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Semiconductors as Materials for Manufacturing Thermoelectric Generators in Medicine

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Abstract: In recent decades, thermoelectric generators (TEGs) have attracted growing attention due to their ability to convert thermal energy into electrical energy. They have gained particular importance in medicine, where they are used to power implantable devices, monitor body temperature, and for other purposes. A key component of thermoelectric generators is semiconductor materials, which possess unique electrical and thermal properties. This article discusses the characteristics of semiconductor materials used in the manufacture of thermoelectric generators, their advantages, limitations, and prospects for application in medicine.

Keywords: thermoelectric generators, thermoelectric generator components, electrical properties, thermal properties, application prospects.

Introduction. Thermoelectric devices are based on the Seebeck effect, which allows the conversion of temperature differences into electrical voltage.

Currently, thermoelectric generators are widely used across various industries, from agriculture to space exploration instruments. In medicine, such devices are in demand due to their ability to create autonomous power sources for specific microsystems. [1–3] They are used in devices with a variety of functions:

1. Power supply for implantable devices. TEGs can provide energy to operate pacemakers, cochlear implants, and other devices, reducing dependence on batteries and increasing system lifespan.
2. Monitoring of physiological parameters. Semiconductor TEGs are used in the creation of sensors that measure body temperature, which is especially important for patients in intensive care or during the postoperative period.
3. Regenerative medicine.

Problem Statement. Given the relevance of TEG applications in medicine, researchers are challenged to develop thermoelectric generators with unique properties and parameters that enable their miniaturization and integration with specific medical instruments and devices.

Semiconductor materials play a key role in the efficiency of thermoelectric generators by determining their thermoelectric parameters such as Seebeck coefficient, thermal conductivity, and electrical conductivity [4].

Thermoelectric Properties of Semiconductors. The efficiency of TEGs is evaluated using the dimensionless figure of merit expressed by the formula:

$ZT = (S^2\sigma T) / \kappa$,

where:

- ✓ S – Seebeck coefficient,
- ✓ σ – electrical conductivity,

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- ✓ κ – thermal conductivity,
- ✓ T – absolute temperature.

High ZT values are achieved by optimizing the balance between electrical conductivity and low thermal conductivity. Semiconductors such as bismuth telluride (Bi_2Te_3), sulfides, and selenides demonstrate high ZT values, making them leading candidates for thermoelectric applications.

Research Methods. Semiconductors used for medical thermoelectric generators can be grouped as follows:

1. Bismuth Telluride (Bi_2Te_3). This is the most studied and widely used material in TEGs due to its high ZT at room temperature. In medicine, Bi_2Te_3 is used to create miniature TEGs that operate based on temperature differences between the human body and the environment.
2. Nanostructured materials. The use of nanoparticles, quantum dots, and multilayer structures significantly enhances the thermoelectric properties of semiconductors. For example, adding nanostructures to Bi_2Te_3 reduces thermal conductivity by phonon scattering.
3. Organic semiconductors. Materials such as polyaniline and polythiophene are biocompatible, which makes them promising for medical applications. Their key advantages include flexibility and the ability to integrate with soft tissues of the body.

Based on the analysis of sources [1–7], the advantages and disadvantages of using semiconductors in medicine can be identified:

Advantages:

- ✓ Miniaturization potential;
- ✓ Autonomous operation;
- ✓ No need for chemical fuel;
- ✓ Durability.

Disadvantages:

- ✓ High manufacturing cost;
- ✓ Toxicity of some materials (e.g., tellurium and bismuth).

The development of flexible thermoelectric films opens new opportunities for using devices in tissue engineering.

Additional Considerations. Another important parameter in selecting materials for TEGs is the electromotive force (EMF) of thermocouples. Thermocouple EMF is generally small—fractions of a volt, sometimes hundredths or even millionths. However, by connecting many thermocouples in series, sufficient electrical energy can be generated to power certain devices.

It should be noted that in many thermocouples, EMF changes nonlinearly with heating. Some show a sharp increase in EMF at the early stages of heating, followed by a plateau and then a decline to zero, and even reversal of polarity.

An example is a thermocouple made from copper and iron. At 100 °C, the EMF reaches 0.00113 V, with current flowing from copper to iron. At 200 °C, EMF increases to 0.00171 V, but at 400 °C it decreases to 0.00120 V. At 541 °C, EMF disappears and then reappears with reversed current flow—from iron to copper.

This behavior is explained by the different rates of voltage change in the materials. Initially, one material generates more potential, but as temperature rises, the second material dominates. This explains the voltage inversion.

To create effective thermocouples, materials should be chosen such that the EMF does not slow or reverse with increasing temperature. It is also important to select materials with low electrical resistance to generate higher current at the same EMF.

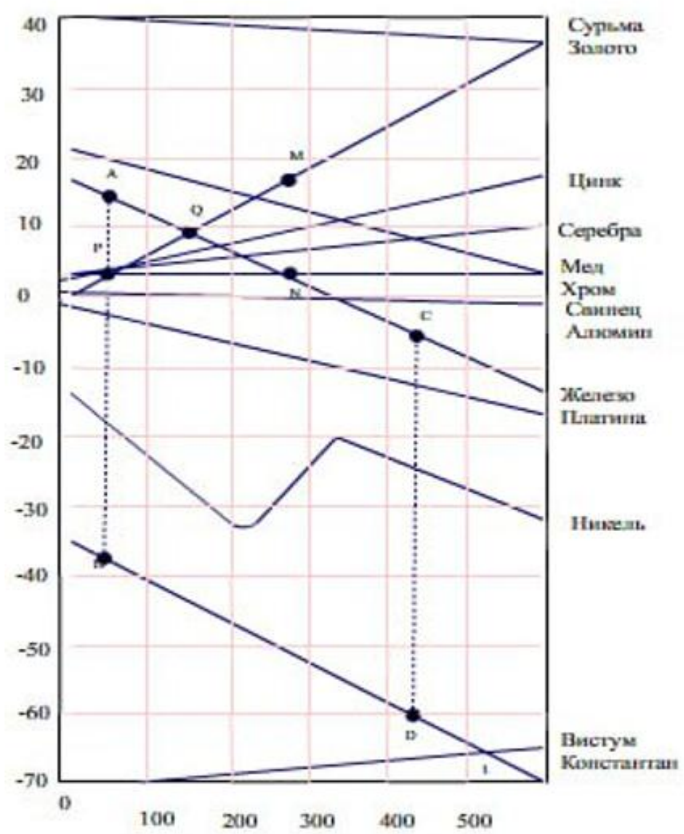

Fig. 1. Thermoelectric Performance of Semiconductor Materials

Figure 1 shows a graphical representation of the thermoelectric capabilities of various semiconductor materials.

For scientific purposes, thermocouples may be made of expensive materials like platinum, while industry favors more affordable alternatives. Examples include iron, copper, and widely used constantan (60% copper and 40% nickel), chromel (90% nickel, 10% chromium), alumel (95% nickel, 5% aluminum), nichrome (80% nickel, 20% chromium), and others.

The most common material combinations include copper and constantan, iron and constantan, nichrome and iron, and chromel and alumel. For temperatures above 1000 °C, thermocouples made of platinum alloys, tungsten, molybdenum, and graphite are used. For low-temperature applications (up to 300 °C), bismuth, antimony, and zinc alloys may be suitable.

The EMF of a thermocouple is defined as the potential difference between the two conductors. For example, if one material produces 2 mV, and the other –3 mV, the resulting EMF will be:

E = 2 – (–3) = 5 mV

For medical applications, specially developed low-temperature alloys and biocompatible materials are used.

Conclusion. Based on the research findings, the following conclusion can be drawn:

Semiconductors play a vital role in the creation of thermoelectric generators for medical applications, offering high energy conversion efficiency and expanding the possibilities of autonomous medical devices. This marks a significant achievement in the field of thermoelectric semiconductor device engineering.

Moreover, the conducted theoretical and experimental studies provide opportunities to develop and manufacture devices designed to deliver targeted thermal effects to specific areas of the human body.

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