THE EXCITATION OF UNSTABLE WAVES OF THERMOELECTROMAGNETIC CHARACTER IN CONDUCTIVE MEDIUMS OF ELECTRONIC TYPE OF CHARGE CARRIER

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From theoretic analysis of excited waves in the medium with one type of charge carrier it is obtained, that thermoelectromagnetic wave is the growing wave and medium becomes the energy radiation source. The frequency and increment of excited waves are expressed in terms of frequencies of electromagnetic and thermomagnetic waves.

Keywords: growing frequency, frequency, energy source, charge carriers, electric conduction tensor.
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INTRODUCTION

The excitation of thermomagnetic waves in isotropic plasma is the theoretically analyzed in work [1]. In this work it is shown that thermomagnetic wave with frequency dependent on constant temperature gradient ($\nabla T = const$) appears at hydrodynamic motions of charge carriers in plasma without external magnetic field. Later, in works [2 – 3] confirmed that excited thermomagnetic wave in solid substance does not interact with sound waves (i.e. lattice small oscillations). Some excitation conditions of thermomagnetic waves in semiconductors investigated in work [4]. In this work, it is shown that the presence of recombination's and generations in semiconductors significantly changes the excitation conditions of thermomagnetic waves in impurity semiconductors with two types of charge carriers. However, some excitation conditions of thermomagnetic waves in anisotropic conductive mediums investigated in work [5]. The expressions for electric conduction tensor dependent on thermomagnetic wave frequency obtained in this work. In this theoretical work, we will investigate some excitation conditions of thermomagnetic waves in conductive medium of electron type of charge carriers. The term "thermomagnetic wave" is firstly introduced.

THE MAIN TASK EQUATIONS

At the presence of temperature gradient, $\nabla T = const$ the concentration gradient ∇n of charge carriers appears and their hydrodynamic motion with $v(\vec{r},t)$ velocity takes place. The variable magnetic field H' in medium appears under influence of external electric field. As a result, the current density in medium has the form:

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

Here E^* is electric field in the medium.

$$\vec{E}^* = \vec{E} + \frac{\left[\vec{\upsilon}^* H' \right]}{c} + \frac{T}{e} \frac{\vec{\nabla} n}{n}; e > 0 \quad (2)$$

E is external electric field, $\frac{\left[\vec{\upsilon}^* H' \right]}{c}$ is electric field appearing at hydrodynamic motions of charge carriers, $\frac{T}{e} \frac{\vec{\nabla} n}{n}$ is electric field appearing at the presence of charge carrier concentration. The diffusion members, which at $T << eE_0 l$ (l is mean free path of charge carriers) are less than σE are not considered in expressions (1-2). From (1-2) we obtain the total electric field in the medium with the help of Maxwell equation $rot\vec{H} = \frac{4\pi}{c} \vec{j}$ by following way. Substituting (2) in (1), we obtain the equation for electric field of following form:

$$\vec{X} = \vec{A} + \left[\vec{B}, \vec{X} \right] \quad (3)$$

From (3) we easily obtain:

$$\vec{X} = \vec{A} + \left[\vec{B} \vec{A} \right] + (\vec{A} \vec{B}) \vec{B} \quad (4)$$

or

$$\vec{E} = -\frac{\left[\vec{v} \vec{H}' \right]}{c} - \Lambda' \left[\nabla T \vec{H}' \right] + \frac{c}{4\pi\sigma} rot\vec{H} - \frac{c\sigma'}{4\pi\sigma^2} \left[rot\vec{H}', \vec{H}' \right] + \frac{T}{e} \frac{\nabla \rho}{\rho} + \Lambda \nabla T \quad (5)$$

Here $\Lambda = \frac{\alpha}{\sigma}$, $\Lambda' = \frac{\alpha'\sigma - \alpha\sigma'}{\sigma}$, σ is electric conduction, Λ is differential thermal e.m.f., Λ' is Nernst-Ettingshausen effect coefficient. In anisotropic conductive mediums, the total electric field has the following form:

$$\vec{E} = \varsigma \vec{j} + \varsigma' \left[\vec{j} \vec{H} \right] + \varsigma'' \left(\vec{j} \vec{H} \right) H + \Lambda \nabla T + \Lambda' \left[\nabla T H \right] + \Lambda'' \left(\left[\nabla T H \right] \right) H \quad (6)$$

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or

$$\vec E = \vec E_1 + \vec E_2 + \vec E_3 + \vec E_4 + \vec E_5 + \vec E_6 \qquad (7)$$

In (7) $\vec E_1$ is electric field towards current direction, $\vec E_2$ is electric field perpendicular to current direction, $\vec E_3$ is electric field directed towards $\vec H$, $\vec E_4$ is electric field directed towards ∇T, $\vec E_5$ is electric field perpendicular to ∇T and $\vec H'$, $\vec E_6$ is electric field directed towards ∇T and $\vec H'$.

In anisotropic mediums, expression (6) has the form:

$$E_i = \varsigma_{im} j'_m + \varsigma'_{im}\left[jH\right]_m + \varsigma''_{im}\left[jH\right]H_m + \Lambda_{im}\nabla_m T + \Lambda'_{im}\left[\nabla TH\right]_m + \Lambda''_{im}\left[\nabla TH\right]H_m \qquad (8)$$

We consider the excitation of thermoelectromagnetic waves in anisotropic mediums without external magnetic field (i.e. $H_0 = 0$) and that is why the main equations of our task with taking under consideration the displacement current, have the following form:

$$E'_i = \varsigma_{im} j'_m + \Lambda'_{im}\left[\nabla TH'\right]_m$$
$$rot\vec H' = \frac{4\pi}{c}\vec j' + \frac{1}{c}\frac{\partial \vec E'}{\partial t} \qquad (9)$$
$$rot\vec E' = -\frac{1}{c}\frac{\partial \vec H'}{\partial t}$$

Suppose that all variable values in (9) change by fluctuation way (i.e. $E' << E_0, \vec j' << \vec j_0$) and have the character of monochromatic waves.

$$(E', H') \sim e^{i(\vec k\vec r - wt)} \qquad (10)$$

k is wave vector, w is oscillation frequency. Thus, we easily obtain from (9):

$$E'_i = \varsigma_{im} j'_m + \Lambda'_{im}\left[\nabla TH\right]_m$$
$$j'_m = \frac{ic^2}{4\pi w}\left[\vec k\left[\vec k\vec E'\right]\right]_m + \frac{iw}{4\pi}E'_m \qquad (11)$$

THEORETICAL CALCULATIONS

For obtaining of dispersion equation from (11), we chose the following coordination system:

$$k_1 \neq 0, k_2 = 0, k_3 = 0 \qquad (12)$$
$$\nabla_1 T \neq 0, \nabla_2 T \neq 0, \nabla_3 T = 0$$

Taking under consideration (12) and (11) we easily obtain:

$$E'_i\left[\frac{ic^2}{4\pi w}\varsigma_{ie}k_e k_m + i\frac{w^2 - c^2k^2}{4\pi w}\varsigma_{im} + \frac{c\Lambda'_{ie}}{w}k_e\nabla_m T - \frac{c\Lambda'_{im}}{w}\vec k\vec\nabla T\right] = \delta_{im}E_{im} \qquad (13)$$

Substituting

$$E'_m = \delta_{im}E'_i \qquad (14)$$

We obtain from (13):

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

where $\delta_{im} = 1$ at $i = m$, $\delta_{im} = 0$ at $i \neq m$.

Determinant from (15) should be equal to zero, i.e.

$$\left|\psi_{im} - \delta_{im}\right| = 0 \qquad (16)$$

From (16) we obtain:

$$(\psi_{11} - 1)(\psi_{22} - 1)(\psi_{33} - 1) + \psi_{12}\psi_{31}\psi_{23} + \psi_{21}\psi_{32}\psi_{13} - \psi_{31}\psi_{13}(\psi_{22} - 1) - \psi_{32}\psi_{23}(\psi_{11} - 1) - \psi_{21}\psi_{12}(\psi_{33} - 1) = 0 \qquad (17)$$

Here

$$\psi_{11} = \frac{iw}{4\pi}\varsigma_{11}, \psi_{12} = i\frac{w^2 - c^2k^2}{4\pi w}\varsigma_{12} + \frac{w_{11} - w_{12}}{w}, \psi_{13} = i\frac{w^2 - c^2k^2}{4\pi w}\varsigma_{13} - \frac{w_{13}}{w}$$
$$\psi_{21} = \frac{iw}{4\pi}\varsigma_{21}, \psi_{22} = i\frac{w^2 - c^2k^2}{4\pi w}\varsigma_{22} + \frac{w_{21} - w_{22}}{w}, \psi_{23} = i\frac{w^2 - c^2k^2}{4\pi w}\varsigma_{23} + \frac{w_{23}}{w}$$
$$\psi_{31} = \frac{iw}{4\pi}\varsigma_{31}, \psi_{32} = i\frac{w^2 - c^2k^2}{4\pi w}\varsigma_{32} + \frac{w_{31} - w_{32}}{w}, \psi_{33} = i\frac{w^2 - c^2k^2}{4\pi w}\varsigma_{33-}\frac{w_{33}}{w}$$
$$w_{11} = ck\Lambda'_{11}\nabla_1 T, w_{12} = ck\Lambda'_{12}\nabla_2 T, w_{13} = ck\Lambda'_{13}\nabla_1 T$$
$$w_{21} = ck\Lambda'_{21}\nabla_2 T, w_{22} = ck\Lambda'_{22}\nabla_1 T, w_{23} = ck\Lambda'_{23}\nabla_1 T$$
$$w_{31} = ck\Lambda'_{31}\nabla_1 T, w_{32} = ck\Lambda'_{32}\nabla_1 T, w_{33} = ck\Lambda'_{33}\nabla_1 T$$

The solution of dispersion equation (17) is impossible because of its high degree and that's why we use the numerical value of ψ_{ik} tensor which depends on medium properties:

$$1)\,\psi_{11}=\psi_{21}=\psi_{31},\ 2)\,\psi_{12}=\psi_{22}=\psi_{32},\ 3)\ \psi_{13}=\psi_{23}=\psi_{33} \qquad (18)$$

Taking under consideration (18) in (17) we easily obtain:

$$\psi_{11}+\psi_{22}+\psi_{33}-1=0 \qquad (19)$$

Substituting tensor values in (19) we obtain:

$$\omega^2+i\frac{4\pi}{\varsigma}\omega-c^2k^2(1-\frac{\varsigma_{11}}{\varsigma})+4\pi i\frac{w_{21}-w_{33}-w_{22}}{\varsigma}=0 \qquad (20)$$

where ω is thermoelectromagnetic wave frequency. From (20) it is seen that if $w_{21}=w_{33}+w_{22}$ then the excited wave has the pure electromagnetic character. Thermoelectromagnetic wave excites under $w_{21}>w_{33}+w_{22}$ conditions or $w_{21}<w_{33}+w_{22}$ conditions.

Under conditions, $w_{21}>w_{33}+w_{22}$ we obtain from (20):

$$\omega_1=-ick+(ckw_{21})^{1/2}+i(ckw_{21})^{1/2}$$
$$\omega_2=-ick-(ckw_{21})^{1/2}-i(ckw_{21})^{1/2} \qquad (21)$$

From (21) it is seen that wave with ω_2 frequency is damping one. The wave with ω_1 frequency can grow at:

$$w_{21}>ck\text{; i.e. at } \Lambda'_{21}\nabla_2 T>1 \qquad (22)$$

Under conditions $w_{21}<w_{33}+w_{22}$ at $(\Lambda'_{22}+\Lambda'_{33})\nabla_1 T>1$ thermoelectromagnetic wave with frequency $\omega_0=\left[ck\left(w_{22}+w_{33}\right)\right]^{1/2}$ and increment $\gamma=\left[ck\left(w_{22}+w_{33}\right)\right]^{1/2}-ck$ is growing one. Under conditions frequency $w_{21}>w_{33}+w_{22}$ and increment of thermoelectromagnetic wave are: $\omega_0=\left(ckw_{21}\right)^{1/2}$, $\gamma=\left(ckw_{21}\right)^{1/2}-ck$. Thus, excited thermoelectromagnetic wave under the considered conditions always has frequency, which is bigger than increment.

DISCUSSION OF OBTAINED RESULTS

The thermoelectromagnetic waves in different directions respective of the electric field direction excite in anisotropic mediums with one type of charge carriers. The frequencies of these waves are different ones in dependence on electric conduction values. The conditions of wave growth of these waves are clear and correspond to experiment. The different thermoelectromagnetic waves with different frequencies are excited. These frequencies depend on temperature gradient values. The increment of growth of these waves is less than their frequency. This theory constructed without external magnetic field. Probably, at the presence of external magnetic field the appearance conditions of these waves essentially change. The frequency numerical values of these waves are approximately by order 10^{10} -10^{11} Hz. In this frequency interval, the phenomena take place with high frequency and can serve as energy sources.

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