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# THE USE OF HIGH EFFICIENCY THERMOELECTRIC MATERIALS TO TRANSFER A HEAT TO ELECTRICITY

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***Abstract:*** Thermoelectric devices for converting the heat into electricity could play an important role in the solution of today's energy problem. In this paper, we consider current state of the efficiency of thermoelectric devices. In the laboratory, the temperature dependence of the output voltage and output current was calculated for $Bi_2Te_3$ alloys. The thermoelectric module has been established on base of this alloy with a certain percentage of the doping elements Sb and Se. $Bi_{2-x}Sb_xTe_3$ was used for p-type alloys, and $Bi_{2-x}Se_xTe_{3-x}$ for the n-type alloys. The number of pairs of n- and p- crystals was 38. The first developed thermoelectric module has a low output power, although we were expected higher result. This can be explained by contact problems of n and p crystals during processing.

***Keywords:*** Thermoelectricity, alloy, heat, efficiency

## 1. Introduction

In the article, based on the latest references, we review the situation in thermoelectrics, consider how to improve the efficiency of such thermoelectric devices devices and end by asking, what can we do? The development of modern technology is associated with the search for new energy sources. At present, more than 80% of electricity generation is provided by power plants. Hydroelectric power plants generate electricity through the action of falling water, which performs mechanical work. Thermal power plants use the same effect, and the work is done by superheated steam. This way of converting one type of energy into another is accompanied by numerous negative effects: the presence of moving parts limits the life of energy converters, creates noise, pollution, and energy losses are also high. It is calculated that, near the end of the century, because of the predicted population and economic growth, the global energy consumption rate approximately will be order of $10^{21}$J [1]. That is why we need a new, ecologically clean and renewable energy resources. Nowadays, Solar energy is considered the most known renewable energy source. It is needed to obtain, convert, and keep this energy. For these purposes, the highly effective thermoelectric materials are used. On the base of these materials in order to convert the heat into electricity, the thermoelectric generators can play a significant role in the solution of today's energy problem.

## 2. Thermoelectricity and their applications

Thermoelectricity is the process of direct conversion of heat to electric current and vice versa. Thermoelectric phenomena are a set of physical phenomena based on the interaction of heat and electric charge conversion processes. The essence of these phenomena is that the temperature difference creates not only a heat flux, but also a flow of charge carriers (electric current), and heat transfer can be carried out not only by a temperature difference, but also by an electric current. Thermoelectric power converters have high stability of operating parameters and high reliability. Based on them, thermoelectric generators have been created that are used in space, under water and on the ground in difficult-to-service conditions. Thermoelectric generators (TEGs) could be used to transfer heat from different sources, especially from the Sun, vehicle exhausts, industrial, residential and geothermal processes to electricity. At the same time, thermoelectric cooling is increasingly being used. The small dimensions of thermoelectric coolers, their practically unlimited service life and high reliability make them suitable for use in infrared and microwave technology, apparatus engineering, electronics, medicine and biology.

Refrigerators based on thermoelectric materials have no moving parts and are able to operate almost silently for an indefinite period of time without experiencing vibrations. The disadvantage of thermoelectric converters is their low efficiency. If the efficiency improves, thermoelectric converters could play an important role in the solution of today's energy problem. To understand the thermoelectric phenomenon, let's go to brief history of the Seebeck (1821), Peltier (1834) and Thomson (1851) effects. Seebeck discovered that in a closed circuit consisting of different conductors connected in series, the contacts between which have a temperature gradient ($\Delta T$), an electric current arises (or conductor generates a voltage, $V$). This phenomenon is called Seebeck effect and the formula is: $V=S\cdot\Delta T$, $S$ is the Seebeck coefficient. Peltier effect is the reverse of the Seebeck effect and states to the change in temperature stimulated by current. Peltier heat produced at the junction per unit time is $Q=\Pi\cdot I$, $\Pi$ and $I$ is the Peltier coefficient and the current, correspondingly. Thomson (Kelvin), investigating thermoelectric phenomena, came to the conclusion, confirming it experimentally, that when current passes through an irregularly heated conductor, an additional release of heat can occur. This phenomenon is called the Thomson phenomenon.

Based on the effects described above, one can establish a thermoelectric module for power generation, or cooling system. The efficiency of thermoelectric devices is characterized by the dimensionless material's figure of merit [2, 7],

$$ZT = \sigma S^2 T/\kappa, \tag{1}$$

where, $\sigma$ is the electrical conductivity, $S$ is the Seebeck coefficient, $T$ is mean operating temperature and $\kappa$ is the thermal conductivity. The higher the $ZT$, the better an efficiency of a thermoelectric cooler or generator. Therefore, there is considerable interest to improve the status of alloys for many applications.

## 3. Overview of a better thermoelectric materials

In a scientific literature, the dependence of thermoelectric materials on their operating temperatures is classified by the following way:

- low-temperature, i.e. alloys of p-type $Bi_2Te_3$ - $Sb_2Te_3$, n-type $Bi_2Te_3$ - $Bi_2Se_3$ are used from negative temperatures up to 200 ℃;
- PbSb, PbTe, GeTe, $AgSbTe_2$, SnTe alloys are used with an average temperature, i.e. from +200℃ to +600 ℃;
- high-temperature, i.e. from +600 ℃ to +1000 ℃ and above, Ge-Si alloys are taken as a basis.

From Equation (1), it is seen that, to increase the $ZT$ means to increase the coefficients of $\sigma$ and $S$ and to decrease the coefficient of κ. But it is difficult to increase $ZT$, because these coefficients strongly depend on the crystal and electron structure of substances and carriers [4].

The material with high *ZT*, over a wide operating temperature range also requires mechanical, metallurgical and thermal characteristics. [5, 7].

It is known that, the substances can be divided into metals, semiconductors, and insulators. This simplified picture is useful to narrow the region for better thermoelectric materials.

Comparative properties of above mentioned materials at 300 K is shown in Table 1.

**Table 1**

Thermoelectric properties of materials at 300K. (ref. [2,7])

| Property | Metals | Semiconductors | Insulators |
|---|---|---|---|
| $S(\mu V K^{-1})$ | $\sim 5$ | $\sim 200$ | $\sim 1000$ |
| $\sigma(\Omega^{-1} cm^{-1})$ | $\sim 10^{6}$ | $\sim 10^{3}$ | $\sim 10^{-12}$ |
| $Z(K^{-1})$ | $\sim 3 \times 10^{-6}$ | $\sim 2 \times 10^{-3}$ | $\sim 5 \times 10^{-17}$ |

The best thermoelectric alloys today have a *ZT* value of around 3. Collaborators from different countries have presented a thermoelectric transformer with an efficiency approximately two times more than obtained analogues. This mixture is not bulk material, but consists of thin layers of iron, refractory elements of vanadium and tungsten and also aluminum deposited on a silicon crystal [8].

In Figure 1, the behaviour of the coefficients are shown for different type of materials.

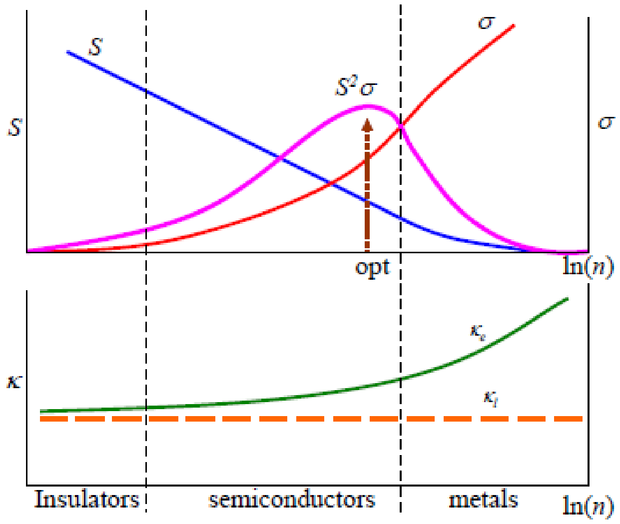

*Fig. 1. The coefficients S, σ, $S^2\sigma$, as a function of free-charge-carrier concentration n. The optimal n is about $1{\times}10^{19}$ $cm^{-1}$, which is indicated by an arrow. (after Refs. [5,6,7]).*

## 4. Methodology and conclusion

For investigation of bulk thermoelectric materials, the measuring devices and equipment have been developed in the laboratory:

1. The oven to synthesize the alloys for 900 °C;
2. The oven with zone melting process has been used to grow crystals;
3. The diffuse pump, filled out the liquid gases, to get a vacuum at $10^{-4}$ mm Hg.;

4. The equipment for cutting crystals;
5. 2 unit of Oscilloscopes;
6. 2 unit of Power supplies;
7. 2 digital Multimeters;
8. 2 unit of transformers;
9. The thermoelectric materials with high percentage;
10. The other units needed to perform the measurements.

In the laboratory designed the output voltage and output current in dependence of temperature were measured for $Bi_2Te_3$ alloys (See Table 2).

**Table 2**

The output voltage and output current in dependence of temperature were measured for $Bi_2Te_3$ alloys.

| Temperature, $^0$C | Current, mA | Voltage, mV |
|---|---|---|
| 20 | 21 | 18.4 |
| 30 | 31 | 27.2 |
| 40 | 44 | 37.7 |
| 50 | 51 | 45 |
| 60 | 68 | 59 |
| 70 | 75 | 67 |
| 80 | 89 | 79 |
| 90 | 100 | 89 |
| 100 | 112 | 100 |
| 110 | 128 | 114 |
| 120 | 141 | 126 |
| 125 | 150 | 133 |
| 130 | 164 | 146 |

On base of this alloy in some percentage of doped Sb and Se elements, the thermoelectric module has been established. $Bi_{2-x}Sb_xTe_3$ has been used for the p-type alloys and $Bi_{2-x}Se_xTe_{3-x}$ for the n-type alloys. The number of the n- and p- crystal’s pair was 38. Each crystal has a size of 2.0x2.0x3.0 mm$^3$. All the crystals have been placed between the ceramic plates in the size of 20.0x25.0mm$^2$. For brazing, it was used the solder up to 139℃. Because of this reason it wasn’t impossible to increase the temperature higher than that value. The first designed thermoelectric module has low output power, although we were expected higher result. It could be explained with contact problems of n and p crystals in a processing. Constructed Thermoelectric Module is illustrated in Figure 2.

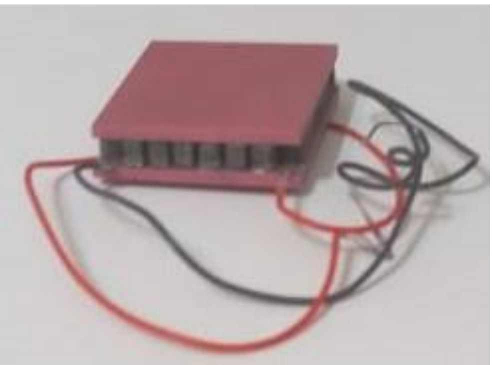

*Fig. 2. Our thermoelectric module*

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## ИСПОЛЬЗОВАНИЕ ВЫСОКОЭФФЕКТИВНЫХ ТЕРМОЭЛЕКТРИЧЕСКИХ МАТЕРИАЛОВ ДЛЯ ПРЕОБРАЗОВАНИЯ ТЕПЛА В ЭЛЕКТРИЧЕСТВО

**Я.Г. Гусейналиев, Л.Я. Гусейналиева**

***Резюме:*** Термоэлектрические устройства для преобразования тепла в электричество могут сыграть важную роль в решении сегодняшней энергетической проблемы. В данной статье рассматривается текущее состояние эффективности термоэлектрических устройств. В лаборатории были рассчитаны температурные зависимости выходного напряжения и выходного тока для сплавов $Bi_2Te_3$. На основе этого сплава с определенным процентным содержанием легирующих элементов Sb и Se был создан термоэлектрический модуль. $Bi_{2-x}Sb_xTe_3$ использовали для сплавов p-типа, а $Bi_{2-x}Se_xTe_{3-x}$ - для сплавов n-типа. Количество пар n- и p-кристаллов составило 38. Первый разработанный термоэлектрический модуль имеет низкую выходную мощность, хотя мы ожидали более высокого результата. Это можно объяснить проблемами контакта n- и p-кристаллов при обработке.

***Ключевые слова:*** Термоэлектричество, сплав, тепло, эффективность

## İSTİLİYİ ELEKTRİK ENERJİSİNƏ ÇEVİRMƏK ÜÇÜN YÜKSƏK PERFORMANSLI TERMOELEKTRİK MATERİALLARIN İSTİFADƏSİ

**Y.H. Hüseynəliyev, L.Y. Hüseynəliyeva**

***Xülasə:*** İstiliyi elektrik enerjisinə çevirmək üçün termoelektrik cihazlar müasir enerji probleminin həllində mühüm rol oynaya bilərdi. Bu işdə termoelektrik cihazların effektivliyinin hazırki vəziyyəti nəzərdən keçirilmişdir. Hazırlanmış laboratoriyada $Bi_2Te_3$ ərintiləri üçün çıxış gərginliyi və çıxış cərəyanının temperaturdan asılılığı hesablanmışdır. Tərkibində müəyyən miqdar Sb və Se aşqar elementlər olan bu ərinti əsasında termoelektrik modul qurulmuşdur. p-tipli ərintilər üçün $Bi_{2-x}Sb_xTe_3$, n-tipli ərintilər üçün isə $Bi_{2-x}Se_xTe_{3-x}$ istifadə edilmişdir. n- və p-kristal cütlərinin sayı 38 olmuşdur. İlk hazırlanmış termoelektrik modul aşağı çıxım gücünə malik olmuşdur, lakin biz daha yüksək nəticə gözləyirdik. Bunu emal zamanı n və p kristallarının təmas problemləri ilə izah etmək olar.

***Açar sözlər:*** Termoelektrik, ərinti, istilik, effektivlik