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ON THE EFFICIENCY OF GYROTROPIC THERMOELEMENTS IN COOLING MODE

Computer simulation of temperature fields for gyrotropic thermoelements of the rectangular, spiral and optimal shapes was performed. BiSb, Ag_2Te and InSb thermoelectric materials for gyrotropic thermoelements were considered. The temperature dependences for gyrotropic thermoelements of various shapes were obtained. It was shown that in the temperature range of 150 – 300 K it is reasonable to use Ag_2Te, whereas BiSb can be efficiently used in the range of 80 – 120 K.

Key words: gyrotropic thermoelement, magnetic field, thermoelectric material, figure of merit.

Introduction

The generalized theory of thermoelectricity allowed developing methods for the discovery of new thermoelement types, and their application in anisotropic media made it possible to devise, investigate and create a number of fundamentally new thermoelement types with unique properties that expanded essentially the opportunities of thermoelectricity.

A promising direction in the development of thermoelectric applications is devising new thermoelement types based on gyrotropic media [1 – 19]. These opportunities of thermoelectricity are little studied, and their implementation will make it possible to expand the element basis of thermoelectricity, to improve the competitiveness of thermoelectric power converters, as well as to create on their basis the thermoelectric products of enhanced performance.

The relevance of this work lies in the need to improve the efficiency and reliability of thermoelectric power converters based on gyrotropic media to be used in instrument engineering.

The purpose of this work is to estimate the efficiency of gyrotropic thermoelements in cooling mode.

Mathematical model

Thermal conductivity equation for a homogeneous gyrotropic medium is given by

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

where κ is thermal conductivity coefficient of a gyrotropic medium; ρ_0 is electrical resistivity; j is electrical current density vector; j_x, j_y are projections of vector $\mathbf{j}$ in the Cartesian coordinate system; $\alpha_B = Q_\perp B$ is the asymmetric part of thermoEMF tensor which in a gyrotropic medium is of the form

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

where $Q_\perp$ is the Nernst-Ettingshausen coefficient.

With regard to the axial symmetry of the system, we write Eq.(1) in the polar coordinate system

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

where j_r, j_φ are the radial and azimuthal components of current density vector $\mathbf{j}$, $r_1 \le r \le r_2$ is thermoelement radius.

Assuming that the hot side (T_1) is adiabatically isolated and ignoring the losses through the lateral surfaces, one can use the known formula for the calculation of maximum temperature difference between thermoelement sides ΔT_{max} [5]

$$(\Delta T)_{max} = \frac{1}{2}T_1^2\frac{\alpha_B^2}{\rho_0\kappa}. \quad (4)$$

Computer simulation results

There is a variety of literary sources describing the properties of gyrotropic materials for low-temperature region [1, 2]. Fig. 1 presents the temperature dependences of figure of merit of *BiSb*, Ag_2Te and *InSb* materials [1, 3, 4].

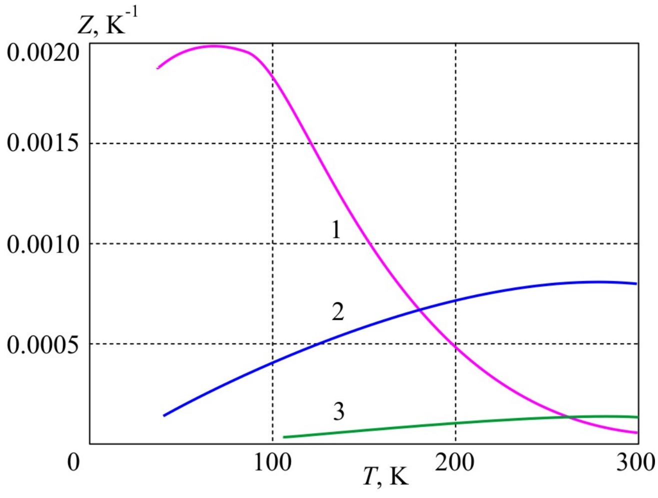

Fig. 1. Figure of merit Z shown as a function of temperature T (1 – BiSb, 2 – Ag_2Te, 3 – InSb) [1, 3, 4].

For the construction of computer model of gyrotropic thermoelements of rectangular, spiral and optimal shapes the Comsol Multiphysics application software package was used [20]. The calculation of temperature distributions in gyrotropic thermoelements was done by finite element method. Computer simulation was used to determine temperature distributions in gyrotropic thermoelements of various shapes for Ag_2Te material in a magnetic field with induction $B = 1$ T. Fig. 1 shows three-dimensional models of finite element method mesh (*a*) and temperature distribution (*b*) in a rectangular-shaped gyrotropic thermoelement (the Ettingshausen thermoelement).

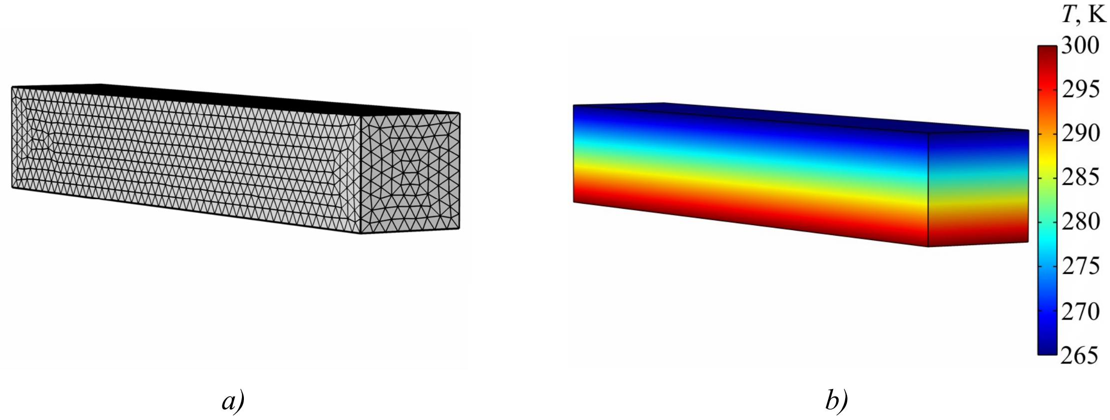

Fig. 2. Three-dimensional models of finite element method mesh (a) and temperature distribution (b) in a rectangular-shaped gyrotropic thermoelement.

Fig. 3 presents three-dimensional models of finite element method mesh (*a*) and temperature distribution (*b*) in a spiral-shaped gyrotropic thermoelement. These thermoelements can be efficiently used for cooling cylinder-shaped objects.

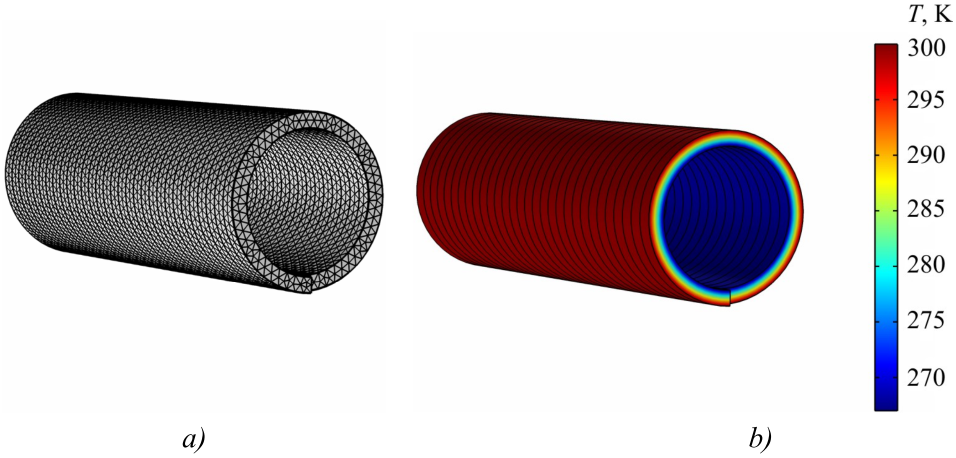

Fig. 3. Three-dimensional models of finite element method mesh (a) and temperature distribution (b) in a spiral-shaped gyrotropic thermoelement.

Fig. 4 presents three-dimensional models of finite element method mesh (*a*) and temperature distribution (*b*) in optimal-shaped gyrotropic thermoelement.

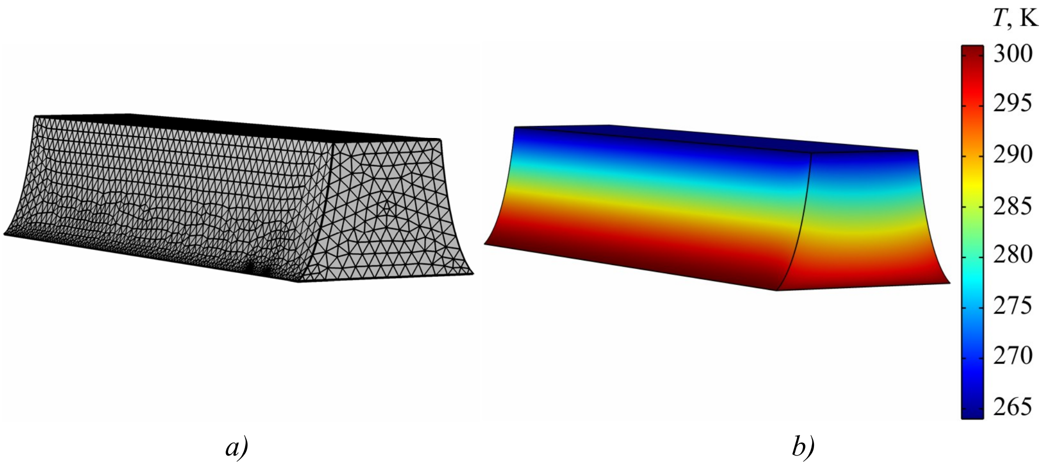

Fig. 4. Three-dimensional models of finite element method mesh (a) and temperature distribution (b) in optimal-shaped gyrotropic thermoelement .

Using the data given in Fig. 1 the dependences of maximum temperature difference on the hot side temperature of thermoelement were obtained for *BiSb*, Ag_2Te and *InSb* (Fig. 5).

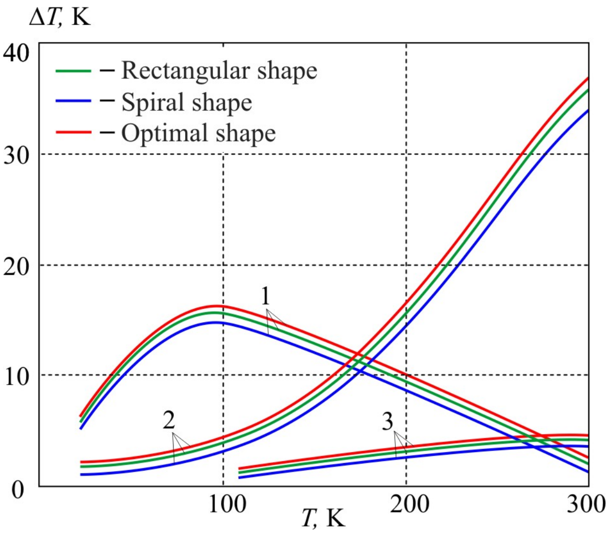

Fig. 5. ΔT_{max} *shown as a function of* T_1 *(1 – BiSb, 2 –* Ag_2Te*, 3 – InSb).*

It is seen that the use of Ag_2Te material in the temperature range of 200 – 300 K yields the highest values of ΔT_{max}, at T_2 = 300 K the value of $\Delta T_{max} \approx 36$ K. Hence, the use of Ag_2Te is more reasonable in this temperature range, and in the temperature range of 80 – 120 K it is better to use *BiSb* – $(\Delta T)_{max} \approx 17$ K. These materials can be used in the manufacture of gyrotropic thermoelements for medical instruments operated in cryogenic area.

Conclusions

1. The analytical and numerical methods were used to study the basic relations for the calculation of optimal characteristics of gyrotropic thermoelements in cooling mode. For the case of Ag_2Te material computer simulation was performed and temperature distributions in gyrotropic thermoelements of various shapes were obtained.
2. The temperature dependences of ΔT_{max} for gyrotropic thermoelements of various shapes were obtained. It was shown that the use of Ag_2Te is more reasonable in the temperature range of 150 – 300 K, when $(\Delta T)_{max} \approx 36$ K, and in the range of 80 – 120 K it is better to use *BiSb* – $(\Delta T)_{max} \approx 17$ K.

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