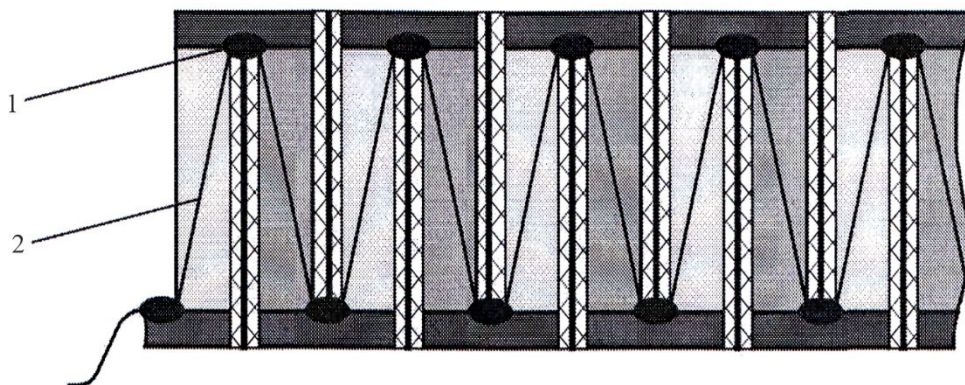


Fig. 7. Fragment of thermopile micromodule with passive resistors:  
1 – soldering of passive resistor, 2 – passive resistor.

To calculate the reliability of the thermopile and optimize the ratio of the thermopile resistances and redundant elements, methods and computer programs developed at the Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine were used. The calculation results are given in Table 1.



*Table 1*

*Dependence of thermopile parameters on the number of broken legs.*

Number of broken legs	$T_c - 50\text{ }^\circ\text{C}$			$T_h - 250\text{ }^\circ\text{C}$		
	$U, \text{B}$	%	$W$	%	$\eta, \%$	%
0	6.75	0	0.180	0	2.95	0
1	6.61	2.0	0.172	4.1	2.85	3.5
2	6.53	3.2	0.168	6.9	2.77	6.0
3	6.45	4.4	0.164	9.0	2.65	10.0
4	6.36	5.8	0.159	11.7	2.57	13.0
5	6.27	7.1	0.155	13.8	2.45	17.0

Experimental studies on the dependence of the parameters of a micro thermopile on the number of broken legs showed good agreement and coincidence with the calculation results given in Table 1.

## Conclusions

1. Special technological modes for manufacturing thermoelectric micro thermopiles with an increased density of elements (up to several thousand) based on highly efficient semiconductor materials have been developed, which significantly simplifies and mechanizes the method of manufacturing thermoelectric medical purpose heat flux sensors and microgenerators for powering low-power medical equipment.
2. The dependences of the parameters of thermoelectric microthermopiles on the number of broken legs and methods for increasing the failure rate of such microthermopiles by optimally selecting the ratio of the resistances of the redundant legs and redundant shunts are established, thereby achieving an acceptable percentage of reduction in the output power of the thermoelectric thermopile for the guaranteed operating time.
3. It has been established that thermoelectric heat flux sensors are promising for monitoring and early diagnosis of inflammatory processes and cancer. The introduction of such sensors into medical practice will become an effective means of diagnosing various human diseases.

## References

1. Anatyshuk L.I. (2003). *Thermoelectricity. Vol. 2. Thermoelectric power converters*. Kyiv, Chernivtsi: Institute of Thermoelectricity.
2. Anatyshuk L.I. (1998). *Thermoelectricity. Vol.1. Physics of thermoelectricity*. Kyiv, Chernivtsi: Institute of Thermoelectricity.
3. Anatyshuk L.I. (2007). Current status and some prospects of thermoelectricity. *J. Thermoelectricity*, 2, 7 – 20.
4. Demchuk B.M., Kushneryk L.Ya., Rublenyk I.M. (2002). Thermoelectric sensors for orthopaedics. *J. Thermoelectricity*, 4, 80 – 85.

5. Patent of Ukraine 53104 A. (2003). Sensor for preliminary diagnosis of inflammatory processes of the mammary glands. A.A. Ashcheulov, A.V. Klepikovskiy, L.Ya. Kushneryk, et al.
6. Ashcheulov A.A., Kushneryk L.Ya. (2004). Thermoelectric device for medico-biological express diagnostics. *Technology and Design in Electronic Equipment*, 4, 38 – 39.
7. *Patent of Ukraine 71619* (2012). Thermoelectric medical heat meter. L.I. Anatyshchuk, R.R. Kobylianskyi. Institute of Thermoelectricity (In Ukrainian).
8. *Patent of Ukraine 72032* (2012). Thermoelectric sensor for temperature and heat flux measurement. L.I. Anatyshchuk, R.R. Kobylianskyi. Institute of Thermoelectricity (In Ukrainian).
9. *Patent of Ukraine 73037* (2012). Thermoelectric medical device. P.D. Mykytiuk, R.R. Kobylianskyi, T.V. Slepniuk. Institute of Thermoelectricity (In Ukrainian).
10. *Patent of Ukraine 78619* (2013). Method for determination of heat flux density. L.I. Anatyshchuk, R.R. Kobylianskyi. Institute of Thermoelectricity (In Ukrainian).
11. *Patent of Ukraine 79929* (2013). Thermoelectric converter of heat flux for gradient heat meters. L.I. Anatyshchuk. Institute of Thermoelectricity (In Ukrainian).
12. Gischuk V.S. (2012). Electronic recorder of human heat flux sensor signals. *J. Thermoelectricity*, 4, 105 – 108.
13. Gischuk V.S. (2013). Electronic recorder with signal processing of thermoelectric heat flux sensor. *J. Thermoelectricity*, 1, 82 – 86.
14. Gischuk V.S. (2013). Modernized device for measuring human heat fluxes. *J. Thermoelectricity*, 2, 91 – 95.
15. Anatyshchuk L.I., Kobylianskyi R.R. (2012). Study of the influence of thermoelectric heat meter on determination of human heat release. *J. Thermoelectricity*, 4, 60 – 66.
16. Anatyshchuk L.I., Kobylianskyi R.R. (2012). 3D-model for determination of the influence of thermoelectric heat meter on the accuracy of measuring human heat release. *Scientific Herald of Chernivtsi University: Collected papers. Physics. Electronics. Vol. 2, Issue 1*. Chernivtsi: Chernivtsi National University, 15 – 20.
17. Anatyshchuk L.I., Kobylianskyi R.R. (2013). Computer simulation of thermoelectric heat meter readings in real-world operating conditions. *J. Thermoelectricity*, 1, 53 – 60.
18. Anatyshchuk L.I., Giba R.G., Kobylianskyi R.R. On some features of the use of medical heat meters in the study of local human heat release. *J. Thermoelectricity*, 2, 67 – 73.
19. Anatyshchuk L.I., Kobylianskyi R.R., Konstantynovich I.A. (2013). On the influence of a thermoelectric power source on the accuracy of temperature and heat flux measurement. *J. Thermoelectricity*, 6, 53 – 61.
20. Ivashchuk O.I., Morar I.K., Kobylianskyi R.R., Nepelyak L.V., Deley V.D. (2013). The role of abdominal heat flow in monitoring acute destructive pancreatitis. *Abstracts of scientific and practical conference "Current issues in surgery"*, Chernivtsi, Ukraine, 254 – 259.
21. Kobylianskyi R.R. (2016). The influence of thermal insulation on the readings of thermoelectric medical sensor. *Scientific Herald of Chernivtsi University: Collected papers. Physics. Electronics. Vol. 5, Issue 1*. Chernivtsi: Chernivtsi National University, 45 – 49.
22. Kobylianskyi R.R. (2016). Computer simulation of readings of a medical thermoelectric sensor. *J. Thermoelectricity*, 4, 69 – 77.
23. Gischuk V.S., Kobylianskyi R.R., Cherkez R.G. (2014). Multichannel device for measuring the temperature and density of heat fluxes. *Scientific Herald of Chernivtsi University: Collected papers. Physics. Electronics. Vol. 3, Issue. 1*. Chernivtsi: Chernivtsi National University, 96 – 100.

24. The use of thermoelectric heat meters in medical diagnostics. *Scientific Herald of Chernivtsi University: Collected papers. Physics. Electronics. Vol. 4, Issue 1.* Chernivtsi: Chernivtsi National University, 90 – 96.
25. Anatyshchuk L.I., Ivashchuk O.I., Kobylianskyi R.R., Postevka I.D., Bodiaka V.Yu., Gushul I.Ya. (2016). Thermoelectric device for measuring the temperature and density of heat flux "ALTEC-10008". *J. Thermoelectricity*, 1, 76 – 84.
26. Anatyshchuk L.I., Yuryk O.E., Kobylianskyi R.R., Roy I.V., Fishchenko Ya.V., Slobodianiuk N.P., Yuryk N.E., Duda B.S. (2017). Thermoelectric device for diagnosing inflammatory processes and neurological manifestations of osteochondrosis of the human spine. *J. Thermoelectricity*, 3, 54 – 67.
27. Yuryk O.E., Anatyshchuk L.I., Roy I.V., Kobylianskyi R.R., Fishchenko Ya.V., Slobodianiuk N.P., Yuryk N.E., Duda B.S. (2017). Peculiarities of heat exchange in patients with neurological manifestations of osteochondrosis in the lumbosacral spine. *Trauma*, 18 (6).
28. Anatyshchuk L.I., Luste O.J., Kobylianskyi R.R. (2017). Information and energy theory of thermoelectric temperature and heat flux sensors for medical purposes. *J. Thermoelectricity*, 4, 5 – 20.
29. Anatyshchuk L.I., Kobylianskyi R.R., Cherkez R.G., Konstantynovych I.A., Hoshovskiy V.I., Tiumentsev V.A. (2017). Thermoelectric device with electronic control unit for diagnostics of inflammatory processes in the human organism. *Tekhnologiya i konstruirovaniye v elektronnoi apparature – Technology and Design in Electronic Equipment*, 6, 44 – 48.
30. Anatyshchuk L.I., Ivashchuk O.I., Kobylianskyi R.R., Postevka I.D., Bodiaka V.Yu., Gushul I.Ya., Chuprovskaya Yu.Ya. (2018). On the influence of ambient temperature on the readings of thermoelectric medical sensors. *Sensor Electronics and Microsystem Technologies*, 15 (1), 17 – 29.
31. Anatyshchuk L.I., Pasyechnikova N.V., Naumenko V.O., Zadorozhnyi O.S., Havryliuk M.V., Kobylianskyi R.R. (2018). Thermoelectric device for determination of heat flux from the surface of eyes. *J. Thermoelectricity*, 5, 52 – 67.
32. Anatyshchuk L.I., Kobylianskyi R.R., Konstantynovich I.A. (2014). Calibration of thermoelectric heat flux sensors. *Proc. of XV International scientific and practical conference "Modern information and electronic technologies"* (Odesa, Ukraine, May 26-30, 2014.) Vol. 2, 30 – 31.
33. Anatyshchuk L.I., Kobylianskyi R.R., Konstantynovich I.A., Lysko V.V., Pugantseva O.V., Rozver Yu.Yu., Tiumentsev V.A. (2016). Calibration bench for thermoelectric heat flux converters. *J. Thermoelectricity*, 5, 71 – 79.
34. Anatyshchuk L.I., Kobylianskyi R.R., Konstantynovich I.A., Kuz R.V., Manyk O.M., Nitsovich O.V., Cherkez R.G. (2016). Manufacturing technology of thermoelectric microthermopiles. *J. Thermoelectricity*, 6, 49 – 54.
35. Anatyshchuk L.I., Razinkov V.V., Bukharayeva N.R., Kobylianskyi R.R. (2017). Thermoelectric bracelet. *J. Thermoelectricity*, 2, 58 – 72.
36. Anatyshchuk L.I., Todurov B.M., Kobylianskyi R.R., Dzhal S.A. (2019). On the use of thermoelectric microgenerators to power pacemakers. *J. Thermoelectricity*, 5, 63 – 88.
37. Anatyshchuk L.I., Yuryk O.E., Strafun S.S., Stashkevich A.T., Kobylianskyi R.R., Cheviuk A.D., Yuryk N.E., Duda B.S. (2021). Thermometric indicators in patients with chronic low back pain. *J. Thermoelectricity*, 1, 51 – 64.
38. Chunzhi Wang, Hongzhe Jiao, Lukyan Anatyshchuk, Nataliya Pasyechnikova, Volodymyr Naumenko, Oleg Zadorozhnyy, Lyudmyla Vikhor, Roman Kobylianskyi, Roman Fedoriv, Orest Kochan (2022). Development of a temperature and heat flux measurement system based on

microcontroller and its application in ophthalmology. *Measurement Science Review*, 22 (2), 73 – 79.

39. Kobylanskyi R.R., Prybyla A.V., Konstantynovich I.A., Boychuk V.V. (2022). Results of experimental investigations of thermoelectric medical heat flux sensors, *J. Thermoelectricity*, 3-4, 70 – 83.
40. Yuryk O., Anatyshuk L., Kobylanskyi R., Yuryk N. (2023). *Measurement of heat flux density as a new method of diagnosing neurological diseases*. Kharkiv: PC Technology Center, 31 – 68.

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**Кобилянський Р.Р., канд. фіз.-мат. наук<sup>1,2</sup>**

**Лисько В.В., канд. фіз.-мат. наук<sup>1,2</sup>**

**Прибила А.В., канд. фіз.-мат. наук<sup>1,2</sup>**

**Константинович І.А., канд. фіз.-мат. наук<sup>1,2</sup>**

**Кобилянська А.К., канд. фіз.-мат. наук<sup>1</sup>**

**Бухарасва Н.Р.,<sup>1</sup>**

**Бойчук В.В.<sup>1,2</sup>**

<sup>1</sup> Інститут термоелектрики НАН та МОН України,  
вул. Науки, 1, Чернівці, 58029, Україна;

<sup>2</sup> Чернівецький національний університет імені Юрія Федьковича,  
вул. Коцюбинського 2, Чернівці, 58012, Україна  
e-mail: anatysh@gmail.com

## **ТЕХНОЛОГІЧНІ РЕЖИМИ ВИГОТОВЛЕННЯ ТЕРМОЕЛЕКТРИЧНИХ СЕНСОРІВ МЕДИЧНОГО ПРИЗНАЧЕННЯ**

У роботі наведено технологічні режими виготовлення термоелектричних перетворювачів теплового потоку. Встановлено, що оптимальним термоелектричним матеріалом для термобатарей є низькотемпературні матеріали на основі  $Bi_2Te_3$ . Експериментально підтверджено ефективність використання таких технологічних режимів для виготовлення термоелектричних мікробатарей, здатних ресструвати лазерне випромінювання з покращеним коефіцієнтом перетворення в 1–1.5 порядки у порівнянні з існуючими вимірювальними перетворювачами. Вказані технологічні режими значно спрощують та механізують методику виготовлення термоелектричних сенсорів теплового потоку медичного призначення та мікрогенераторів для живлення малопотужної медичної апаратури.

**Ключові слова:** технологічний режим, термоелектричний перетворювач, термоелектричний сенсор теплового потоку медичного призначення.

### **Література**

1. Анатичук Л.І. Термоелектрика. Т.2. Термоелектричні перетворювачі енергії. Київ, Чернівці: Інститут термоелектрики, 2003. – 376 с.
2. Anatyshuk L.I. (1998). *Thermoelectricity. Vol.1. Physics of thermoelectricity*. Kyiv, Chernivtsi: Institute of Thermoelectricity.

3. Анатичук Л.І. Сучасний стан і деякі перспективи термоелектрики // Термоелектрика. – 2007. – № 2. – С. 7 – 20.
4. Демчук Б.М., Кушнерик Л.Я., Рубленик І.М. Термоелектричні датчики для ортопедії.// Термоелектрика. – 2002. – №4. – С. 80 – 85.
5. Патент України 53104 А. Датчик для попередньої діагностики запальних процесів молочних залоз // А.А. Ашеулов, А.В. Клепіковський, Л.Я. Кушнерик та ін. – 2003.
6. Ашеулов А.А., Кушнерик Л.Я. Термоелектричний прилад для медико-біологічної експрес-діагностики // Технологія та конструювання в електронній апаратурі. – №4. – 2004. – С. 38 – 39.
7. Пат. 71619 Україна, МПК H01L 35/00. Термоелектричний медичний тепломір / Анатичук Л.І., Кобилянський Р.Р.; Інститут термоелектрики. – № u 2011 14007; заявл. 28.11.11; опубл. 25.07.12, Бюл. № 14.
8. Пат. 72032 Україна, МПК H01L 35/00. Термоелектричний сенсор для вимірювання температури і теплового потоку / Анатичук Л.І., Кобилянський Р.Р.; Інститут термоелектрики. – № u 2011 14005; заявл. 28.11.11; опубл. 10.08.12, Бюл. № 15.
9. Пат. 73037 Україна, МПК H01L 35/02. Термоелектричний медичний пристрій / Микитюк П.Д., Кобилянський Р.Р., Слепенюк Т.В.; Інститут термоелектрики. – № u 2012 01922; заявл. 20.02.12; опубл. 10.09.12, Бюл. № 17.
10. Пат. 78619 Україна, МПК H01L 35/00. Метод визначення густини теплового потоку / Анатичук Л.І., Кобилянський Р.Р.; Інститут термоелектрики. – № u 2012 11018; заявл. 21.09.12; опубл. 25.03.13, Бюл. № 6.
11. Пат. 79929 Україна, МПК H01L 35/00. Термоелектричний перетворювач теплового потоку для градієнтних тепломірів / Анатичук Л.І.; Інститут термоелектрики. – № u 2012 11857; заявл. 15.10.12; опубл. 13.05.13, Бюл. № 9.
12. Гищук В.С. Електронний реєстратор сигналів сенсорів теплового потоку людини // Термоелектрика. – № 4. – 2012. – С. 105 – 108.
13. Гищук В.С. Електронний реєстратор з обробкою сигналів термоелектричного сенсора теплового потоку // Термоелектрика. – № 1. – 2013. – С. 82 – 86.
14. Гищук В.С. Модернізований прилад для вимірювання теплових потоків людини // Термоелектрика. – №2. – 2013. – С. 91 – 95.
15. Анатичук Л.І., Кобилянський Р.Р. Дослідження впливу термоелектричного тепломіра на визначення тепловиділення людини // Термоелектрика. – № 4. – 2012. – С. 60 – 66.
16. Анатичук Л.І., Кобилянський Р.Р. 3D-модель для визначення впливу термоелектричного тепломіра на точність вимірювання тепловиділення людини // Науковий вісник Чернівецького університету: збірник наук. праць. Фізика. Електроніка. – Т. 2, Вип. 1. – Чернівці: Чернівецький національний університет, 2012. – С. 15 – 20.
17. Анатичук Л.І., Кобилянський Р.Р. Комп'ютерне моделювання показів термоелектричного тепломіра в умовах реальної експлуатації // Термоелектрика. – № 1. – 2013. – С. 53 – 60.
18. Анатичук Л.І., Гіба Р.Г., Кобилянський Р.Р. Про деякі особливості використання медичних тепломірів при дослідженні локальних тепловиділень людини // Термоелектрика. – № 2. – 2013. – С. 67 – 73.
19. Анатичук Л.І., Кобилянський Р.Р., Константинович І.А. Про вплив термоелектричного джерела живлення на точність вимірювання температури і теплового потоку // Термоелектрика. – № 6. – 2013. – С. 53 – 61.

20. Іващук О.І., Морар І.К., Кобилянський Р.Р., Непеляк Л.В., Делей В.Д. Роль теплового потоку черевної порожнини в моніторингу гострого деструктивного панкреатиту // Збірник тез науково-практичної конференції "Актуальні питання хірургії", м. Чернівці, Україна. – 2013. – С. 254 – 259.
21. Кобилянський Р.Р. Про вплив теплової ізоляції на покази термоелектричного сенсора медичного призначення // Науковий вісник Чернівецького університету: збірник наук. праць. Фізика. Електроніка. – Т. 5, Вип. 1. – Чернівці: Чернівецький національний університет, 2016. – С. 45 – 49.
22. Кобилянський Р.Р. Комп'ютерне моделювання показів термоелектричного сенсора медичного призначення // Термоелектрика. – № 4. – 2016. – С. 69 – 77.
23. Гищук В.С., Кобилянський Р.Р., Черкез Р.Г. Багатоканальний прилад для вимірювання температури і густини теплових потоків // Науковий вісник Чернівецького університету: збірник наук. праць. Фізика. Електроніка. – Т. 3, Вип. 1. – Чернівці: Чернівецький національний університет, 2014. – С. 96 – 100.
24. Кобилянський Р.Р., Бойчук В.В. Використання термоелектричних тепломірів у медичній діагностиці // Науковий вісник Чернівецького університету: збірник наук. праць. Фізика. Електроніка. – Т. 4, Вип. 1. – Чернівці: Чернівецький національний університет, 2015. – С. 90 – 96.
25. Анатичук Л.І., Іващук О.І., Кобилянський Р.Р., Постевка І.Д., Бодяка В.Ю., Гушул І.Я. Термоелектричний прилад для вимірювання температури і густини теплового потоку "АЛТЕК-10008" // Термоелектрика. – № 1. – 2016. – С. 76 – 84.
26. Анатичук Л.І., Юрик О.Є., Кобилянський Р.Р., Рой І.В., Фіщенко Я.В., Слободянюк Н.П., Юрик Н.Є., Дуда Б.С. Термоелектричний прилад для діагностики запальних процесів та неврологічних проявів остеохондрозу хребта людини // Термоелектрика. – № 3. – 2017. – С. 54 – 67.
27. Юрик О.Є., Анатичук Л.І., Рой І.В., Кобилянський Р.Р., Фіщенко Я.В., Слободянюк Н.П., Юрик Н.Є., Дуда Б.С. Особливості теплового обміну у пацієнтів з неврологічними проявами остеохондрозу в попереково-крижовому відділі хребта // Травма. – Т.18. – № 6. – 2017.
28. Анатичук Л.І., Лусте О.Я., Кобилянський Р.Р. Інформаційно-енергетична теорія термоелектричних сенсорів температури і теплового потоку медичного призначення // Термоелектрика. – № 4. – 2017. – С. 5 – 20.
29. Anatychuk L.I., Kobylianskyi R.R., Cherkez R.G., Konstantynovych I.A., Hoshovskyi V.I., Tiumentsev V.A. (2017). Thermoelectric device with electronic control unit for diagnostics of inflammatory processes in the human organism. *Tekhnologiya i konstruirovane v elektronnoi apparature – Technology and Design in Electronic Equipment*, 6, 44 – 48.
30. Анатичук Л.І., Іващук О.І., Кобилянський Р.Р., Постевка І.Д., Бодяка В.Ю., Гушул І.Я., Чупровська Ю.Я. Про вплив температури навколишнього середовища на покази термоелектричних сенсорів медичного призначення // Сенсорна електроніка і мікросистемні технології. – Т. 15. – № 1. – 2018. – С. 17 – 29.
31. Анатичук Л.І., Пасєчнікова Н.В., Науменко В.О., Задорожний О.С., Гаврилюк М.В., Кобилянський Р.Р. Термоелектричний прилад для визначення теплового потоку з поверхні очей // Термоелектрика. – № 5. – 2018. – С. 52 – 67.
32. Анатичук Л.І., Кобилянський Р.Р., Константинович І.А. Градування термоелектричних сенсорів теплового потоку // Труды XV Міжнародної науково-практичної конференції

- «Сучасні інформаційні та електронні технології» 26-30 травня 2014 року. – Т. 2. – Одеса, Україна. – 2014. – С. 30 – 31.
33. Анатичук Л.І., Кобилянський Р.Р., Константинович І.А., Лисько В.В., Пуганцева О.В., Розвер Ю.Ю., Тюменцев В.А. Стенд для градування термоелектричних перетворювачів теплового потоку // Термоелектрика. – № 5. – 2016. – С. 71 – 79.
34. Анатичук Л.І., Кобилянський Р.Р., Константинович І.А., Кузь Р.В., Маник О.М., Ніцович О.В., Черкез Р.Г. Технологія виготовлення термоелектричних мікробатарей // Термоелектрика. – № 6. – 2016. – С. 49 – 54.
35. Анатичук Л.І., Разінков В.В., Бухараєва Н.Р., Кобилянський Р.Р. Термоелектричний браслет // Термоелектрика. – № 2. – 2017. – С. 58 – 72.
36. Анатичук Л.І., Тодуров Б.М., Кобилянський Р.Р., Джал С.А. Про використання термоелектричних мікрогенераторів для живлення електрокардіостимуляторів // Термоелектрика. – № 5. – 2019. С. 63 – 88.
37. Анатичук Л.І., Юрик О.Є., Страфун С.С., Сташкевич А.Т., Кобилянський Р.Р., Чев'юк А.Д., Юрик Н.Є., Дуда Б.С. Теплометричні показники у пацієнтів з хронічним болем у попереку // Термоелектрика. – № 1. – 2021. С. 51 – 64.
38. Chunzhi Wang, Hongzhe Jiao, Lukyan Anatychuk, Nataliya Pasyechnikova, Volodymyr Naumenko, Oleg Zadorozhnyy, Lyudmyla Vikhor, Roman Kobylianskyi, Roman Fedoriv, Orest Kochan (2022). Development of a temperature and heat flux measurement system based on microcontroller and its application in ophthalmology. *Measurement Science Review*, 22 (2), 73 – 79.
39. Кобилянський Р.Р., Прибила А.В., Константинович І.А., Бойчук В.В. Результати експериментальних досліджень термоелектричних медичних сенсорів теплового потоку // Термоелектрика №3-4. – 2022. С. 70 – 83.
40. Yuryk O., Anatychuk L., Kobylianskyi R., Yuryk N. (2023). *Measurement of heat flux density as a new method of diagnosing neurological diseases*. Kharkiv: PC Technology Center, 31 – 68.

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