A.A. Ashcheulov

A.A. Ashcheulov, *Doc. Tech Sc, Prof.*

Institute of Thermoelectricity of the NAS and MES of Ukraine,
1 Nauky str, Chernivtsi, 58029, Ukraine,
e-mail: ashcheulovaa@rambler.ru

ON ENERGY OPPORTUNITIES IN ANISOTROPIC BIPOLAR ELECTRICALLY CONDUCTIVE MEDIA

A study was made of the features of electric current transformation by an anisotropic electrically conductive medium characterized by different types of conductivity (p- and n-types) in selected crystallographic directions under ohmic contact conditions. It has been established that in the case of an external sinusoidal electric current flowing through a device based on a rectangular plate of the above mentioned anisotropic material, electric current vortices occur in its bulk. Based on the analysis of the function m (K, α) (case | m |> 1), which determines the transformation coefficient of the device, a conclusion is made about the energy interaction between the bulk of the anisotropic plate and the external medium.. Studies have shown that the use of anisotropic electrically conductive bipolar material leads to a significant higher (m> 1) or lower (m <-1) value of the transformation coefficient m than in the case of unipolar anisotropic electrically conductive materialss. The phenomenon of electroohmic transformation is caused by the appearance of electric field vortices which are characterized by turbulent flow represented by the expression $\mathrm{rot}\ j = \pm\omega$, *, where ω is a circular frequency of vortex rotation, and signs «+» and «–» denote the direction of its rotation and are determined by the value of the anisotropy coefficient K=σ11/σ22. Such electric vortices with a turbulent flow are an efficient mechanism of pumping energy between the external medium and, in our case, the anisotropic plate of the device. It should be noted that in some cases there is an anomalous value of the abovementioned coefficient. The application of the considered method of electric current transformation with the help of the proposed devices, which are based on a plate made of anisotropic electrically conductive material, significantly expands the field of alternative electricity and other related fields of science and technology. Bibl.14, Fig. 7.*

Key words: *anisotropic medium; electrical conductivity; transformation; electric current; efficiency; heating; cooling; generation.*

Introduction

In [1], for the first time, the possibility of the transformation effect in anisotropic electrically conductive unipolar media was shown. In this case, the device called anisotropic electroohmic transformer is a rectangular plate of length *a*, height *b* and width *c*, made of anisotropic single-crystal or layered electrically conductive materials, characterized by linear volt-ampere characteristicss. The selected crystallographic axes of anisotropic material 1 and 2, having the values of electrical conductivity σ_{11} and σ_{22}, which are unipolar in sign, are located in the plane of lateral faces $a \times b$ of the plate, one of them being oriented at an angle α. On the end faces $b \times c$ and the upper and lower face $a \times c$ of this plate are the input and output electrical wires, respectively.

In the case of sinusoidal alternating electric current flowing through the end contacts 4 and 5 of the electric current J_{in}, the electric current J_{out} flows through the output contacts 6, 7, and the transformation coefficient m of such a device (Fig. 1) is represented by the following expression

$$J_{out} / J_{in} = m = p \cdot f \tag{1}$$

where p is transformation coefficient of plate material, $f = a / b$ is its form factor.

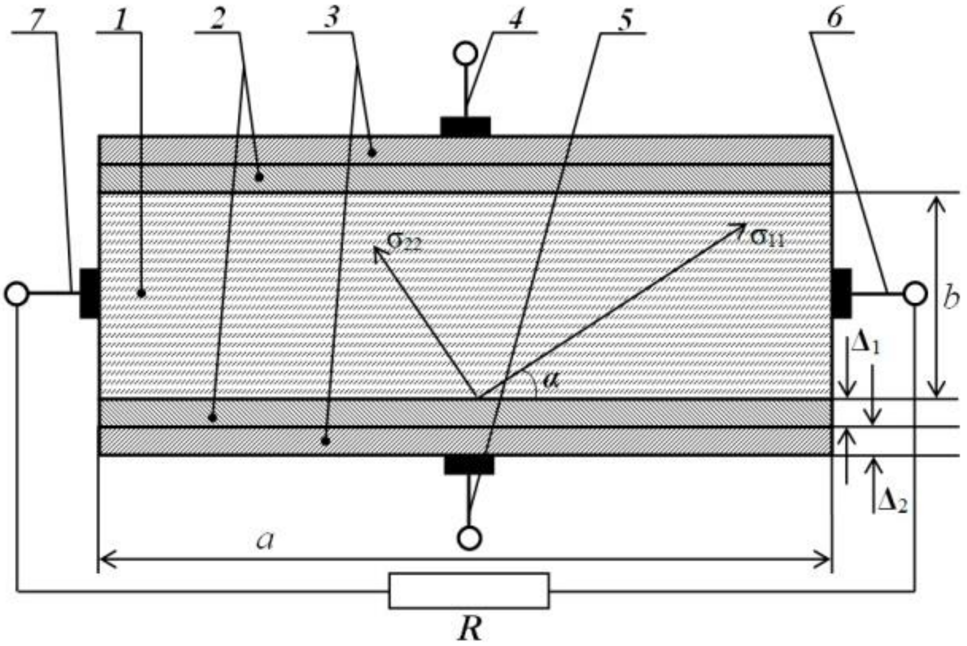


Fig. 1. Schematic of anisotropic transformer design
1 – Plate of anisotropic electrically conductive material; 2 – electrical insulating layers;
3 – electrically conductive layers; 4, 5 – input electrical wires; 6, 7 – output electrical wires.

In so doing, the optimal value of slope angle α is found from the relationship

$$\alpha = arctg\sqrt{K} \tag{2}$$

where $K = \sigma_{11} / \sigma_{22}$ is anisotropy coefficient of plate material.

Since in the case under study the condition $\frac{\partial E_{11}}{\partial x} \neq \frac{\partial E_{22}}{\partial y}$ is satisfied, an eddy electric current arises in the bulk of this anisotropic plate, which is characterized by a laminar flow [2].

The studies have shown that in the case under study the value of transformation coefficient does not exceed 1 ($m \leq 1$) for the cases of both $0 < K < 1$ and $1 < K < \infty$. In the case of $K = 1, n = 0$.

The method of transformation considered in [1, 3] is significantly different from the existing ones and has a number of relevant advantages and disadvantages.

Presentaton of the main material and analysis of the results

The situation will change if we move to an anisotropic electrically conductive medium characterized by different types of conductivity (*p*- and *n*-types) in the 1st and 2nd selected crystallographic directions (Fig. 2), while the contact between all layers is ohmic [4].

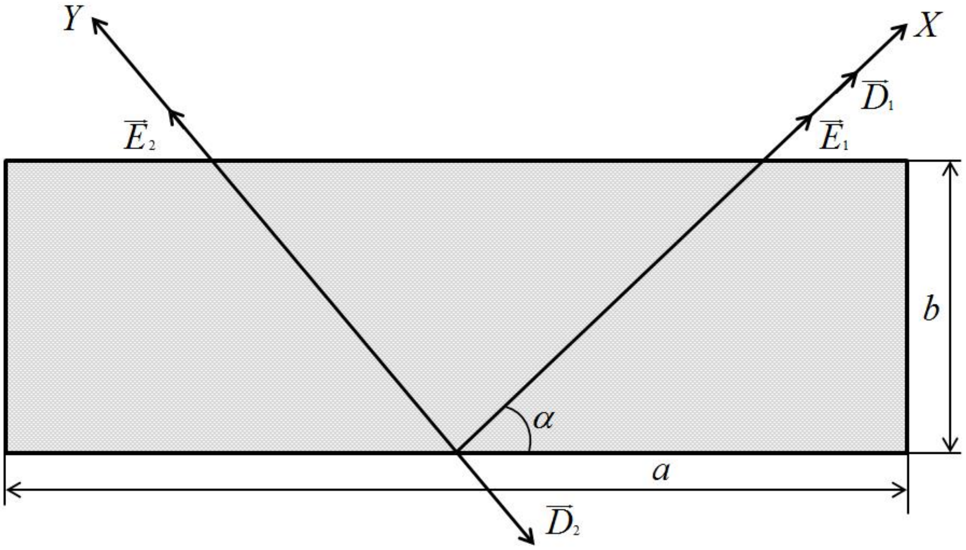


Fig. 2. Orientation of the OX, OY and OZ crystallographic axes of anisotropic electrically conductive plate and location of electric field vectors $\vec{E}_1$, $\vec{E}_2$, *and induction vectors* $\vec{D}_1$, $\vec{D}_2$

The electrical conductivity tensor of such a single-crystal or artificial anisotropic medium is given by

$$\hat{\sigma} = \sigma_0 \begin{vmatrix} \sigma_{11} & 0 & 0 \\ 0 & -\sigma_{22} & 0 \\ 0 & 0 & \sigma_{33} \end{vmatrix} = \begin{vmatrix} \sigma_n & 0 & 0 \\ 0 & -\sigma_p & 0 \\ 0 & 0 & \sigma_n \end{vmatrix} \tag{3}$$

Creation from this material of a rectangular plate with dimensions $a \times b \times c$ ($a \approx c >> b$) whose main crystallographic axes *OX* and *OY* are arranged in the plane of its lateral surface $a \times b$, and one of these axes is located at an angle α to the edge a ($0 < a < 90^\circ$) (Fig. 2), allows us to represent tensor $\hat{\sigma}$ as follows [5]:

$$\hat{\sigma} = \sigma_0 \begin{vmatrix} \sigma_{11}\cos^2\alpha - \sigma_{22}\sin^2\alpha & (\sigma_{11} + \sigma_{22})\sin\alpha\cos\alpha & 0 \\ (\sigma_{11} + \sigma_{22})\sin\alpha\cos\alpha & \sigma_{11}\sin^2\alpha - \sigma_{22}\cos^2\alpha & 0 \\ 0 & 0 & \sigma_{33} \end{vmatrix} \tag{4}$$

which is characterized by the presence of both longitudinal ($\sigma_{||}$) and transverse ($\sigma_{\perp}$) components

$$\sigma_{||} = \sigma_0\left(\sigma_{11}\cos^2\alpha - \sigma_{22}\sin^2\alpha\right) \tag{5}$$

$$\sigma_{\perp} = \sigma_0\left(\sigma_{11} + \sigma_{22}\right)\sin\alpha\cos\alpha\,. \tag{6}$$

In so doing, the transformation coefficient m_1 of the device based on the above rectangular plate is given by

$$m_1 = \frac{\sigma_{\perp}}{\sigma_{||}} = \frac{\left(\sigma_{11} + \sigma_{22}\right)\sin\alpha\cos\alpha}{\sigma_{11}\cos^2\alpha - \sigma_{22}\sin^2\alpha} \tag{7}$$

Numerical estimates show that under $a \approx c >> b$ the boundary conditions on the end $b\times c$ and lateral $a\times b$ faces can be ignored [2].

Investigation of function

$$m_1(K,\alpha) = \frac{(K+1)tg\alpha}{K - tg^2\alpha} \tag{8}$$

for extremum ($\partial m/\partial\alpha = 0, \partial^2 m/\partial\alpha^2 < 0$) demonstrates that function extremum points are absent.

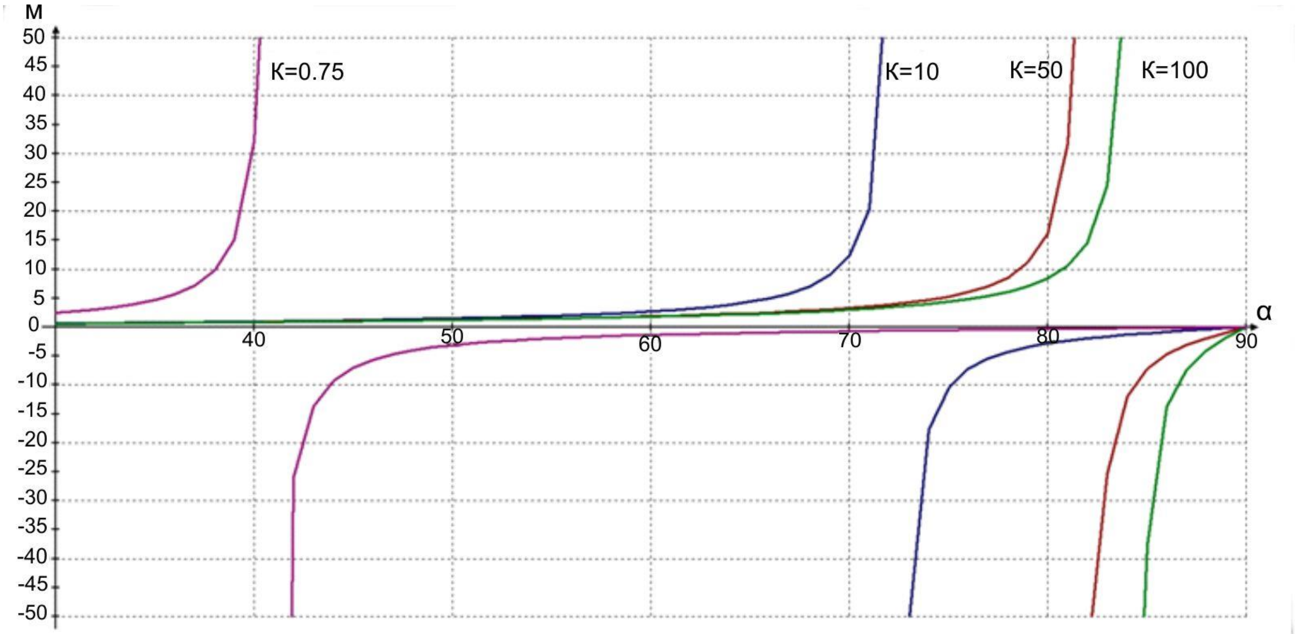


Fig. 3. Dependence of the transformation coefficient m on the angle α at fixed anisotropy coefficients of electrically conductive material K=0.75; 10; 50; 100.

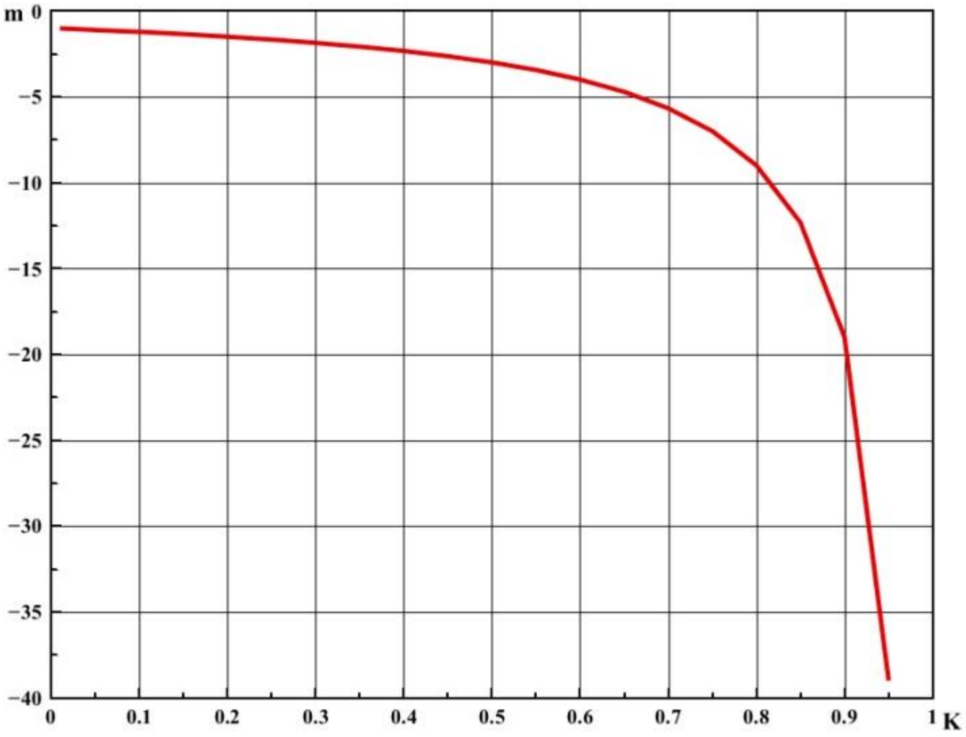
This allows one to vary the value of the coefficient *m* of this device in a wide range by selecting the appropriate angle α. This possibility is shown in Fig. 3 for four anisotropic electrically conductive bipolar materials with anisotropy coefficients 0.75, 10, 50 and 100. From this plot it follows that there is always the possibility of selecting the angle α for a given *m* with the required value and sign.

For the angle α = 45° the expression (7) acquires the following form

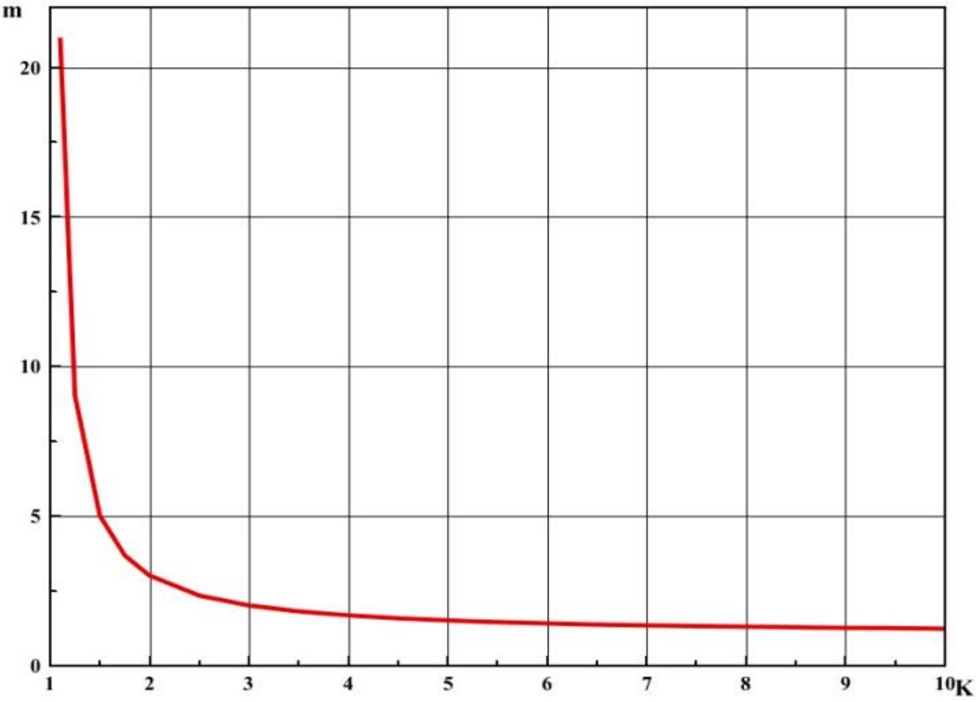
$$m = \frac{\sigma_{11} + \sigma_{22}}{\sigma_{11} - \sigma_{22}} = \frac{K+1}{K-1} \tag{9}$$

Analysis of these functions shows that the value of coefficient $|m| > 1$ allows making a conclusion on the energy interaction between the bulk of anisotropic plate 1 and the external medium. Thus, the use of anisotropic electrically conductive bipolar material leads to a much higher value of transformation coefficient *m* than in the case of unipolar anisotropic electrically conductive materials (Fig. 4.).

The explanation of this phenomenon can be presented using the concepts of vortex electrodynamics. If an external electric current of a sinusoidal shape is passed through the plate, then electric current vortices appear in its bulk, which are characterized by a turbulent flow. [6, 7] In our case, similarly to [8, 9], the change in the nature of a vortex with a laminar flow to a turbulent one is due to the reorientation of the directions of the corresponding components of the electric current and field vectors. In this case, the longitudinal component of the electric current and field vector is located parallel to the crystallographic direction of the second selected crystallographic axis. In so doing, the direction of the electric current is parallel to the direction of the electric field.



a)



b)

Fig. 4. Dependence of the transformation coefficient m on the value of anisotropy to electrically conductive material at $\alpha=45^\circ$ a) Dependence of the transformation coefficient m on the anisotropy value at $0<K<1$ and the angle $\alpha=45^\circ$; b) Dependence of the transformation coefficient m on the anisotropy value at $1<K<\infty$ and the angle $\alpha=45^\circ$.

The flow of input electric current through the end contacts J_{on} causes an electric current J_{out} to appear at the output contacts.

In this case, the vortex of electric current according to [10, 11] is as follows:

$$rot\,\vec{J} = -\omega, \qquad \text{для} \qquad 0<K<1, \tag{10}$$

$$rot\,\vec{J} = \omega, \qquad \text{для} \qquad 1<K<\infty \tag{11}$$

where $\omega = F(\sigma_{11}, \sigma_{22}, a, b, c, \alpha)$ is the circular frequency of rotation of the electric vortex, the signs «+» and «–» denote the direction of its rotation.

Such electric vortices are an efficient mechanism of pumping energy between the external medium and, in our case, the bulk of the anisotropic electrically conductive alternating bipolar plate.

The presented mechanism of energy interaction has a good outlook for modern science and technology.

Possible applications of the proposed method of energy conversion

In the general case, the choice of a specific design of the anisotropic device is determined by its purpose and functional features, as well as the conditions of its operation.

In all possible designs of this device the basis is a rectangular plate 1 of anisotropic material which in the selected crystallographic axes *Ox* and *Oy* is characterized by *p*- and *n*- types of conductivity, respectively. When using artificial anisotropic electrically conductive material, it will be an alternating layered structure based on the layers of electrically conductive material 1 with thickness τ_1 and electrically conductive material 2 with thickness τ_2. The method of calculating this structure and its optimization is similar to the method described in [12].

Selecting the appropriate value of the anisotropy coefficient of layers 1 and 2 of this plate, as well as its geometrical dimensions makes it possible to create the required instruments and devices with respective parameters. Consider the designs of specific devices based on the above anisotropic plates.

Anisotropic electroohmic generator (AEG)

In this case, the converter is AEG which is based on a rectangular anisotropic plate characterized by the positive value of transformation coefficient m ($1<K<\infty$) and the orientation of crystallographic axis σ_{11} at certain selected angle α.

The schematic design of such a generator is represented in Fig. 5, consisting of plate 1; electrical insulating layer 2 and electrically conductive layer 3; input electrical wires 4, 5 connected to external source of electric energy created by the master generator; output electrical wires 6, 7 to which the external load is connected, with resistance Z.

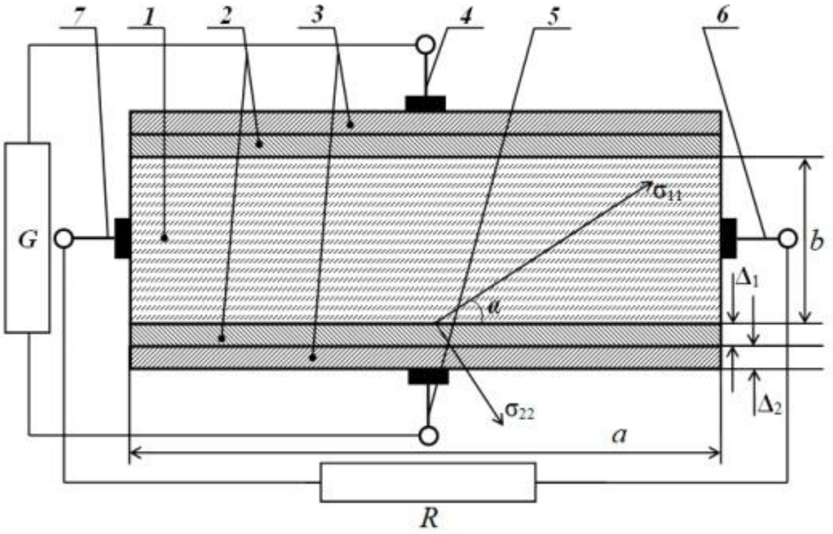


Fig. 5. Schematic of AEG design
1 – Plate of anisotropic electrically conductive material; 2 –electrical insulating layers;
3 –electrically conductive layers; 4, 5 – input electrical wires; 6, 7 – output electrical wires.

When some power $P(t) = P_0 \sin(\omega_1 t)$ is supplied in the form of a master generator to AEG input, electric vortices with turbulent flow appear in the bulk of plate 1, which then interact with the external medium. This leads to origination of energy flows directed from this medium to the bulk of the plate which is converted into electrical one. This results in the appearance on the output electrical wires 6, 7 of some electrical power P_{out} which is represented as follows:

$$P_{out} = P_0 \sin(\omega_1 t_0)\frac{(K+1)\cdot tg\alpha}{K - tg^2\alpha}\,, \tag{12}$$

Thus, right-hand rotation of electric vortices with turbulent flow determines the possibility of operation of the plate in the mode of electricity generationn. Here, ω_1 is the frequency of the electric vortex which is determined by the master generator.

The efficiency η_1 in this case is as follows:

$$\eta_1 = \frac{1}{1 + P_1/P_2}\,, \tag{13}$$

where P_1/P_2 are powers released in the bulk of both the plate and the external load of resistance Z, respectively.

Maximum value of electrical power P_{max} which can be generated by AEG is determined as follows:

$$P_{max.} = (s \cdot M \cdot \Delta T)/(P_1/P_2)\,, \tag{14}$$

where $M = a \cdot b \cdot c \cdot d$ is the weight of the plate; d is the density of its material; s is specific heat of material; T_0 is ambient temperature; T_{max} is boundary operating temperature of plate 1 material.

Numerical estimates show that the efficiency value of the proposed device is within 0.5÷0.99

It should be noted that under certain conditions the AEG under study can also actively function in the mode of thermal power generation.

Anisotropic electroohmic heater (AEH)

A feature of this heater in comparison with the generator is the increased values of the internal resistance of the plate. The schematic design of such AEH (Fig. 6) is similar to the design of the above AEG with the difference that the resistance $R=0$.

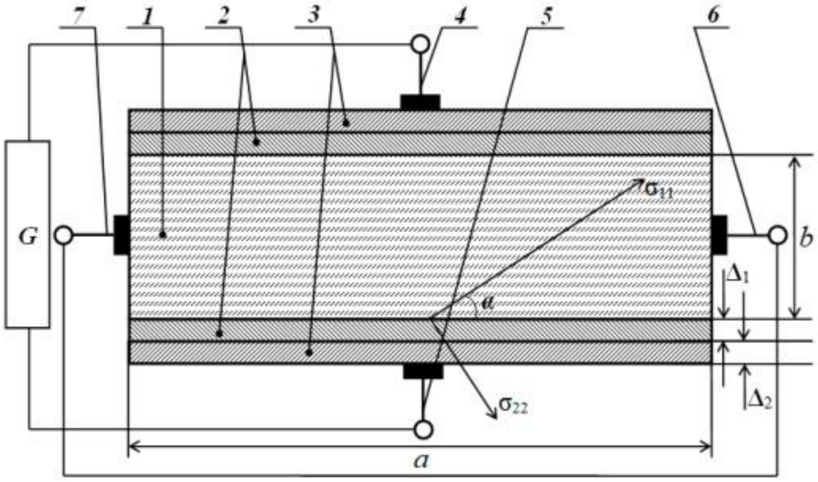


Fig. 6. Schematic of AEH design
1 – Plate of anisotropic electrically conductive material;
2 – electrical insulating layers;
3 – electrically conductive layers;
4, 5 – input electrical wires;
6, 7 – output electrical wires.

Anisotropic electroohmic cooler (AEC)

Unlike AEG and AEH, the design of AEC consists of anisotropic rectangular plate 1 and electrical wires 4, 5 (Fig. 7). The anisotropy of electrical conductivity of the materials of plate 1 is selected with the coefficient $0<K<1$.

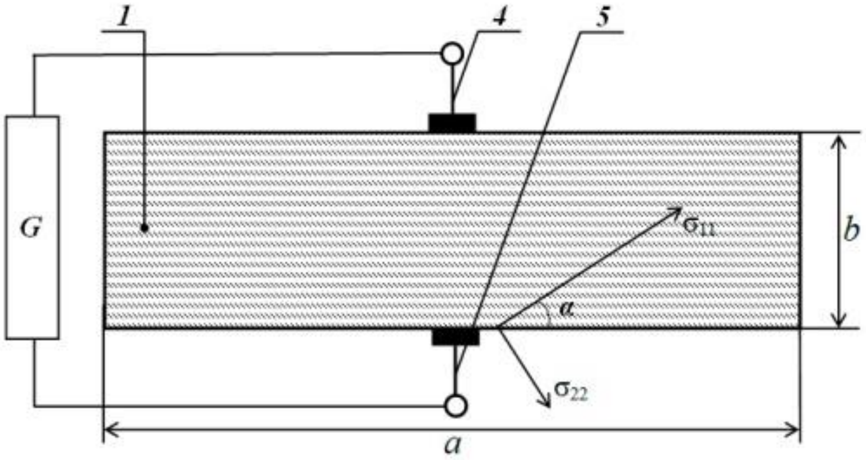


Fig.7. Schematic of AEC design
1 – Plate of anisotropic electrically conductive material;
4, 5 – input electrical wires; 6, 7 – output electrical wires.

In this case, the application to contacts 4, 5 of the generator power leads to the occurrence in its bulk of turbulent vortices of electric current with left-hand rotation. This leads to a decrease in the internal energy of the anisotropic plate, which ultimately leads to a corresponding decrease in the plate temperature T.

With a positive half-cycle of power supplied to the input of such a device, part of its internal energy is absorbed by the external medium through one of the lateral faces ($a \times b$), with a negative half-cycle – through the opposite lateral face ($a \times b$).

In this case, cooling capacity Q is determined as follows [13]:

$$Q = W_{out}\frac{(K+1)\cdot tg\alpha}{K - tg^2\alpha}, \tag{15}$$

and temperature difference ΔT between the external medium and the anisotropic device, which is achieved by the adiabatic isolation of the faces of the plate,

$$\Delta T = (Q - q_{los})/(s \cdot M), \tag{16}$$

where q_{los} are losses due to cooling of electrically conductive and metal layers on the upper and lower faces of the converter, s is heat capacity, M is its weight.

The efficiency ϑ of the analysed cooling process is represented by the classical expression:

$$\vartheta = (T_1 - T_2)/T_1$$

where T_1 is ambient temperature, T_2 is anisotropic plate temperature which is achieved on cooling.

It should be noted that as materials for the plate it is possible to use both semiconductors with a narrow energy gap, semiconductors of *p*- and *n*- type conductivity, semimetals and metals of appropriate conductivity.

The results of the studies show the outlook for using this device as highly efficient cooling elements. This method allows for efficient utilization and accumulation of thermal energy released by specific objects, various instruments and devices, pumping it into the external medium.

Conclusions

For the first time, an original physical model is proposed for energy interaction between vortex electric field of a plate made of anisotropic electrically conductive material characterized by different types of conductivity in the selected crystallographic axes and the external medium. The analysis of this model shows that in the range $0<K<1$ the transformation coefficient m is characterized by the negative value, and in the range $1<K<\infty$ - by the positive value. In the former case, there is cooling effect, in the latter – the mode of electric energy generation and heat release.

The use of single-crystal and artificial anisotropic electrically conductive materials with different conductivity types in the selected crystallographic axes makes it possible to obtain the value of module $m > 1$ which is caused by the action of electric field vortices with a turbulent flow in the bulk of the anisotropic plate.

Promising areas of practical application of such devices in the form of generators of electricity, heat and cold are determined, calculated expressions are obtained for their efficiency, which is in the range $\eta = 0.5 \div 0.98$, and the cooling temperature of this device when using appropriate materials with the necessary temperature dependence of their kinetic coefficients can reach the temperature of liquid helium.

The proposed model will promote the emergence of new scientific and technical lines in the field of electricity and all related areas.

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Ащеулов А.А. *док. техн. наук, професор*

Інститут термоелектрики НАН і МОН України,
вул. Науки, 1, Чернівці, 58029, Україна,
e-mail: ashcheulovaa@rambler.ru

ПРО ЕНЕРГЕТИЧНІ МОЖЛИВОСТІ У АНІЗОТРОПНОМУ БІПОЛЯРНОМУ ЕЛЕКТРОПРОВІДНОМУ СЕРЕДОВИЩІ

Проведено дослідження особливостей перетворення електричного струму анізотропним електропровідним середовищем яке характеризується різними типами провідності (p- та n- типи) у вибраних кристалографічних напрямках в умовах омічного контакту. Встановлено, що у випадку протікання зовнішнього електричного струму синусоїдальної форми через пристрій в основі якого є прямокутна пластина із згадуваного вище анізотропного матеріалу, в її об'ємі виникають вихори електричного струму. На основі аналізу функції $m(K, \alpha)$ (випадок $|m| > 1$), що визначає коефіцієнт перетворення пристрою, зроблено висновок про енергетичну взаємодію між об'ємом анізотропної пластини і зовнішнім середовищем. Проведені дослідження показали, що використання анізотропного електропровідного біполярного матеріалу призводить до значно вищої ($m>1$) або нижчої ($m<-1$) величини коефіцієнта перетворення m ніж у випадку уніполярних анізотропних електропровідних матеріалів. До феномену електроомічного перетворення веде поява вихорів електричного поля, які характеризуються турбулентною течією, що представляються виразом $\mathrm{rot}\, j = \pm\omega$, де ω – кругова частота обертання вихору, а знаки «+» та «–» – позначають напрямок його обертання та визначаються величиною коефіцієнта анізотропії $K=\sigma_{11}/\sigma_{22}$. Такі електричні вихори з турбулентним характером течії є ефективним механізмом, що перекачує енергію між зовнішнім середовищем і в нашому випадку, анізотропною пластиною пристрою. Слід відмітити, що в окремих випадках спостерігається аномальне значення згадуваного коефіцієнта. Застосування розглянутого методу перетворення електричного струму за допомогою запропонованих пристроїв, в основі роботи яких є пластина виготовлена з анізотропного електропровідного матеріалу, значно розширює галузі альтернативної електроенергетики та інших пов'язаних з ним областей науки та техніки. Бібл. 14, рис.7.

Ключові слова: анізотропне середовища; електропровідність; перетворення; електричний струм; коефіцієнт корисної дії; нагрів; охолодження; генерація.

Ащеулов А.А. *док. техн. наук, профессор*

Институт термоэлектричества НАН и МОН Украины,
ул. Науки, 1, Черновцы, 58029, Украина,
e-mail: ashcheulovaa@rambler.ru

О ЭНЕРГЕТИЧЕСКИХ ВОЗМОЖНОСТЯХ В АНИЗОТРОПНЫХ БИПОЛЯРНЫХ ЭЛЕКТРОПРОВОДНЫХ СРЕДАХ

Проведено исследование особенностей преобразования электрического тока анизотропной электропроводной средой, характеризующейся разными типами проводимости (p- и n-типы) в выбранных кристаллографических направлениях в условиях омического контакта. Установлено, что в случае протекания внешнего электрического тока синусоидальной формы через устройство, в основе которого имеется прямоугольная пластина из вышеупомянутого анизотропного материала, в ее объеме возникают вихри электрического тока. На основе анализа функции m(K, α) (случай $|m| > 1$*), определяющий коэффициент преобразования устройства, сделан вывод об энергетическом взаимодействии между объемом анизотропной пластины и внешней средой. Проведенные исследования показали, что использование анизотропного электропроводного биполярного материала приводит к значительно более высокой (*$m > 1$*) или более низкой (*$m < -1$*) величине коэффициента преобразования m, чем в случае униполярных анизотропных электропроводных материалов. К феномену электрохимического превращения ведет появление вихрей электрического поля, характеризующихся турбулентным течением, представляемым выражением* $\mathrm{rot}\, j = \pm\omega$ *где ω – круговая частота вращения вихря, а знаки «+» и «–» – обозначают направление его вращения и определяются величиной коэффициента анизотропии* $K=\sigma11/\sigma22$*. Такие электрические вихри с турбулентным характером течения являются эффективным механизмом, перекачивающим энергию между внешней средой и в нашем случае, анизотропной пластиной устройства. Следует отметить, что в редких случаях наблюдается аномальное значение упомянутого коэффициента. Применение рассматриваемого метода преобразования электрического тока с помощью предложенных устройств, в основе работы которых пластина изготовлена из анизотропного электропроводящего материала, значительно расширяет области альтернативной электроэнергетики и другие, связанных с ней области науки и техники. Библ. 14, рис.7.*

Ключевые слова: анизотропная среда; электропроводность; превращение; электрический ток; коэффициент полезного действия; нагрев; охлаждение; генерация.

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