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The Phenomenon of Electric Field Energy Conversion in Anisotropic Metadielectric Media

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Abstract: The features of electric field transformation by anisotropic metamedium at a negative value of the dielectric constant in one of the selected principal crystallographic directions are studied. It is established that at the moment of application to the upper and lower faces of anisotropic metadielectric plate, which is the basis of the proposed alternative transformer, a certain potential difference leads to polarization of its volume and the appearance of both longitudinal and transverse components of the vortex electric field. This situation leads to axial folding of its internal field, which in turn leads to the appearance of electric field vortices characterized by a turbulent flow. Such electric vortices with a turbulent flow are an efficient mechanism for pumping energy between the physical vacuum and, in our case, the anisotropic metadielectric converter plate. The dependence of the transformation ratio of this medium on the anisotropy value of the plate material is analyzed. It is found that the use of anisotropic metadielectric material in comparison with the classical one is characterized by the values of transformation ratio greater than 1. Note that in some cases there is an anomalous increase in the above mentioned ratio. The use of anisotropic metadielectric converter under consideration will significantly expand the fields of alternative power engineering and other related fields of science and technology.

Keywords: Anisotropic Metamedia, Dielectric Constant, Converter, Cooling, Generation

1. Introduction

Features of electric phenomena in classical anisotropic dielectric media led to the emergence of a new method, as well as a number of original devices for transforming both alternating and constant electric fields, which make it possible to expand the practical possibilities of electrical engineering, as well as related industries [1-4].

The transformation coefficient n of a classical anisotropic dielectric converter is represented by the formula

$$n = m \cdot f\ , \qquad (1)$$

$$m = \varepsilon_{\perp} / \varepsilon_{\parallel} = (\varepsilon_{11} - \varepsilon_{22}) \sin\alpha \cos\alpha \Big/ \left(\varepsilon_{11}\cos^2\alpha + \varepsilon_{22}\sin^2\alpha\right)$$

where m is transformation ratio of a classical anisotropic unipolar plate material, $f = a / b$ is its form factor [3, 4].

The study of the values of the transformation ratio m for an extreme angle α ($dm/d\alpha = 0$) showed that the maximum value of m is observed at the angle $\alpha_{\max.} = arctg\sqrt{\varepsilon_{11}/\varepsilon_{22}}$

$$m_{\max.} = m(\alpha_{\max.}) = \frac{\sqrt{K}(K-1)}{2K}, \qquad (2)$$

where $K = \varepsilon_{11}/\varepsilon_{22}$.

In so doing, it should be noted that when classical anisotropic dielectric materials are used, the value of the transformation ratio m grows smoothly in comparison with the growth of the coefficient K, directly depends on the choice of materials and, in this regard, is quite limited. Note that the maximum value of the transformation ratio m in the case of using classical anisotropic dielectric materials does not exceed 1.

Note that the volume of an anisotropic dielectric plate, which is the basis of the transformer, is characterized by the presence of a vortex electric field with only a laminar flow.

In 1931, P. Dirac showed the possibility of the existence of states with a negative value of dielectric (ε) and magnetic (μ) permeability in the region of helium temperatures.

The physical interpretation of the effect that causes negative values of ε and μ of substances, later called metamaterials, was first presented in 1967 by V. G. Veselago [5]. Experimental confirmation of this phenomeon was established by American researchers at the University of California San Diego in 2000 [6].

To date, more than 1000 papers have been published in this direction, mainly in the fields of optics, radiophysics, and others [6-9].

This paper presents the results of previous research on the possibility of using anisotropic metadielectric materials for the electric field transformation.

2. Model of Anisotropic Metadielectric Transformer (AMDT)

Let us consider an anisotropic medium, the dielectric constant tensor $\hat{\varepsilon}$ of which, in the main crystallographic axes *OX*, *OY*, *OZ*, is given by:

$$\hat{\varepsilon} = \varepsilon_0 \begin{vmatrix} \varepsilon_{11} & 0 & 0 \\ 0 & -\varepsilon_{22} & 0 \\ 0 & 0 & \varepsilon_{33} \end{vmatrix}. \tag{3}$$

One of the variants of such an anisotropic metadielectric medium is an alternating layered structure based on dielectrics with the positive and negative values of the dielectric constant ε.

Creating from such a material a rectangular plate of size $a \times b \times c$ ($a \approx c >> b$), the crystallographic axes *OX* and *OY* of which are located in the plane of its lateral face $a \times b$, and one of these axes is located at some angle α to the edge a ($0 < a < 90^\circ$) (Figure 1), allows us to represent the tensor $\hat{\varepsilon}$ as follows:

$$\hat{\varepsilon} = \varepsilon_0 \begin{vmatrix} \varepsilon_{11}\cos^2\alpha - \varepsilon_{22}\sin^2\alpha & (\varepsilon_{11}+\varepsilon_{22})\sin\alpha\cos\alpha & 0 \\ (\varepsilon_{11}+\varepsilon_{22})\sin\alpha\cos\alpha & \varepsilon_{11}\sin^2\alpha - \varepsilon_{22}\cos^2\alpha & 0 \\ 0 & 0 & \varepsilon_{33} \end{vmatrix} \tag{4}$$

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

$$\varepsilon_{\|} = \varepsilon_0 \left(\varepsilon_{11}\cos^2\alpha - \varepsilon_{22}\sin^2\alpha\right) \tag{5}$$

$$\varepsilon_{\perp} = \varepsilon_0 \left(\varepsilon_{11}+\varepsilon_{22}\right)\sin\alpha\cos\alpha\ . \tag{6}$$

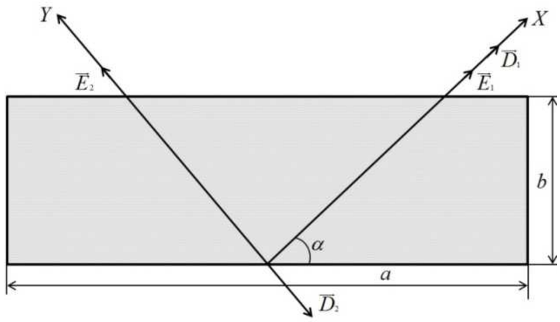


Figure 1. *Orientation of crystallographic axes OX, OY and OZ of anisotropic metadielectric plate and location of vectors of electric fields* $\vec{E}_1$, $\vec{E}_2$, *and induction* $\vec{D}_1$, $\vec{D}_2$.

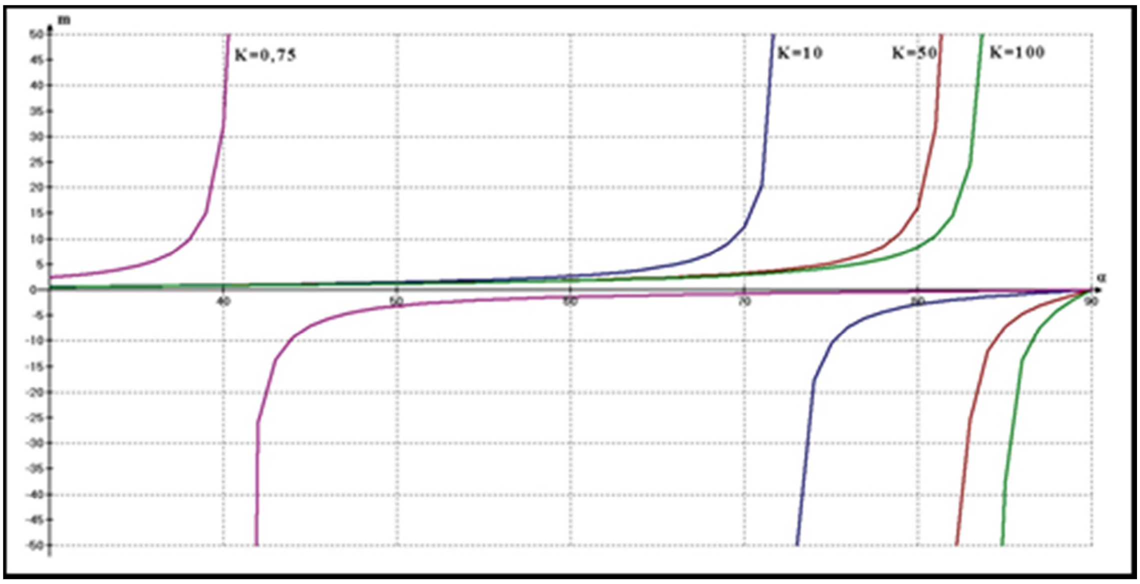


Figure 2. *Dependence of transformation ratio m of AMDT on the angle α at fixed anisotropy coefficients of metadielectric material K=0,75; 10; 50; 100..*

In so doing, the transformation ratio m of such a plate is of the form:

$$m_1 = \frac{\varepsilon_\perp}{\varepsilon_\parallel} = \frac{(\varepsilon_{11} + \varepsilon_{22}) \sin\alpha \cos\alpha}{\varepsilon_{11} \cos^2\alpha - \varepsilon_{22} \sin^2\alpha} \tag{7}$$

Numerical estimates show that at $a \approx c >> b$ the boundary conditions on the end $b \times c$ and lateral $a \times b$ faces can be neglected [3].

Investigation of function

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

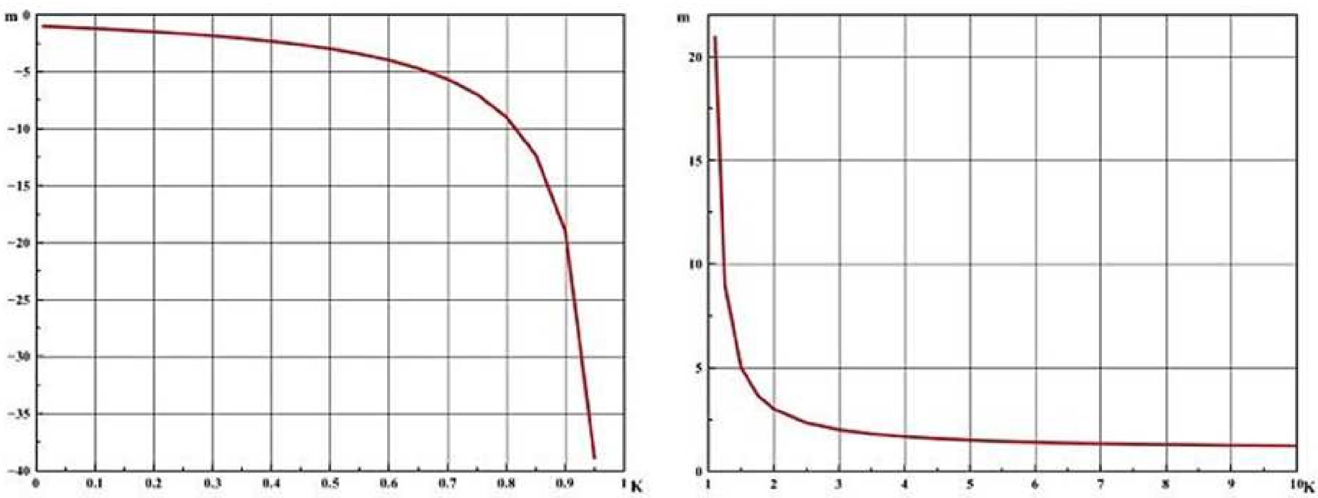
for an extremum ($\partial m / \partial\alpha = 0, \partial^2 m / \partial\alpha^2 < 0$) demonstrates that extremum function points are missing.

It should be noted that the value of the m ratio of anisotropic metadielectric material can be varied within wide limits by selecting the optimal angle α. This possibility is shown in Figure 2 for four anisotropic metadielectric materials with anisotropy coefficients 0.75, 10, 50 and 100. From this graph it follows that there is always the possibility of selecting the angle α for a given m with the required value and sign.

In case of $\alpha.=45^\circ$ formula (7) will be given by

$$m_1 = \frac{\varepsilon_{11} + \varepsilon_{22}}{\varepsilon_{11} - \varepsilon_{22}} = \frac{K+1}{K-1} \tag{9}$$

Thus, the use of metamaterial with a negative value of the dielectric constant ε_{22} in one of the selected main crystallographic directions leads to an anomalous increase in the value of the transformation ratio m, AMDT (Figure 3).



a) b)

Figure 3. *Dependence of transformation ratio m of AMDT on the anisotropy value for dielectric metamaterial at α.=45°.*

a) Dependence of transformation ratio m of AMDT on the anisotropy value at 0<*K*<1 and the angle *α.=45°*;
b) Dependence of transformation ratio m of AMDT on the anisotropy value at 1<*K*<∞ and the angle *α=45°*.

The explanation of this phenomenon in the first approximation can be presented using the concepts of vortex electrodynamics and physical vacuum.

The negative value of the dielectric constant of metamaterials is due to the antiparallel arrangement of the vectors of phase $\overline{V}_\Phi$ and group $\overline{V}_B$ velocities of the electric field $\overline{E}$ [5-12].

In the case of AMDT, the values of the coefficient K of the anisotropic metadielectric material are determined by the selected crystallographic directions. In the first crystallographic direction OX (Figure 1) the arrangement of the vectors $\overline{V}_\Phi$ and $\overline{V}_B$ is mutually parallel (classical), and in the OY direction the vectors $\overline{V}_\Phi$ and $\overline{V}_B$ have antiparallel (meta) orientation.

The application of some potential difference $U(t) = U_m \cdot \sin(\omega t)$ to the upper and lower faces a×b of such a plate (Figure 1) leads to the polarization of its volume and the emergence of both longitudinal $\vec{E}_\parallel$ and transverse $\vec{E}_\perp$ components of the vortex electric field [13]. This situation leads to axial folding of its internal field, which in turn leads to the appearance of a vortex electric field with a turbulent flow, given by the following expression [14, 15]

$$rot\vec{E} = \omega, \tag{10}$$

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

We write the criterion for the appearance of a vortex by the formula

$$\frac{\partial E_{11}}{\partial x} \neq -\left|\frac{\partial E_{22}}{\partial y}\right|, \tag{11}$$

where E_{11}, E_{22} are electric field intensities along the chosen crystallographic axes.

Such axial electric vortices are an effective mechanism that pumps energy between the physical vacuum and, in our case, AMDT.

As is known, the physical vacuum is a highly symmetrical structured vortex system characterized by the presence of an ultra-high amount of energy [16-19]. In the general case, it is represented by the formula as follows

$$W = A \cdot \sum_{n=1}^{\infty} 0,5\,\hbar\,\omega, \tag{12}$$

where A is the coefficient, $\hbar$ is the Planck constant; ω is circular frequency [17].

Depending on the direction of rotation of the electric vortex of the plate, which is determined by the anisotropy coefficient K of the plate material at $1<K<\infty$ – right, and at $0<K<1$ – left – physical vacuum, respectively, gives energy to AMDT or receives it from the converter.

Thus, the proposed model allows us to present the original technology for creating a method of energy transformation with high environmental performance.

The application of the described AMDT shows that its transformation coefficient is the following expression

$$n_1 = \frac{(K+1)tg(\alpha_{opt.})}{K - tg^2(\alpha_{opt.})} \cdot \frac{a}{b} = m_1 \cdot f \tag{13}$$

and here there is a sharp increase in the value of the transformation coefficient n_1.

The proposed method of interaction between AMDT and physical vacuum allows the generation of both electricity and heat and cold.

A detailed presentation of the physical and mathematical model of this method is planned to be presented in future publications.

3. Design Features of AMDT

In the general case, the choice of a specific AMDT design is determined both by the purpose and functional features, and by the conditions of its operation. One of the possible design options for this device is shown in Figure 4.

The basis of AMDT is a rectangular plate *1* of anisotropic metadielectric material, selected crystallographic axes *OX* and *OY* of which are located in the plane of the side face a × b, while the axis *OY* is oriented at an angle α to the length a [20]. The upper and lower faces a × c of this plate contain electrically insulating layers 2, of thickness Δ1 with dielectric constant ε_c, on the outer sides of which are placed conductive layers 3 of thickness Δ_2 with input electric wires 4, 5. Output electric wires 6, 7 are placed on opposite end faces $b \times c$.

The analysis of the volumetric distribution of the electric field of the plate 1 with the orientation of the crystallographic axis *OY* at an angle α (Figure 1) showed that the presence of electrically conductive layers 3 leads to some distortion in the distribution of equipotential surfaces of the electric field, and, consequently, to a decrease in the value of the transformation ratio *m*.

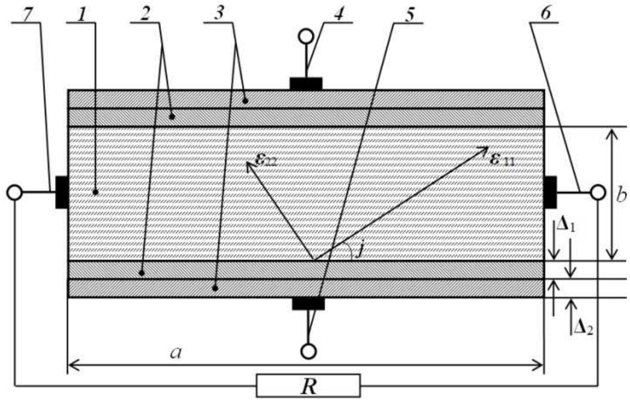


Figure 4. *AMDT design.*

1 - Plate of anisotropic metadielectric material; 2 - electrically insulating layers; 3 - electrically conductive layers; 4, 5 - input; 6, 7 - output electric wires.

If, however, the axis *OY* is located at an angle $j = \alpha - \beta$, the equipotential surfaces of the electric field are parallel to the faces $a \times c$, (Figure 5), the value of the transformation coefficient of AMDT being determined by the expression:

$$n_2 = \frac{(\varepsilon_{11} + \varepsilon_{22}) \cdot \sin j \cos j}{\varepsilon_{11}\cos^2 j - \varepsilon_{22}\sin^2 j} \cdot \frac{a}{b}. \tag{14}$$

The value of the angle β in this case follows from the following expression:

$$\beta = arctg\frac{\varepsilon_{11} + \varepsilon_{22}}{\varepsilon_{11} - \varepsilon_{22}}. \tag{15}$$

This design solution almost completely eliminates the impact of the conductive layers 3 on the volumetric distribution of the equipotential electric surfaces of the AMDT under consideration, and may also lead to some increase in the transformation coefficient.

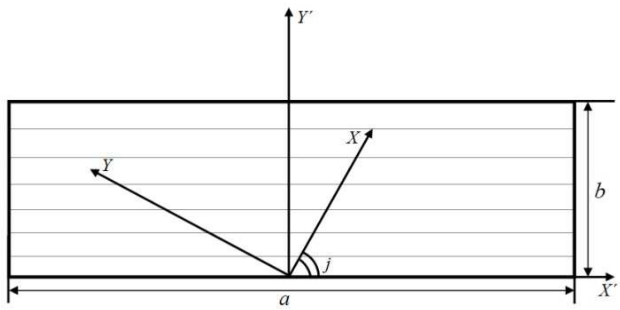


Figure 5. *Distribution of equipotential surfaces of the electric field when the OY axis is oriented at an angle j = α – β.*

The equivalent electrical substitution circuit of this device with respect to electric wires 4 and 5 is three capacitors C_1, C_2,

C_3 connected in series (capacitors C_1, C_3 are formed by an electrically conductive layer 3 and surfaces $a \times c$ on both sides of the plate C_2 - the upper and lower surfaces $a \times c$. Wherein

$$C_1 = C_3 = \varepsilon_c \cdot (ac/\Delta_1), \quad (16)$$

$$C_2 = 0,5 \cdot (\varepsilon_{11} - \varepsilon_{22}) \cdot (bc/a). \quad (17)$$

As long as $\varepsilon_c >> (\varepsilon_{11} - \varepsilon_{22})$, and $b >> \Delta_1$, then $C_1 = C_3 >> C_2$, hence, almost the entire potential difference ΔU, connected to electric wires 4, 5, turns to be applied directly to the upper and lower faces $a \times c$ of plate 1.

The transverse potential difference that occurs between the end faces $b \times c$ of the plate forms the output capacitance C_4.

$$C_4 = 0,5 \cdot (\varepsilon_{11} + \varepsilon_{22}) \cdot \frac{bc}{a}. \quad (18)$$

It should be noted that anisotropic metadielectric material is a layered alternating structure based on the layers of classical dielectric 1 of thickness τ_1 and metadielectric 2 of thickness τ_2. The method for calculation of this structure and its optimization is similar to the method described in previous publications and patents of Ukraine [20].

Thus, selecting the appropriate value of the anisotropy coefficient for the materials of the anisotropic plate, as well as its geometric dimensions, we get the opportunity to create AMDT with the necessary parameters.

4. Anisotropic Metadielectric Electric Field Generator

In this case, anisotropic metadielectric material is characterized by positive value of transformation ratio m ($1<K<\infty$) and orientation of crystallographic axis ε_{11} at some chosen optimal angle α [21].

The circuit of such a generator consists of an AMDT, the input electric wires 4, 5 of which are connected to an external source of electricity generated by the master generator. An external load with resistance Z is connected to the output electric wires 6, 7.

When a certain power $P(t) = P_0 \sin(\omega_1 t)$ is supplied to the input of the AMDT, electric vortices appear in the volume of plate 1, which interact with the physical vacuum. This leads to the emergence of an energy flow directed from the physical vacuum into the bulk of the AMDT. With a positive half-cycle, the energy of the physical vacuum is absorbed by the device, passing through one of the side faces of the AMDT, with a negative value - through the opposite side face ($a \times b$). Finally, this results in the appearance on the output electric wires 6, 7 of electric power P_{out} which is given by:

$$P_{out} = P_0 \sin(\omega_1 t_0) \frac{(K+1) \cdot tg\alpha}{K - tg^2\alpha}, \quad (19)$$

thus, the right-hand rotation of electric vortices with a turbulent flow determines the possibility of AMDT operation in the power generation mode.

The efficiency η_1 in this case looks like this:

$$\eta_1 = \frac{1}{1 + \frac{(K+1) \cdot tg\alpha}{K - tg^2\alpha} + tg\delta}, \quad (20)$$

where $tg\,\delta$ is dielectric loss of the material of plate 1.

The maximum value of the electric power P_{max}, which can be generated by the AMDT, is determined by the following expression:

$$P_{\max.} = (s \cdot M \cdot \Delta T)/tg\delta, \quad (21)$$

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

Table 1 shows some characteristics of the proposed device with different values of the anisotropy coefficient K, the form factor of AMDT $f = 0.1$.

Analysis of these data shows an increase in the value of $E_\perp$ and $P_\perp$ with a decrease in the anisotropy K of the plate material.

Table 1. *Characteristics of AMDT with form factor* $f = 0,1$.

Anisotropy coefficient, $K = \varepsilon_{11}/\varepsilon_{22}$	Electric field magnitude, $E_\parallel$ V·cm^{-1}	Electric field magnitude, $E_\perp$ V·cm^{-1}	Power value, $P_\parallel$ W	Power value, $P_\perp$ W
2	1	30	1	27
1,5	1	50	1	125
1,2	1	110	1	1331
1,1	1	210	1	9261
1	1	0	1	0

It should be noted that, under certain conditions, the considered AMDT can also actively operate in the heat power generation mode.

5. Anisotropic Metadielectric Cooler

As noted above, the left-hand rotation of electric vortices with a turbulent flow of the plate leads to a decrease in the internal energy of the AMDT. This brings about a corresponding decrease in the temperature T of the anisotropic plate [22].

With a positive half-cycle of power supplied to the AMDT input, part of its internal energy is absorbed by the physical vacuum through one of the side faces ($a \times b$) with a negative half-cycle - through the opposite side face *($a \times b$).*

In this case, the cooling capacity Q is determined as follows

[23]:

$$Q = W_{out} \frac{(K+1) \cdot tg\alpha}{K - tg^2\alpha}, \quad (22)$$

and the temperature difference ΔT between the environment and AMDT, which is achieved by adiabatic isolation of the plate faces,

$$\Delta T = (Q - q_{loss})/(s \cdot M), \quad (23)$$

where q_{loss} is loss due to cooling of dielectric and metal layers on the upper and lower faces of the transformer, s is heat capacity, M is its mass.

The efficiency η_2 of the analyzed cooling process is as follows:

$$\eta_2 = \frac{1}{1 + \frac{(K+1) \cdot tg\alpha}{K - tg^2\alpha} + tg\delta} \quad (24)$$

where $tg\,\delta$ is dielectric loss of the plate material.

Table 2 presents the numerical values of the cooling capacity Q of AMDT depending on the value of the anisotropy coefficient K.

Table 2. *AMDT cooling capacity values.*

D_{in}	1	1	1	1
K	0.1	0.5	0.9	0.95
Q	1.2	3	19	37

With a value of $K = 0.1 \div 0.98$ and $tg\,\delta = 10^{-2}$ the efficiency η_2 is within $\eta_2 = 0.5 \div 0.98$ and cooling capacity $\theta = 1.2 \div 9.8$ W.

The results of the research show the prospects for using this device as highly efficient refrigeration elements. This method allows for efficient utilization and accumulation of the released thermal energy from specific objects, various instruments and devices, pumping it into the physical vacuum medium.

6. Conclusion

For the first time, an original physical model of the energy interaction between the vortex electric field of an anisotropic metadielectric transformer plate and a physical vacuum was proposed. Analysis of this model shows that in the interval $0<K<1$ the value of the transformation ratio m is characterized by a negative value, and in the interval $1<K<\infty$ – positive. In the former case, there is a cooling effect, in the latter – power generation mode.

The use of metadielectric material as compared to classical one is characterized by values of m greater than 1, which is primarily due to electric field vortices with a turbulent flow in the bulk of the anisotropic plate.

Along with the vortex device considered above, the AMDT can amplify various signals in a wide spectral range; work effectively as an emitter in a wide spectral range; with an appropriate selection of optical materials, function as a generator of radiant energy in the IR, visible, UV and X-ray spectra; as a device for interfacing antenna devices with transceiver systems, etc.

The areas of practical application of AMDT in the form of generators of electricity, heat and cold are determined, calculated expressions are obtained for their efficiency, which is in the range of $\eta = 0.5 \div 0.98$, and the cooling temperature of this device can reach the temperature of liquid helium.

The proposed model will contribute to the advent of new directions in power engineering and other related fields of science and technology.

7. Recommendations

Further studies of this strategic direction, allowing to solve issues of general energy supply, should be carried out in the areas of research on the mechanisms of energy interaction of electric field vortices of a laminar and turbulent nature of the flow with the external environment.

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