T.V.Zakharchuk[1],
I.A. Konstantynovych *cand. phys.– math. sciences, dochent*[1,2],
A.V. Konstantynovych *doc. phys.– math. sciences, dochent*[1],
A.V.Forbatiuk[1]

[1]Chernivtsi National University, 2 Kotsiubynskyi Str.,
Chernivtsi, Ukraine, 58012
[2]Institute of Thermoelectricity of the NAS and MES of Ukraine,
1, Nauky str., Chernivtsi, 58029, Ukraine;
aconst@ukr.net, dj_kneo@ukr.net

ON THE EFFICIENCY OF SPIRAL GYROTROPIC THERMOELEMENTS IN COOLING MODE

In this paper, the characteristics of BiSb, Ag_2Te and InSb materials in constant magnetic field were considered. Analytical and numerical methods were used to study the basic relations for the calculation of optimal parameters of spiral gyrotropic thermoelements in cooling mode. The dependences of maximum temperature difference for gyrotropic thermoelements of various shapes were obtained. It was shown that at constant magnetic fields the use of BiSb is more reasonable in the temperature range of 80-120 K, whereas in the range of 200 – 300 K it is worthwhile to use Ag_2Te. Bibl. 25, Tabl. 2, Fig. 14.
Key words: gyrotropic medium, magnetic field induction, spiral gyrotropic thermoelement.

Introduction

Thermoelectric devices are known to be widely used in power engineering, refrigeration and measurement techniques. However, the possibilities of practical application of thermoelectricity depend on the progress in physics of thermoelectric power conversion, since the main feature of thermoelectric devices is their ability to use interconversion of the electrical and thermal energies [1–12]. Advances of thermoelectricity in the area of instrument engineering are mainly achieved on the basis of physics of thermocouple elements. The generalized theory of thermoelectricity afforded an opportunity to develop methods for devising new types of thermoelements. Their application in anisotropic media helped to discover, create and research a variety of basically new types of thermoelements with unique features which significantly expanded the potential of thermoelectricity. Searching for new types of thermoelements based on the gyrotropic media is one of the best lines in the development of thermoelectric applications. These opportunities of thermoelectricity are little studied, and their implementation will make it possible to expand the element basis of thermoelectricity, create thermoelectric products of enhanced performance and increase the competitiveness of such power converters.

Of vital importance is the avenue for increasing the efficiency and reliability of power converters for their application in instrument engineering. Another advantage offered by gyrotropic thermoelements is the absence of internal junctions, assuring reliability and ease of manufacture, possibility of junction-free connection of rings into a space spiral structure, which sufficiently increases the functionality of thermoelements, especially when used in refrigeration and measurement technique.

The purpose of the work is to evaluate the efficiency of spiral gyrotropic thermoelements in cooling mode for their subsequent use in refrigeration and measurement technique.

Mathematical model

Thermal conductivity equation for homogeneous gyrotropic medium is given by

$$\kappa\Delta T+\rho_0 j^2+2\alpha_B\left(j_y\frac{\partial T}{\partial x}-j_x\frac{\partial T}{\partial y}\right)=0, \qquad (1)$$

де T – temperature, ρ_0 is electrical resistivity in gyrotropic medium; κ is thermal conductivity; j is modulus of electric current density vector; j_x, j_y are projections of j vector in the Cartesian coordinate system; $\alpha_B=Q_\perp B$ is asymmetric part of thermoEMF tensor; $Q_\perp$ is the Nernst –Ettingshausen coefficient; B is magnetic field induction.

ThermoEMF tensor in gyrotropic medium is of the form

$$\alpha=\begin{pmatrix}\alpha_0 & \alpha_B & 0\\ -\alpha_B & \alpha_0 & 0\\ 0 & 0 & \alpha_\perp\end{pmatrix}, \qquad (2)$$

In the polar coordinate system, with regard to the system axial symmetry, we have

$$\kappa\Delta T+\rho_0 j^2+2Q_\perp B\left(j_\varphi\frac{\partial T}{\partial r}-\frac{j_r}{r}\frac{\partial T}{\partial\varphi}\right)=0, \qquad (3)$$

where r is the thermoelement radius; j_r, j_φ are the radial and azimuthal components of the current density vector.

Cooling mode

There is a variety of references describing the properties of gyrotropic materials [1–8]. For *BiSb, Ag_2Te* and *InSb* materials subject to constant magnetic field the temperature dependences of the figure of merit were built [1–4].

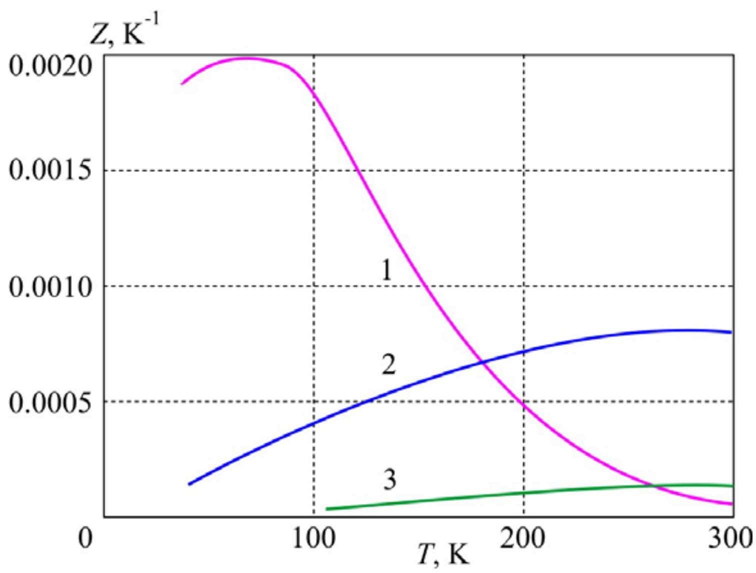
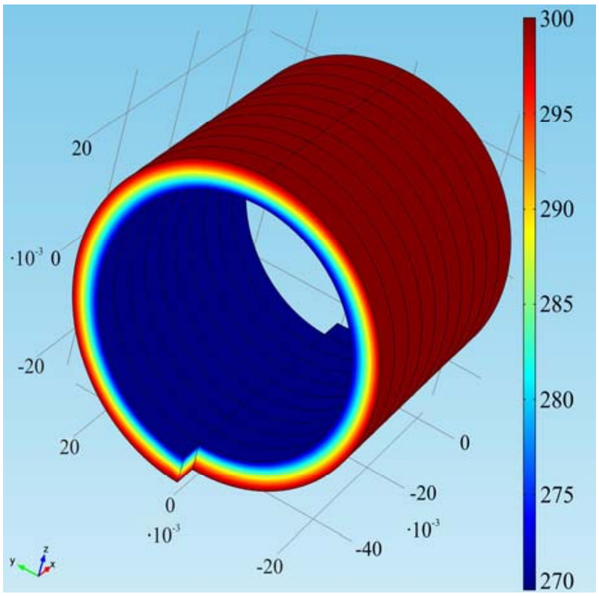


Fig. 1. Figure of merit Z shown as a function of temperature T
(1 – BiSb, 2 – Ag_2Te, 3 – InSb) [1–4].

The simulation of gyrotropic thermoelements for Ag_2Te material was carried out. The thermoelements were exposed to the magnetic field with induction of $B = 1$ T. Fig. 2 shows a three-dimensional model of temperature distribution in the spiral gyrotropic thermoelement (round section) [13].



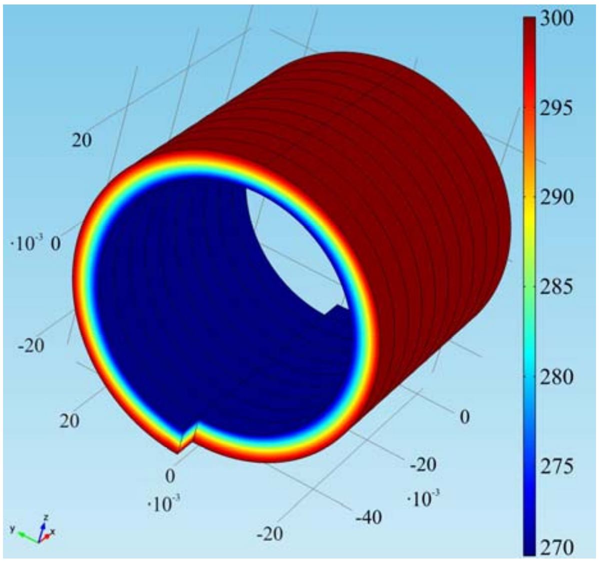


Fig. 2. Model of temperature distribution in the spiral gyrotropic thermoelement (round section)

Fig. 3 shows a three-dimensional model of temperature distribution in the spiral gyrotropic thermoelement (square section).

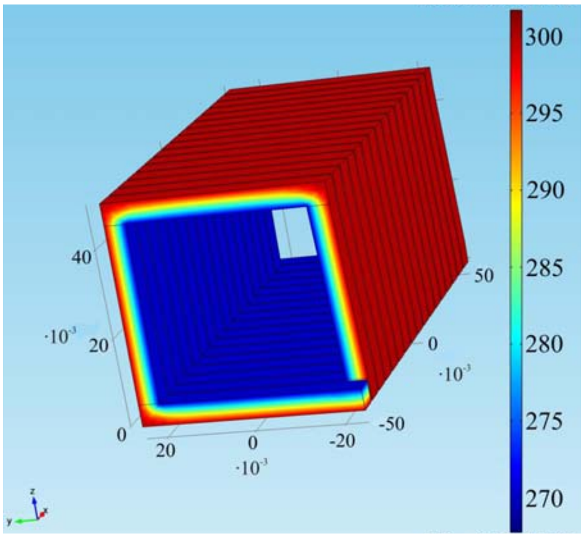


Fig. 3. Model of temperature distribution in the spiral gyrotropic thermoelement (square section)

Assuming that the hot side of spiral gyrotropic thermoelement is adiabatically isolated and ignoring the losses through the side surfaces of the thermoelement, one can use the formula for calculating maximum temperature difference ΔT_{max} between the sides of spiral gyrotropic thermoelement [5]. Using the data presented in Fig. 1, it is possible to obtain the dependence of maximum temperature difference on the hot side temperature of thermoelement for *BiSb*, Ag_2Te and *InSb* (Fig. 4).

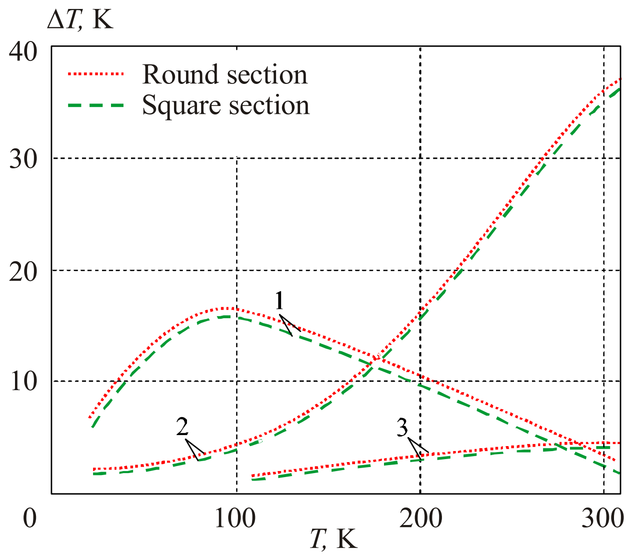


Fig. 4. ΔT_{max} *shown as a function of* T_1 *(1 – BiSb, 2 –* Ag_2Te*, 3 – InSb)*

From Fig. 4 it can be seen that the use of Ag_2Te material in the temperature range of 200 – 300 K yields the highest values of $(\Delta T)_{max}$, at $T_2 = 300$ K the value of $(\Delta T)_{max} \approx 37$ K. It means that the use of Ag_2Te is more reasonable in the temperature range of 200-300 K, and in the temperature range of 80 – 120 K it is worthwhile to use *BiSb* – $\left(\Delta T\right)_{max} \approx 17$ K for round section.

Conclusions

1. The analytical and numerical methods were used to study the basic relations for the calculation of optimal parameters of gyrotropic thermoelements in cooling mode. For Ag_2Te material, computer simulation was performed and the temperature distributions in gyrotropic thermoelements were obtained.
2. It was shown that the use of Ag_2Te material is more reasonable in the temperature range of 200 – 300 K, when $(\Delta T)_{\max} \approx 37$ K, and in the range of $80-120$ K it is worthwhile to use *BiSb* – $(\Delta T)_{max} \approx 17$ K for round section.

References

1. Anatychuk L.I. (1979). *Termoelementy i termoelektricheskiie ustroistva. Spravochnik. [Thermoelements and thermoelectric devices. Reference Book]*. Kyiv: Naukova Dumka [in Russian].
2. Osipov E.V., Varich N.I., Mikitey P.P. (1971). Study of the Ettingshausen effect in $Bi_{1-x}Sb_x$ single crystals. *Semiconductors*, 5(11), 2202 – 2204.
3. Aliev S.A., Aliev M.I., Agaev Z.F., Arasli D.G. (1981). Material for Ettingshausen's cooler. *Certificate of Authorship №828269.*
4. Aliev S.A., Zulfigarov E.I. (2009). *Termomagnitnyie i termoelektricheskiie effekty v nauke i tekhnologii [Thermomagnetic and thermoelectric effects in science and technology]*. Baku: Elm Publ. [in Russian].
5. Samoilovich A.G. (2006*). Termoelektricheskiie i termomagnitnyie metody preobrazonaniia energii [Thermoelectric and thermomagnetic energy conversion methods]*. Chernivtsi: Ruta [in Russian].
6. Anatychuk L.I. (2003). *Termoelektrichestvo, T.2, Termoelektricheskiie preobrazovateli energii [Thermoelectricity, Vol.2, Thermoelectric Power Converters]*. Kyiv, Chernivtsi: Naukova Dumka [in Russian].
7. Samoilovich A.G., Korenblit L.L. (1953). Current status of theory of thermoelectric and thermomagnetic effects in semiconductors. *Advances in Physical Sciences*, 49(2), 243 – 272.
8. Nakamura H., Ikeda K., and Yamaguchi S. (1997). Transport coefficients of InSb in a strong magnetic field. *Proc. of XVI International Conference on Thermoelectrics* (Dresden, Germany, 1997).
9. Anatychuk L.I., Luste O.J., Fedoruk Ya.G., Shinkaruk S.M. (2004). Eddy thermoelectric currents in gyrotropic medium with a radial temperature distribution. *J.Thermoelectricity* 1, 19 – 24.
10. Luste O.J., Fedoruk Ya.G. (2006). Gyrotropic thermoelement in the inhomogeneous magnetic field. *J.Thermoelectricity*, 1, 16 – 22.
11. Luste O.J., Fedoruk Ya.G. (2008). Optimization of materials for gyrotropic thermoelements. *J.Thermoelectricity*, 4, 21 – 26.
12. Konstantynovych I.A., Rendigevych O.V. (2016). On the efficiency of gyrotropic thermoelements in generation mode *J.Thermoelectricity*, 1, 64 – 69.
13. Konstantynovych I.A. (2016). On the efficiency of gyrotropic thermoelements in cooling mode. *J.Thermoelectricity*, 3, 46 –50.

Submitted 07.02.2019

Захарчук Т.В.[1], Константинович І.А *канд. фіз.– мат. наук, доцент*[1,2], **Константинович А.В.** *док. фіз.– мат. наук, доцент* [1], **Форбатюк А.В.[1]**

[1]Чернівецький національний університет
ім. Юрія Федьковича, вул. Коцюбинського 2,
Чернівці, 58012, Україна
[2]Інститут термоелектрики НАН і МОН України,
вул. Науки, 1, Чернівці, 58029, Україна;
e-mail: anatych@gmail.com

ПРО ЕФЕКТИВНІСТЬ СПІРАЛЬНИХ ГІРОТРОПНИХ ТЕРМОЕЛЕМЕНТІВ У РЕЖИМІ ОХОЛОДЖЕННЯ

Розглянуто характеристики матеріалів BiSb, Ag_2Te й InSb в постійному магнітному полі. Досліджено основні співвідношення для розрахунку оптимальних параметрів спіральних гіротропних термоелементів у режимі охолодження, аналітичними та числовими методами. Отримано залежності максимальної різниці температір для гіротропних термоелементів різних форм. Показано, що при постійних магнітних полях доцільно використовувати BiSb в температурному діапазоні 80 – 120 К, а Ag_2Te для 150 – 300 К.

Ключові слова: гіротропне середовище, індукція магнітного поля, спіральний гіротропний термоелемент.

Захарчук Т.В.,[1] **Константинович І.А.** *канд. физ.– мат. наук*[1,2]
Константинович А.В. *док. физ.– мат. наук, доцент*[1]
Форбатюк А.В.[1]

[1]Черновицкий национальный университет
имени Юрия Федьковича, ул. Коцюбинского,
2, Черновцы, 58012, Украина;
[2]Институт термоэлектричества НАН и МОН Украины, ул. Науки,
1, Черновцы, 58029, Украина, *e-mail: anatych@gmail.com*;

ОБ ЭФФЕКТИВНОСТИ СПИРАЛЬНЫХ ГИРОТРОПНЫХ ТЕРМОЭЛЕМЕНТОВ В РЕЖИМЕ ОХЛАЖДЕНИЯ

Рассмотрены характеристики материалов BiSb, Ag_2Te и InSb в постоянном магнитном поле. Исследованы основные соотношения для расчетов оптимальных параметров спиральных гиротропных термоэлементов в режиме охлаждения, аналитическими и числовыми методами. Получены зависимости максимального перепада температур для гиротропных термоэлементов различной формы. Показано, что при постоянных магнитных полях целесообразно использовать BiSb в температурном диапазоне 80 – 120 К, а Ag_2Te для 150 – 300 К. Библ. 13, рис. 4.

Ключевые слова*:* гиротропная среда, индукция магнитного поля, спиральный гиротропный термоэлемент.

References

1. Anatychuk L.I. (1979). *Termoelementy i termoelektricheskiie ustroistva. Spravochnik. [Thermoelements and thermoelectric devices. Reference Book].* Kyiv: Naukova Dumka [in Russian].
2. Osipov E.V., Varich N.I., Mikitey P.P. (1971). Study of the Ettingshausen effect in $Bi_{1-x}Sb_x$ single crystals. *Semiconductors*, 5(11), 2202 – 2204.
3. Aliev S.A., Aliev M.I., Agaev Z.F., Arasli D.G. (1981). Material for Ettingshausen's cooler. *Certificate of Authorship №828269.*
4. Aliev S.A., Zulfigarov E.I. (2009). *Termomagnitnyie i termoelektricheskiie effekty v nauke i tekhnologii [Thermomagnetic and thermoelectric effects in science and technology].* Baku: Elm Publ. [in Russian].
5. Samoilovich A.G. (2006*). Termoelektricheskiie i termomagnitnyie metody preobrazonaniia energii [Thermoelectric and thermomagnetic energy conversion methods].* Chernivtsi: Ruta [in Russian].
6. Anatychuk L.I. (2003). *Termoelektrichestvo, T.2, Termoelektricheskiie preobrazovateli energii [Thermoelectricity, Vol.2, Thermoelectric Power Converters].* Kyiv, Chernivtsi: Naukova Dumka [in Russian].
7. Samoilovich A.G., Korenblit L.L. (1953). Current status of theory of thermoelectric and thermomagnetic effects in semiconductors. *Advances in Physical Sciences*, 49(2), 243 – 272.
8. Nakamura H., Ikeda K., and Yamaguchi S. (1997). Transport coefficients of InSb in a strong magnetic field. *Proc. of XVI International Conference on Thermoelectrics* (Dresden, Germany, 1997).
9. Anatychuk L.I., Luste O.J., Fedoruk Ya.G., Shinkaruk S.M. (2004). Eddy thermoelectric currents in gyrotropic medium with a radial temperature distribution. *J.Thermoelectricity* 1, 19 – 24.
10. Luste O.J., Fedoruk Ya.G. (2006). Gyrotropic thermoelement in the inhomogeneous magnetic field. *J.Thermoelectricity*, 1, 16 – 22.
11. Luste O.J., Fedoruk Ya.G. (2008). Optimization of materials for gyrotropic thermoelements. *J.Thermoelectricity*, 4, 21 – 26.
12. Konstantynovych I.A., Rendigevych O.V. (2016). On the efficiency of gyrotropic thermoelements in generation mode *J.Thermoelectricity*, 1, 64 – 69.
13. Konstantynovych I.A. (2016). On the efficiency of gyrotropic thermoelements in cooling mode. *J.Thermoelectricity*, 3, 46 –50.

Submitted 07.02.2019