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TECHNOLOGY FOR MANUFACTURING THERMOELECTRIC MICROTHERMOPILES

The present paper gives the results of development of technology for manufacturing thermoelectric microthermopiles which simplifies considerably and mechanizes the method for manufacturing thermoelectric heat flux sensors and microgenerators for power supply to low-power medical equipment. It was established that proposed technology reduces the percentage of rejected thermoelectric material plates and thus reduces the cost of thermoelectric microthermopiles. The efficiency of using such technology for manufacturing thermoelectric microthermopiles with the legs of small cross-section from 0.02 × 0.02 mm to 1.0 × 1.0 mm and the length up to 30 mm was experimentally confirmed.

Key words: manufacturing technology, thermoelectric microthermopile, heat flux sensor, thermoelectric microgenerator.

Introduction

General characterization of the problem. It is known that as early as the first stages of designing thermoelectric microgenerators (for instance, for power supply to low-power electronic devices, telemetry and navigation systems, IR-detectors, as well as military and medical equipment) it was established that thermopiles for them must have unusual design that differs markedly from traditional generator modules [1 – 3]. For instance, for isotopic thermoelectric microgenerators with electric power in the range of 0.05 ÷ 2.5 W, temperature difference on the module 100 ÷ 200 K and operating voltage 5 ÷ 15 V it is necessary to use thermopile legs of the length up to 10 ÷ 20 mm and cross-section from 0.2 × 0.2 mm to 0.5 × 0.5 mm. However, for power supply to low-power medical equipment at small temperature differences on the module to 10 K and electric power in the range of 0.05 ÷ 5 mW one must use thermopile legs of cross-section from 0.02 × 0.02 mm to 1 × 1 mm. In so doing, the number of legs in the thermopile must be from several hundreds to several thousands and more. Fulfillment of such requirements is a rather complicated technological problem [4 – 8].

The attempts of creating such microthermopiles were reduced to using film technologies [9]. Film thermopiles were created in the form of tapes which then can be folded into a compact roll. To manufacture such thermopiles, magnetron sputtering and other techniques were employed in combination with photolithography methods. Thermoelectric materials based on *Bi-Te* were used in the thermopiles. However, the results of testing film thermopiles revealed a number of their significant shortcomings, namely the substrates on which the thermopiles were formed shunted thermal flux which caused the reduction of efficiency; the difference in linear expansion coefficient between films and substrate (generally polyamide 5 μm) gave rise to thermal stresses in the thermopiles, which led to failures in their operation; recrystallization processes in the films led to degradation of thermopiles and deterioration of their thermoelectric properties; creation of reliable thermal contacts between the thermopile, heat source and package caused difficulties which led to additional losses of temperature difference on thermopile faces. The totality of the above problems resulted in the abandonment of film thermopiles in thermoelectric microgenerators.

Therefore, *the purpose of this work* is to develop special technology for manufacturing thermoelectric microthermopiles with increased density of components (up to several thousand legs of small cross-section from 0.02 × 0.02 mm to 1.0 × 1.0 mm and length up to 30 mm) to produce thermoelectric heat flux sensors and microgenerators for power supply to low-power medical equipment.

Technology for manufacturing thermoelectric microthermopiles with increased density of components [10, 11]

The technology for manufacturing thermoelectric microthermopiles given in [10] was taken as a basis. The technology for manufacturing a thermoelectric microthermopile [11] proposed here comprises preparation of *n*- and *p*-type plates with deposition on the end surfaces of anti-diffusion layers, making cuts in these plates, coating of the internal surfaces of plates with cuts by electrically insulating compound and connection of the plates so as to form between them a gap of 10 ÷ 30 μm, filled with compound; after polymerization of compound the external parts of the plates are removed to form a plate consisting of interconnected *n*- and *p*-type legs; the plates of *n*- and *p*-type legs are arranged one above the other and connected by compound to form a thermoelectric microthermopile, whose legs are connected by metalized anti-diffusion layers; heat spreaders on the hot and cold surfaces of thermoelectric microthermopile are created by high-temperature compound with thermally conductive fillers.

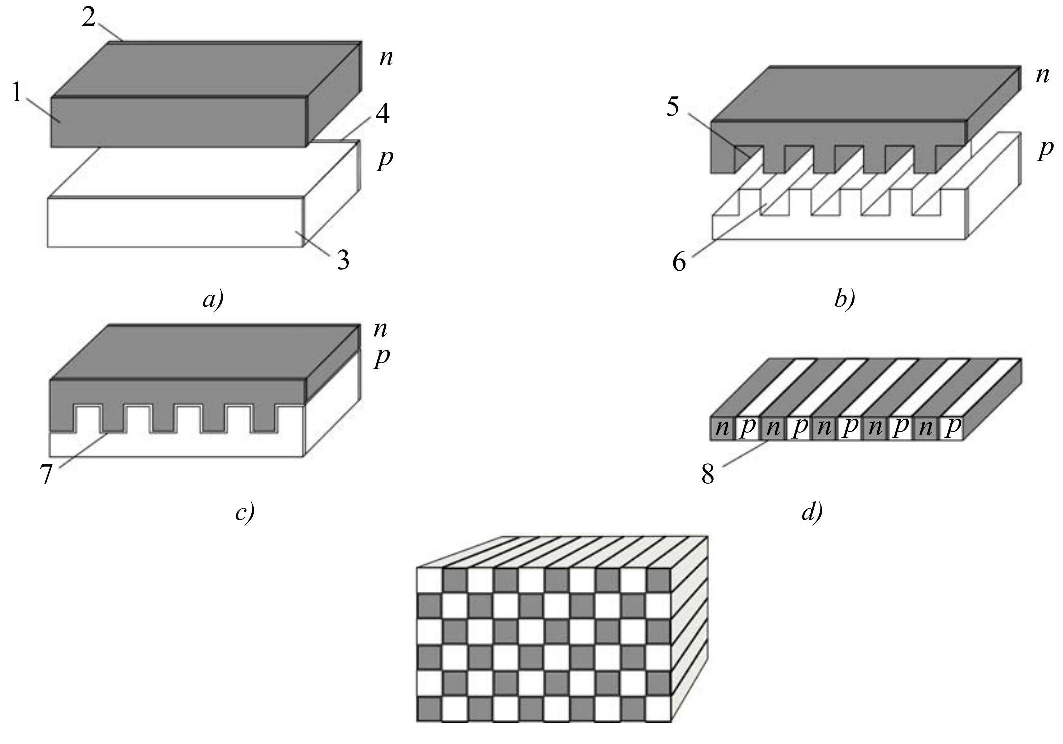

Fig. 1. Schematic of technology for manufacturing thermoelectric microthermopiles with increased density of components [11].

Fig. 1 shows a schematic demonstrating the idea of proposed technology for manufacturing thermoelectric microthermopiles with increased density of components [11]. The technology is as follows. At first, rectangular plates of *n*- and *p*-type are manufactured with deposition on the end surfaces of anti-diffusion layers 1 – 4 (Fig. 1*a*). Cuts of necessary size 5 – 6 are made in the plates on specially elaborated equipment (for instance, multi-wire cutting machine) (Fig. 2*b*). The internal surfaces of the plates are coated with high-temperature compounds with the operating temperature 300 – 400 °C, following which the plates are connected in such a way as to form a gap of 10 – 30 μm filled with compound 7 (Fig. 2*c*). After polymerization of compound the external parts of the plates are removed to form plate 8 which consists of interconnected *n*- and *p*-type legs (Fig. 1*d*). Then the plates of *n*- and *p*-type legs are arranged one above the other and connected by compound to form a thermoelectric microthermopile (Fig. 1*e*). Connection of legs is done by metalized anti-diffusion layers. Heat spreaders on the hot and cold surfaces of thermopiles are created by high-temperature compound with thermally conductive fillers – diamond or corundum powders.

Testing of proposed technology has proved the efficiency of its use for manufacturing thermoelectric microthermopiles with the legs of small cross-section from 0.02 × 0.02 mm to 1.0 × 1.0 mm. Such technology simplifies considerably and mechanizes the method for manufacturing thermoelectric microthermopiles with a large number of legs of *n*- and *p*-type conductivity.

Improvement of technology for manufacturing thermoelectric microthermopiles [12]

The disadvantage of the above technology for manufacturing thermoelectric microthermopiles is significant percentage of rejected thermoelectric material plates due to microcracks that may arise when grinding.

Said problem is solved by using an improved technology for manufacturing thermoelectric microthermopiles [12] which consists in the removal of the external parts of connected plates in three stages: grinding of plates on the one side, gluing such plates with their ground sides together and grinding of both external sides of the newly-formed double plates.

The proposed technology allows joint formation of the legs with small cross-section from 0.01 × 0.01 mm to 1.0 × 1.0 mm and makes it possible to combine them into thermoelectric microthermopiles with the length of legs up to 30 mm.

Fig. 2 shows a schematic which demonstrates the idea of proposed technology for manufacturing a thermoelectric microthermopile [12]. The technology is as follows. At first, rectangular plates of *n*- and *p*-type conductivity are manufactured with deposition on the end surfaces of anti-diffusion layers 1 – 4 (Fig. 2*a*). Cuts of necessary size 5 – 6 are made in the plates on specially elaborated equipment (for instance, multi-wire cutting machine) (Fig. 2*b*). The internal surfaces of the plates are coated with high-temperature compounds with the operating temperature 300 – 400 °C, following which the plates are connected in such a way as to form a gap of 10 – 30 μm filled with compound 7 (Fig. 2*c*). After polymerization of compound the external parts of connected plates are removed in three stages: grinding of plates on the one side to form plate 8 (Fig. 2*d*), gluing of such plates with their ground sides together to form plate 9 (Fig. 2*e*) and grinding of both external sides of newly-formed double plates 9 to form plate 10 consisting of interconnected *n*- and *p*-type legs (Fig. 2*f*). Then the plates of *n*- and *p*-type legs are arranged one above the other and connected with compound to form a thermoelectric microthermopile 11 (Fig. 2*g*). Connection of legs is done by metallized anti-diffusion layers. Heat spreaders on the hot and cold surfaces of thermopiles are created by high-temperature compound with thermally conductive fillers – diamond or corundum powders.

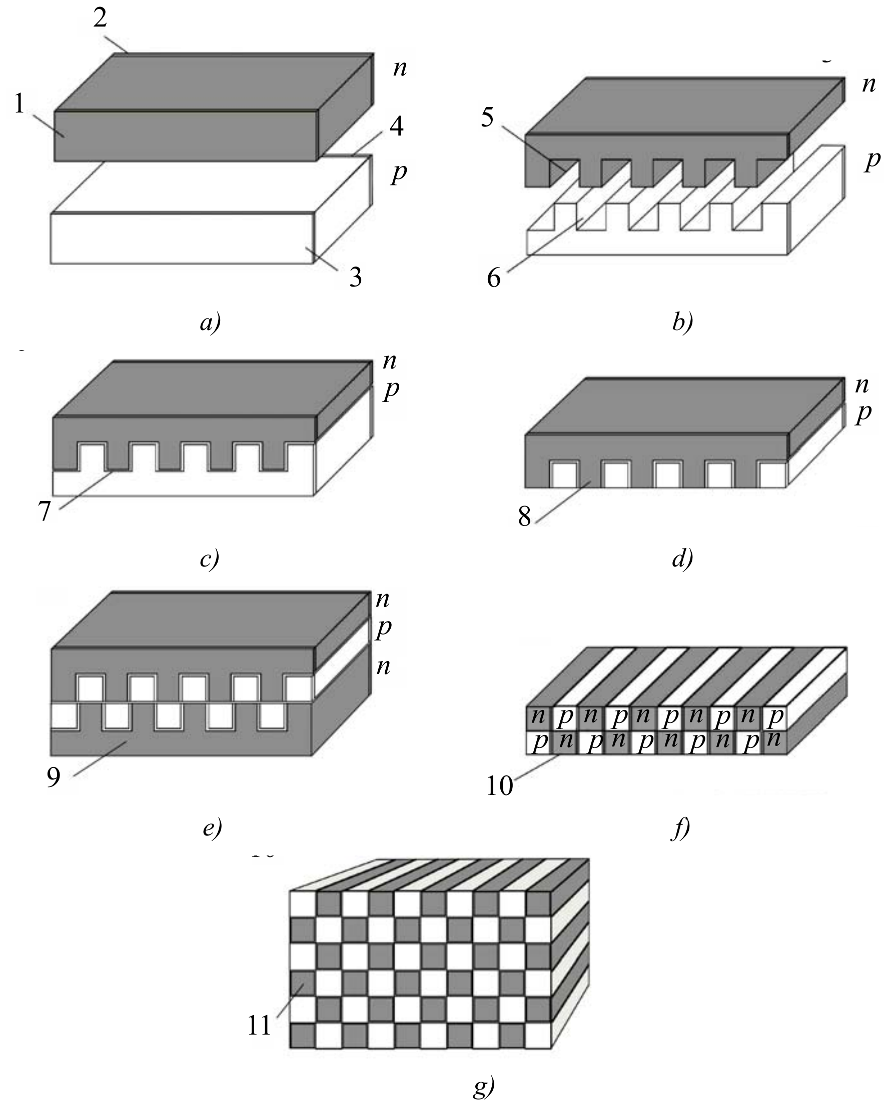

Fig. 2. Schematic of technology for manufacturing thermoelectric microthermopiles [12].

Experimental tests of proposed technology have proved the efficiency of its use for manufacturing thermoelectric microthermopiles with the legs of small cross-section from 0.01 × 0.01 mm to 1.0 × 1.0 mm. Such technology reduces considerably the percentage of rejected thermoelectric material plates due to decrease in the number of microcracks that may arise when grinding, and, thus, reduces the cost of thermoelectric microthermopiles. This, in turn, improves the reliability of produced thermoelectric heat flux sensors and microgenerators for power supply to low-power medical equipment.

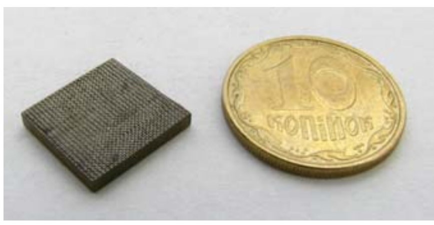

Fig. 3. Appearance of a thermoelectric thermopile produced by the above technology of size (10 × 10 × 2) mm with cross-section of the legs 0.02 × 0.02 mm.

Fig. 3 shows a thermoelectric microthermopile produced by the above technology of size (10 × 10 × 2) mm with cross-section of the legs 0.02 × 0.02 mm.

Based on the above technology, a series of thermoelectric microthermopiles has been manufactured with the size (10 × 10 × 2) mm and the legs of small cross-section from 0.02 × 0.02 mm to 1.0 × 1.0 mm. In this way the efficiency of using said technology for manufacturing thermoelectric microthermopiles with increased density of components was experimentally verified.

Conclusions

1. A special technology was developed for manufacturing thermoelectric microthermopiles with increased density of components (up to several thousand) based on high-performance semiconductor materials that simplifies considerably and mechanizes the method for manufacturing thermoelectric heat flux sensors and microgenerators for power supply to low-power medical equipment.
2. The efficiency of using proposed technology for manufacturing thermoelectric microthermopiles with the legs of small cross-section from 0.02 × 0.02 mm to 1.0 × 1.0 mm and the length of legs up to 30 mm was experimentally confirmed.
3. It was established that the proposed technology reduces the percentage of rejected thermoelectric material plates due to decrease in the number of microcracks that may arise when grinding and, thus, reduces the cost of thermoelectric microthermopiles.

References

1. L. I. Anatychuk. *Thermoelements and Thermoelectric Devices: Reference Book* (Kyiv: Naukova Dumka, 1979), 768 p.
2. L. I. Anatychuk. *Thermoelectricity, Vol.1, Physics of Thermoelectricity* (Kyiv, Chernivtsi: Institute of Thermoelectricity, 1998), 376 p.
3. L. I. Anatychuk. *Thermoelectricity, Vol.2, Thermoelectric Power Converters* (Kyiv, Chernivtsi: Institute of Thermoelectricity, 2003), 376 p.
4. O. A. Geraschenko. *Foundations of the Heat Flux Measurement* (Kyiv: Naukova Dumka, 1971), p.192.
5. O. A. Geraschenko, T. G. Grischenko, L. V. Dekusha. Methods of Designing Optimal Heat Flux Converters, *Problems of Energy Saving* 3, 36 – 42 (1990).
6. B. M. Demchuk, O. J. Luste. Information and Energy Description of Thermoelectric Multiple Thermopiles, *J.Thermoelectricity* 2, 54 – 56 (2003).
7. L. I. Anatychuk, B. M. Demchuk, O. J. Luste. *Patent № 67369A*, Thermopile, 2004.
8. B. M. Goltsman, Z. M. Dashevsky, V. I. Kaidanov, N. V. Kolomoyets. Film *Thermoelements: Physics and Application* (Moscow: Nauka, 1985), 232 p.
9. B. M. Demchuk, O. J. Luste. Method of Assembling a Thermopile, *Certificate of Authorship № 1145857*, 1984.
10. L. I. Anatychuk, I. A. Konstantynovych. *Patent of Ukraine № 93217*, *InCl* H_01L 35/00, Method for Manufacturing Thermoelectric Microthermopile; Application № u201403210; filed 31.03.14; publ. 25.09.14, Bul. № 18.
11. L. I. Anatychuk, R. R. Kobylianskyi. *Application for a Utility Model № u201612914 of 19.12.2016.* Method for Manufacturing a Thermoelectric Microthermopile, Institute of Thermoelectricity; Yu. Fedkovych Chernivtsi National University.

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