International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

March 2016 | Issue 26 | Volume 8 | Number 1 | Pages 50-54

THERMOMAGNETIC WAVES IN ANISOTROPIC CONDUCTORS

E.R. Hasanov [1] **A.V. Islamzade** [2] **H.Sh. Hasanov** [2]

1. Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan
2. Institute of Physics Problems, Baku State University, Baku, Azerbaijan
aygul_islamzade@mail.ru

Abstract- Theory of thermomagnetic waves in anisotropic conductive waves is conducted. Frequency and grows of the waves are calculated. Intervals of the changes in electrical conductivity at which unstable waves are generated inside the anisotropic conducting medium without an external magnetic field are defined.

Keywords: Temperature Gradients, Increment, Electric Field, Alternating Magnetic Field.

I. INTRODUCTION

In the articles [1, 2, 3] it has been proven that magnetic field is generated by non-equilibrium plasma with thermal gradient. Plasma with a thermal gradient $\vec{\nabla} T$, in contrast to a conventional plasma, creates waves. Plasma with waves is completely different from a plasma at equilibrium. The thermomagnetic longitudinal waves occur in such plasma even in the absence of an external magnetic field and absence of hydrodynamic motion.

Only the magnetic field varies in these waves. When there exist a constant external magnetic field $\vec{H}_0$, the wave vector of thermomagnetic waves is perpendicular to $\vec{H}_0$ and lies in the plane of ($\vec{H}_0$, $\vec{\nabla} T$).

The Alfven wave splits into two magneto-hydrodynamic waves and the vectors $\vec{V}$ and $\vec{H'}$ are perpendicular to the vector $\vec{\nabla} T$. The magnetosonic wave spectrum changes. In this case, thermomagnetic wave propagation speed is close to the speed of the sonic wave. The magnetic field propagates in the direction of the thermal gradient.

Plasma with $\nabla T = \text{constant}$ is considered. It is assumed that at distance $L = \frac{T}{\Delta T}$ temperature variance is very little. If pressure P = constant then plasma at such ∇T can be regarded as stationary, i.e. $\frac{\vec{\nabla}\rho}{\rho} = \frac{\vec{\nabla} T}{T}$ (where ρ is density of plasma). If small magnetic field is created in this plasma, $\Omega\tau \ll 1$, ($\Omega = \frac{eH}{mc}$ electron Larmor frequency, $1/\tau$ - electrons collision frequency).

II. BASIC EQUATIONS

In electric field $\vec{E}$ and $\vec{\nabla} T$ is velocity of hydrodynamic motion $\vec{V}(\vec{r},t)$, the density of electric current is calculated as shown below [1].

$$\vec{j} = \sigma \vec{E}^* + \sigma' \left[\vec{E}^* \vec{H} \right] - \alpha \vec{\nabla} T - \alpha' \left[\vec{\nabla} T \vec{H} \right] \quad (1)$$

where,

$$\vec{E}^* = \vec{E} + \frac{\vec{V}\vec{H}}{C} + \frac{T}{e}\frac{\vec{\nabla} n}{n}, \quad e>0 \quad (2)$$

and n is concentration of electrons.

From Equation (1) the electric field $\vec{E}$ can be determined by the vector equation below.

$$\vec{y} = \vec{a} + \left[\vec{b}\vec{y} \right] \quad (3)$$

where, $\vec{y}$ is unknown vector.

From Equation (3),

$$\left[\vec{b}\vec{y} \right] = \left(\vec{b}\vec{a} \right), \qquad \vec{b}[\vec{b}\vec{y}] = 0 \quad (4)$$

In expression $[\vec{b}\vec{y}]$ we put $\vec{y}$ from (3)

$$\vec{y} = \vec{a} + \left[\vec{b}\vec{a} \right] + \left[\vec{b} \left[\vec{b}, \vec{y} \right] \right]$$

$$\left[\vec{b} \left[\vec{b}, \vec{y} \right] \right] = b \left(\vec{b}\vec{y} \right) - \vec{y} b^2 \quad (5)$$

$$\vec{y} = \frac{\vec{a} + \left[\vec{b}\vec{a} \right] + \left(\vec{a}\vec{b} \right) \vec{b}}{1 + b^2}$$

Using equation $\vec{H} = \frac{4\pi}{c} \vec{j}$ from Equations (5) and (1) we can obtain the below expression for electric filed $\vec{E}$.

$$\vec{E} = -\frac{\left[\vec{V}\vec{H} \right]}{c} - \Lambda' \left[\vec{\nabla} T, \vec{H} \right] + \frac{c}{4\pi\sigma} \text{rot} \vec{H} - \frac{c\sigma'}{4\pi\sigma^2} \left[\text{rot} \vec{H}, \vec{H} \right] + \frac{T}{e} \frac{\nabla \rho}{\rho} + \Lambda \nabla T \quad (6)$$

where, $\Lambda = \frac{\alpha}{\sigma}$, $\Lambda' = \frac{\alpha'\sigma - \alpha\sigma'}{\sigma}$, σ is electrical conductivity, Λ is differential term, Λ' is Hernst-Ettingauzen dimensionless coefficient.

$$\frac{\partial \vec{H}}{\partial t} = -c.\text{rot}\vec{E} \quad (7)$$

Inserting in Equation (6),

$$\frac{\partial \vec{H}}{\partial t} = \text{rot}\left[(\vec{V} + c\Lambda'\vec{\nabla}T - \frac{c\sigma'}{4\pi\sigma^2}\text{rot}\vec{H}), \vec{H}\right] + + \frac{c^2}{4\pi\sigma}\text{rot}\vec{H} + \Lambda\vec{\nabla}T + \frac{T}{e}\frac{\vec{\nabla}\rho}{\rho} \quad (8)$$

Equation (8) defines the magnetic field during hydrodynamic motion in plasma at thermal gradient $\vec{\nabla}T$. Analytical solution of equation (8) was described in detail in the work [1]. In [2-3] thermomagnetic waves in solid-state plasma were analyzed, the frequencies of transverse $\vec{K} \perp \vec{\nabla}T$ and longitudinal $\vec{K} // \vec{\nabla}T$ the magnetic waves in homogeneous conducting medium were calculated. In [4, 5, 6] the thermomagnetic waves were theoretically investigated in isotropic conducting medium.

Clearly, in anisotropic conducting mediums (metals and semiconductors) the thermo-magnetic waves in different directions of crystal will be spread over with different frequencies. In case of anisotropic conducting medium, direction and values of alternating magnetic and electric fields created in different directions and changing with respect to thermal gradient will affect the frequencies of the thermomagnetic waves.

The frequencies of the thermo-magnetic waves depend on values of conductivity tensor σ_{ik} for different directions of the Hernst-Ettingauzen tensor Λ'. The aim of our work is investigation of the condition of occurrences and frequencies of thermomagnetic waves in anisotropic electronic-type conducting mediums.

It is required to write the above described system of equations in tensor. We show the dependence of electric field on current density in isotropic medium as:

$$\vec{E} = \eta\vec{j} + \eta'\left[\vec{j}\vec{H}\right] + +\eta''\left(\vec{j}\vec{H}\right)\vec{H} + \Lambda'\left[\vec{\nabla}T, \vec{H}\right] + +\Lambda''\left(\vec{\nabla}T\vec{H}\right)\vec{H} + \Lambda\vec{\nabla}\text{T} \quad (9)$$

or

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \Lambda\nabla\vec{T} + \vec{E}_4 + \vec{E}_5 \quad (10)$$

where, $\vec{E}_1$ is electric field changing in direction of current $\vec{j}$, $\vec{E}_2$ is electric field changing perpendicular to direction of current $\vec{j}$ and magnetic filed $\vec{H}$, $\vec{E}_3$ is electric filed changing in direction of current $\vec{j}$ and magnetic field $\vec{H}$, $\Lambda\nabla T$ is electric filed changing in direction of thermal gradient, $\vec{E}_4$ is electric filed changing perpendicular to direction of thermal gradient and magnetic filed $\vec{H}$, $\vec{E}_5$ is electric filed changing in direction of thermal gradient and magnetic filed $\vec{H}$).

In anisotropic medium the Equation (9) depending on directions and in tensor form is written as follows:

$$E_i = \eta_{im} j_m + \eta'_{im}\left[\vec{j}\vec{H}\right]_m + \eta''_{im}\left(\vec{j}\vec{H}\right)H_m + +\Lambda_{im}\frac{\partial T}{\partial x_m} + \Lambda'_{im}\left[\vec{\nabla}TH\right]_m + \Lambda''_{im}\left(\vec{\nabla}TH\right)H_m \quad (11)$$

When external magnetic filed $\vec{H}_0 = 0$, if in Equation (11) tensors Λ'_{im}, η''_{im}, Λ''_{im} and ∇T = constant, then tensor Λ_{im} is zero. Combining the equations of Maxwell and (11) we will receive the following system of equations:

$$E'_i = \eta_{im} j'_m + \Lambda'_{im}\left[\vec{\nabla}TH\right]_m \quad \text{rot}\vec{E}' = -\frac{1}{c}\frac{\partial \vec{H}'}{\partial t} \quad \text{rot}\vec{H}' = \frac{4\pi}{c}j' + \frac{1}{c}\frac{\partial \vec{E}'}{\partial t} \quad (12)$$

If the variables are being changed as monochromatic wave, (i.e. $E', H' \sim \text{e}^{i(\vec{k}\vec{r} - \omega t)}$) the system of Equations (12) becomes as system shown below.

$$E'_i = \eta_{im} j'_m + \Lambda'_{im}\left[\vec{\nabla}T\vec{H}\right]_m \quad j'_i = \frac{ic^2}{4\pi\omega} + \left[\vec{k}\left[\vec{k}\vec{E}\right]\right]_m + \frac{i\omega}{4\pi}E'_m \quad (13)$$

where, ω is frequency of the wave, and $\vec{k}$ is wave vector of the wave.

Form Equation (13), we can find alternating electric filed E'_i

$$E'_i = \begin{bmatrix} A\eta_{il}K_e K_m + B\eta_{im} + \\ + \frac{c\Lambda'_{ie}}{\omega}K_e\frac{\partial T}{\partial x_m} \end{bmatrix} E'_m \quad A = \frac{ic^2}{4\pi\omega}, \quad B = i\frac{\omega^2 - c^2k^2}{4\pi\omega} \quad (14)$$

In Equation (14), $E'_m = \delta_{im}E'$ and;

$$\partial_{im} = \begin{cases} 1, & i = m \\ 0, & i \neq m \end{cases}$$

Considering above, we receive the below equation in tensor form,

$$\left(N_{im} - \delta_{im}\right)E'_i = 0 \quad (15)$$

$$N_{im} = A\eta_{il}K_e K_m + B\eta_{im} + \frac{c\Lambda'_{ie}}{\omega}K_e\frac{\partial T}{\partial x_m} \quad (16)$$

To satisfy the system of Equations (15) determinants must be $\left|\left(N_{im} - d_{im}\right)\right| = 0$.

To solve the dispersion Equation (16), it is necessary to select a coordinate system. We select the below coordinate system:

$$k = k_i, \quad k_2 = k_3 = 0 \quad \frac{\partial T}{\partial x_1} \neq 0, \quad \frac{\partial T}{\partial x_2} \neq 0, \quad \frac{\partial T}{\partial x_3} = 0 \quad (17)$$

Using (17) we receive the following dispersion equation

$$\left|\left(N_{im}-\partial_{im}\right)\right|=\left(N_{11}-1\right)\left(N_{22}-1\right)\left(N_{33}-1\right)+ +N_{21}N_{13}N_{32}+N_{12}N_{23}N_{31}-N_{13}N_{31}\left(N_{22}-1\right)- -N_{32}N_{23}\left(N_{11}-1\right)-N_{21}N_{12}\left(N_{33}-1\right)=0 \quad (18)$$

where,

$$N_{11}=\frac{i\omega}{4\pi}\eta_{11}\ ,\ N_{12}=\frac{i(\omega^2-c^2k^2)\eta_{12}}{4\pi\omega}+\frac{-\omega_{11}+\omega_{12}}{\omega}$$

$$N_{13}=\frac{i(\omega^2-c^2k^2)\eta_{13}}{4\pi\omega}+\frac{\omega_{13}}{\omega}\ ,\ N_{21}=\frac{i\omega\eta_{21}}{4\pi}$$

$$N_{22}=\frac{i(\omega^2-c^2k^2)\eta_{22}}{4\pi\omega}+\frac{\omega_{22}-\omega_{21}}{\omega}$$

$$N_{23}=\frac{i(\omega^2-c^2k^2)\eta_{23}}{4\pi\omega}+\frac{\omega_{23}}{\omega}$$

$$N_{31}=\frac{i\omega\eta_{31}}{4\pi}\ ,\ N_{32}=\frac{i(\omega^2-c^2k^2)\eta_{32}}{4\pi\omega} \quad (19)$$

$$N_{33}=\frac{i(\omega^2-c^2k^2)\eta_{33}}{4\pi\omega}+\frac{\omega_{33}}{\omega}$$

$$\omega_{11}=-ck\Lambda'_{11}\nabla_2T\ ,\ \omega_{12}=-ck\Lambda'_{12}\nabla_1T\ ,\ \omega_{13}=-ck\Lambda'_{13}\nabla_1T$$

$$\omega_{21}=-ck\Lambda'_{21}\nabla_2T\ ,\ \omega_{22}=-ck\Lambda'_{22}\nabla_1T\ ,\ \omega_{23}=-ck\Lambda'_{23}\nabla_1T$$

$$\omega_{33}=-ck\Lambda'_{33}\nabla_1T$$

Substituting (19) to (18), we receive the below dispersion equation

$$\varphi_1\omega^6+\varphi_2\omega^5+\varphi_3\omega^4+\varphi_4\omega^3+\varphi_5\omega^2+\varphi_6\omega+\varphi_0=0 \quad (20)$$
$$\varphi_i,(i=0,1,2,3,4,5,6)$$

Dispersion Equation (20) can be solved by values φ_i depending on parameters (19).

It is clear that such solution is mathematically impossible. Therefore, we will solve the Equation (20) by the following physical method. It is clear that values of tensor N_{ik} will determine analytical expressions of frequencies obtained from solution of this equation. Tensor N_{ik} depends on the tensors η_{ik} and Λ'_{ik}.

Tensors η_{ik} and Λ'_{ik} are values of anisotropic conducting medium in different directions. Infinite tensors N_{ik} have a specific numeric value at certain values of η_{ik} and Λ'_{ik}. Such values of the tensor N_{ik} are non-zero and different. We seek solution of Equation (18) at below values of N_{ik},

$$N_1=N_{23}=N_{33}=1$$
$$\omega_{13}=\omega_{23}=\omega_{33} \quad (21)$$

In N_{33} =1, considering $\omega=\omega_0+ij$,

$$\frac{\omega_0\eta_{33}}{2\pi}\gamma=\omega_{33}-\omega_0$$
$$\frac{(\omega_0^2-\gamma^2-c^2k^2)\eta_{33}}{4\pi}=\gamma \quad (22)$$

From (22), we receive

$$\gamma=\frac{2\pi\omega_{33}}{\omega_0\eta_{33}}-\frac{2\pi}{\eta_{33}} \quad (23)$$

$$\omega_0^4\eta_{33}^2+(4\pi^2-c^2k^2\eta_{33}^2)\omega_0^2-4\pi^2\omega_{33}^2=0 \quad (24)$$

By entering real part of the frequency ω_0 obtained from Equations (24) into (23), we receive condition of instability of waves with a frequency ω_0 as such

$$\omega_{33}>\omega_0 \quad (25)$$

As can be seen from Equation (24), the values of infinite parameter $ck\eta_{33}$ dramatically changes the frequency ω_0. Denoting $ck\eta_{33}=r$, we consider the below conditions:

(1) $r<2\pi$ (26)

$$\omega_0=\left(\frac{2\pi\omega_{33}}{\eta_{33}}\right)^{1/2}\left[\frac{1}{\omega_{33}\eta_{33}}\left(1-\frac{2}{\pi^{3/2}}\right)+1\right]^{1/2} \quad (27)$$

$$\gamma=\frac{2\pi}{\eta_{33}}\left(\frac{1}{2^{3/4}}-1\right) \quad (28)$$

It can be seen from (28) that wave with frequency (27) is a damped wave. It means that when $r<2\pi$ instability do not exist. Substituting (29) to (24)

(2) $r=2\pi$ (29)

$$\omega_0=\left(\frac{2\pi\omega_{33}}{\eta_{33}}\right)^{1/2} \quad (30)$$

$$\gamma=\left(ck\omega_{33}\right)^{1/2}\left[1-\left(\frac{ck}{\omega_{33}}\right)^{1/2}\right] \quad (31)$$

From (31) it can be seen that when $\omega_{33}>ck$ then $\gamma>0$ and the wave with frequency ω_0 is instable.

(3) $r>2\pi$

$$\omega_0=\left[\left(\frac{2\pi\omega_{33}}{\eta_{33}}\right)^2+\frac{c^2k^2}{2}\right]^{1/2} \quad (32)$$

$$\gamma=\left(\frac{2\pi\omega_{33}}{\eta_{33}}\right)^{1/2}-\frac{2\pi}{\eta_{33}} \quad (33)$$

From (33) it can be seen that instability is created when $\omega_{33}\eta_{33}>2\pi$. Instability of waves generated under conditions 1, 2, 3 in conducting medium depends on inverse value of conductivity tensor η_{ik} and the Hernst-Ettingauzen coefficient Λ'_{ik}.

Under conditions $r<2\pi$, $r=2\pi$, $r>2\pi$ the values of conductivity in different directions if condition (21) is satisfied will be defined from the equation of dispersion (18). From (21) and (18) we receive:

$$N_{21}+N_{22}=N_{11}+N_{22} \quad (34)$$

If we input expression of tensor N_{ik} from (19) to (34), we receive below connections between values of conductivity tensor at different directions:

$$\eta_{21}+\eta_{12}=\eta_{11}+\eta_{22}$$
$$\Lambda'_{11}\Lambda'_{22}=\Lambda'_{21}\Lambda'_{12} \quad (35)$$

$$\omega_0^2=\frac{c^2k^2}{2}+\gamma^2 \quad (36)$$

If we put ω_0 and γ in (36), under $r<2\pi$, $r=2\pi$, $r>2\pi$ analytical expression of η_{33} is as following:

$$\eta_{33}(r<2\pi)=\frac{2\pi\omega_{33}}{c^2k^2}\left[1\pm\sqrt{1-\left(\frac{ck}{\omega_{33}}\right)^2}\right]$$

$$\eta_{33}(r=2\pi)=\frac{2\pi}{ck} \quad (37)$$

$$\eta_{33}(r>2\pi)\approx\frac{2^{3/4}\pi}{ck}$$

$$\omega_{33}\eta_{33}=\frac{1}{2}$$

where, r_s is the stator resistance, L_{1s} and $\bar{L}_m$ are the leakage and magnetizing inductances $L_{ss}=L_{1s}+\frac{3}{2}\bar{L}_m$ and ψ_m is the amplitude of the flux linkages established by the permanent magnet.

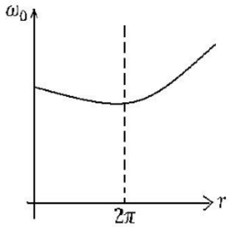

Figure 1. The variation of frequency ω_0

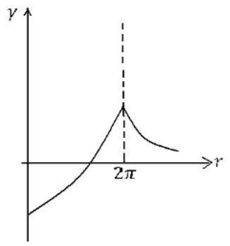

Figure 2. The variation of increments γ

As can be seen from the graphs of frequency ω_0 and increments γ, although the frequency of the generated wave is at its highest at values of infinite parameter r less than 2π, the wave is a damping one.

This means that the waves created in one local point of the crystal is rapidly damped and the charge distribution inside the crystal is homogeneous. At intervals $r=2\pi,\ \ r>2\pi$ the waves are instable and the charge distribution is non-homogeneous.

III. CONCLUSIONS

In anisotropic conducting mediums in absence of external magnetic field alternating magnetic field occurs due to thermal gradient. The waves in medium with alternating magnetic field and electric filed generated due to thermal gradient are of electromagnetic and thermomagnetic character. The wave vectors of such waves are either parallel to thermal gradient $\vec{K}\,//\,\vec{\nabla}T$ or perpendicular to thermal gradient $\vec{K}\perp\vec{\nabla}T$. However the wave vector always lies in plane of $\vec{\nabla}T$ and magnetic field.

Depending on electrical conductivity in plane of anisotropic medium, the expression of wave frequency which depends on values of $r_{ik}=ck\eta_{ik}$ (where ck is acceleration, η is inverse value of conductivity) show that intervals of increase and decrease (instability) of waves exist.

Graphical analysis of wave frequencies and increments at different values of parameter $r_{ik}=ck\eta_{ik}$ is provided. The waves generated at specific r_{ik} are thermomagnetic. Solution of the dispersion Equation (18) under conditions (21) is provided. However if the conditions (18) are changed then analytical expression of the wave frequency and grows that have been received from equation (20) will also change.

These changes can occur only at tensor η_{ik}, i.e. at electrical conductivity σ_{ik} of the infinite tensor r_{ik}. This may be balanced by rotating the anisotropic crystal thermos-recombination waves extrinsic semiconductors with two types of charge carries.

In various experimental conditions, these impurity centers are more or less active, so the recombination and generation proceed generally via a certain number of impurity centers. For example, in experiment [6] (we will use its results), singly and doubly negatively charged Au centers in Ge were active centers.

In the presence of an electric field, electrons and holes gain energy on the order of $eE_0\ell_{\pm}$ (where e is the positive elementary charge) due to the electric field. Therefore, in the presence of the electric field, electrons can overcome the Coulomb barrier of the singly charged center and be captured. Electrons can also be generated owing to thermal transitions from impurity centers to the conduction band.

The number of holes increases due to the capture of electrons from the valence band by impurity centers, and decreases due to the capture of electrons from impurity centers by holes. The probability of charge carrier generation and the probability of charge carrier recombination are different, and it leads to the change in concentrations of electrons and holes in semiconductors.

A detailed description of kinetic equations for electrons and holes in above-mentioned semiconductor were given in paper [7]. These equations are of the following form:

$$\frac{\partial n_-}{\partial t}+\mathrm{div}\vec{j}_-=\gamma_-(0)n_{1-}N_-$$
$$-\gamma_-(E)n_-N=\left(\frac{\partial n_-}{\partial t}\right)_{rec} \quad (38)$$

$$N_0=N_-+N_+=\text{const}$$
$$n_{1-}=\frac{n_-^0N_0}{N_-^0} \quad (39)$$

where, N_0 is a total concentration of the singly negatively charged centers N and the doubly negatively charged centers N_-, and n_{1-} is a characteristic concentration found on condition that

$$E_0 = 0\,,\ \left(\frac{\partial n_-}{\partial t}\right)_{rec} = 0 \tag{40}$$

$$\frac{\partial n_+}{\partial t} + \mathrm{div}\vec{j}_+ = \gamma + (E) n_{1+} N_-$$

$$-\gamma_+(0) n_+ N_- = \left(\frac{\partial n_+}{\partial t}\right) \tag{41}$$

$$n_{1+} = \frac{n_+^0 N_-^0}{N_0}_{rec}$$

In Equations (38)-(41), $\gamma_-(0)$ is the coefficient of electron emission by the doubly negatively charged centers in the absence of electric field, $\gamma_-(E)$ is the coefficient of electron capture by the singly negatively charged centers, and $\gamma_+(0)$ is the coefficient of hole capture by the doubly negatively charged centers.

The variation in the doubly negatively charged traps with time determines the variation in the singly negatively charged centers. Therefore, the equation determining the variation in charged centers with time is of the form:

$$\frac{\partial N_-}{\partial t} = \left(\frac{\partial n_+}{\partial t}\right)_{rec} - \left(\frac{\partial n_-}{\partial t}\right)_{rec} \tag{42}$$

In order to obtain the $\omega(k)$ dispersion relation, the set of Equations (38)-(42) must be solved simultaneously, taking into account the Maxwell equation

$$\frac{\partial \vec{H}}{\partial t} = -c.\mathrm{rot}\vec{E} \tag{43}$$

where c is the velocity of light.

For this purpose, we linearize the Equations (5)-(10) in the following way:

$$\vec{E} = \vec{E}_0 + \vec{E}\,;\ n_\pm = n_\pm^0 + n'_\pm\,;\ \vec{\nabla}T = \mathrm{const}$$

$$\left(\vec{E}', n'_\pm\right) \sim e^{i(\vec{k}\vec{r} - \omega t)} \tag{44}$$

$$\vec{E}' << \vec{E}_0\,;\ \ n'_\pm << n_\pm^0$$

where, $\vec{k}_-$ is a wave vector, and ω is the wave frequency.

REFERENCES

[1] L.E. Gurevich, "Thermomagnetic Waves and Excitation of the Magnetic Field in Non-Equilibrium Plasmas", JETP, Vol. 44, pp. 548-555, 1963.

[2] L.E. Gurevich, V.I. Vladimirov, "Kinetic Properties of Discharged Plasma with Large Radiation Pressure and Effects of Combine Motion of Electrons and Photons", JETP, Vol. 44, pp. 166-176, 1963.

[3] E.R. Hasanov, M.F. Novruzov, A.Z. Panahov, A.I. Demirel, "Instability of Thermomagnetic Waves in the GeAu Semiconductors with Impurities", International Journal of Pure and Applied Physics, ISSN 0973-1776, Vol. 4, No. 1, pp. 23-28, 2008.

[4] E.R. Hasanov, H. Rasoul Nezhad, A.Z. Panahov, A. Ihsan Demirel, "Impurity Semiconductor as an Energy Radiator in Presence of Constant External Electric Field", Applied Physics, ISSN 0973-176, Vol. 5, No. 3, pp. 239-242, 2009.

[5] E.R. Hasanov, H. Rasoul Nezhad, A.Z. Panahov, A. Ihsan Demirel, "Accruing Recombination Waves in Semiconductors with Deep Traps", International Journal of Pure and Applied Physics, ISSN 0973-1776, Vol. 7, No. 1, pp. 89-95, 2011.

[6] E.R. Hasanov, M.F. Novruzov, A.Z. Danahov, A.I. Demirel, "Energy Generation and Amplitude of Thermomagnetic Waves in the Conducting Medium", Modern Phys. Lett., B, Vol. 22, No. 6, pp. 455-457, 2008.

[7] E.R. Hasanov, R.R. Huseynov, M.F. Novruzov, "Energy Generation and Amplitude of Thermomagnetic Waves in the Conducting Medium", 3rd International Conference on Technical and Physical Problems in Power Engineering (ICTPE-2006), Ankara, Turkey, pp. 653-654, 29-31 may 2006.

[8] E.R. Hasanov, M.F. Novruzov, "The Current Oscillations in the Conducting Medium in Presence of Thermomagnetic Waves", International Conference of Physics, Baku, Azerbaijan, pp. 235-236, June 2005.

[9] L.E. Gurevichand, B.L. Gel'mont, "Hydro-Thermo-Magnetic Waves in a Weakly Inhomogeneous Plasma", Soviet Physics JETP, Vol. 20, No. 5, pp. 604-614, 1965 [J. Exptl. Theoret. Phys. (USSR), Vol. 46, pp. 884-901, 1964].

[10] L.E. Gurevich, E.R. Gasanov, "Theory of Spontaneous Oscillations of Current in Crystals with Deep Traps", Fiz. Tverd. Tela, Vol. 11, p. 1433, 1962.

BIOGRAPHIES

Eldar Rasul Hasanov was born in Azerbaijan, 1939. He graduated from Azerbaijan State University, Baku, Azerbaijan. Currently, he is working in Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan. He is the Head of Laboratory.

Aygul V. Islamzade was born in Azerbaijan on January 21, 1991. She graduated from Baku State University, Baku, Azerbaijan, in 2014. From 2014 to the present she has been working as a Researcher at Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan.

Hasan Shirin Hasanov was born in Tovuz, Azerbaijan in 1938. He received the M.Sc. degree from Faculty of Physics, Baku State University, Baku, Azerbaijan in 1961. Currently, he is Doctor of Physical Science and working in the Institute of Physical Problems, Baku State University, Baku, Azerbaijan.