International Journal of Pure and Applied Physics
ISSN 0973-1776 Volume 4 Number 1 (2008) pp. 23–28

http://www.ripublication.com/ijpap.htm

Instability of Thermomagnetic Waves in the GeAu Semiconductors with impurities

E.R. Hasanov[1], M.F., Novruzov[1] A.Z Panahov[2] and A.I. Demirel[2]

*[1]Baku State University, 23 Z. Khalilov str., Az 1148, Baku city-
Physical Institute of the Azerbaijan National Academy of Sciences,
33 H. Javid ave., Az 1143, Baku city
[2]Yüzüncü Yil University, Faculty of Sciences and Arts 65080 Van-Turkey*

Abstract

The thermomagnetic waves theory in the semiconductors with impurities is constructed. It is shown that the thermomagnetic waves' frequency depends on a frequency of the current carriers recombination and in the concrete conditions the recombination wave suppresses the thermomagnetic waves.

Introduction

Thermomagnetic effects, like galvanomagnetic ones, are known to characterize the scattering mechanisms and value of mobility of charge carriers [1]. There have been several observations about the electromotive force generation in semiconductors illuminated with various radiation sources in a static magnetic field. When a semiconductor placed in a magnetic field $\boldsymbol{B}$ is irradiated with the radiation having the energy larger than the bandgap and the wave vector $\boldsymbol{k}$ the DC voltage can be generated in the direction of $\boldsymbol{B}\times\boldsymbol{k}$. This is understood as a kind of Hall effect associated with bipolar current due to diffusion of optically injected electron-hole pairs near the illuminated surface. This is known as the photoelectromagnetic (PEM) effect and has been extensively studied to investigate the recombination process of electron-hole pairs in bulk or at interfaces. If we employ the microwave or the far-infrared radiation as the illuminated source instead of the bandgap light, the absorption occurs resonantly at a special magnetic field. In such resonant absorption, electron–hole pairs could not be created. Nevertheless, the electromotive force is observed and a variety of interpretations have been proposed.. Here we refer to this effect as the resonant-photoelectromagnetic (R-PEM) effect [2].

One main interpretation to R-PEM effect is due to optically induced Nernst-Ettingshausen effect, that the heat generated by the resonant absorption brings forth thermal gradient inside the sample in the incidence direction of the radiation in *x*-

direction, and transverse electromotive force is induced in the *y*-direction through thermomagnetic process. A drag effect on electrons by the nonequilibrium phonon plays a dominant role in generation of the transverse voltage. The effect has been reported in bulk n-InSb and obtained the conclusion to support the thermomagnetic interpretation [3].

Thermomagnetic Vaves in the GeAu Semiconductors with Impurities

The works [4-6] include the theory of instability of the thermomagnetic waves in solids. Frequencies and amplitudes of the thermomagnetic waves are calculated as functions of external electric and magnetic fields via the mathematic method of Bogolyubov-Mitropolsky [7]. In this theoretical work we will interpret the theory of spreading of the thermomagnetic waves in the Ge type semiconductors doped by gold atoms.

If the temperature gradient $\overrightarrow{\nabla T}$ in the semiconductor does not depend on the coordinates and time in case of existence of constant electric and magnetic fields without consideration of the hydrodynamic motion the electric current density has the following form:

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

Where

$$\vec{E}^* = \vec{E} + \frac{T}{e}\frac{\nabla n}{n} \tag{2}$$

(e>0), n – is concentration of charge carriers. Determination of $\vec{E}$ from the vector equation

(1) comes to solution of the vector equation

$$\vec{x} = \vec{a} + \left[\vec{в}, \vec{x}\right] \tag{3}$$

for the unknown vectors $\vec{x}, (\vec{в}\vec{x}) = (\vec{в}\vec{a})$ because $\left[\vec{в}\left[\vec{в}\vec{x}\right]\ \right] = 0$. Putting $\vec{a} + \left[\vec{в}\vec{x}\right]$ instead of $\left[\vec{x}\vec{в}\right]$ at the right side of we obtain (3)

$$\vec{x} = \vec{a} + \left[\vec{в}\vec{a}\right] + \left[\vec{в}\left[\vec{в}\vec{x}\right]\ \right]; \qquad \vec{x} = \frac{\vec{a} + \left[\vec{в}\vec{a}\right] + \left[\vec{a}\vec{в}\right]\vec{в}}{1 + в^2}$$

Using the Maxwell's equations $rot\vec{H} = \frac{4\pi}{c}\vec{j}$ we'll obtain for electric field

$$\vec{E} = -\Lambda'\left[\overrightarrow{\nabla T}\vec{\mathrm{H}}\right] + \frac{c}{4\pi\sigma}rot\vec{H} - \frac{c\sigma'}{4\pi\sigma^2}\left[rot\vec{H}, \vec{H}\right] + \frac{\mathrm{T}}{\mathrm{E}}\frac{\nabla n}{n} + \Lambda\nabla\mathrm{T} \tag{4}$$

Here $\Lambda = \frac{\alpha}{\sigma};\ \Lambda' = \frac{\alpha'\sigma - \alpha\sigma'}{\sigma^2},\ \sigma -$ is the electrical conductivity coefficient,

Λ - is the differential thermoelectromotive and Λ' - is coefficient of the Nernst-Ettinshausen's effect. We'll review the electronic semiconductor neglecting its intrinsic conductivity (in particular, we neglect existence of free holes). Let's besides the alloy small donors (their concentration is N_α) have more negatively charged traps (in concentration N). Their trapping charge is equal to - Ze (e>0), and after trapping is -(Z+1)e. The recombination coefficient $\gamma(E)$ depends on the tensity of the electric field E, and increases upon increase of E. Probability of reverse outliers will be considered independrnt from the field. It's allowable (in non-degenerate semiconductor) at non-strong fields when the probability of autoionization of the impurity center may be neglected. The small donors might be considered as completely charged and their participation in the recombination process will be neglected. In case of germanium crystals such a treatment is justified. We'll sign via N_- the concentration of the recombination centers already trapping each upon electron. In condition of equilibration the recombination coefficient is signed via $\gamma(0)$ and

$$f(E)=\frac{\gamma(E)}{\gamma(0)}\geq 1$$.

In conditions of equilibration $n_1=\frac{n^{(0)}(N-N\_)^0}{N\_}$ (5)

Then the main equations describing distribution of the charge and the field in the semiconductor will have the form

$$\frac{\partial n}{\partial t}+div\vec{j}-\left(\frac{\partial n}{\partial t}\right)_{rek}=0; \qquad \left(\frac{\partial n}{\partial t}\right)_{rek}=\gamma(0)\{n_1 N\_-(N-N\_)n\, f(E)\}$$

$$\frac{\partial N\_}{\partial t}-\left(\frac{\partial N\_}{\partial t}\right)_{rek}=0; \qquad \vec{j}=-\mu n\vec{E}-D\nabla n \tag{6}$$

Hereby, μ, D *and* ξ are mobility, diffusion coefficient and dielectric constant of the environment.

In stationary conditions

$$N\_=\frac{Nnf(E)}{n_1+nf(E)} \tag{7}$$

In crystal Ge with alloy gold Au the concentration of traps is determined from expression of [8] $N_d-2N=n+N\_$ (8)

Using the Maxwell's equations $\frac{\partial\vec{H}}{\partial t}=-c\, rot\vec{E}$ and linearizing the equations system

(6) together with (4) we'll get for variable electric field the following vector equation

$$\vec{E}'=i\frac{\Lambda_0' c}{\omega}\left[\vec{k}\left(\overrightarrow{\nabla T}\vec{E}'\right)-\vec{E}'\left(\overrightarrow{\nabla T}\vec{k}\right)\ \right]-\Lambda_0'\beta\left[\overrightarrow{\nabla T}\mathrm{H}_0\right]\frac{\vec{E}_0\vec{E}'}{E_0{}^2}-$$

$$-i\frac{c^2}{4\pi\sigma\omega}\left[\vec{k}\left(\vec{k}\vec{E}'-k^2\vec{E}'\right)\right]+\frac{\mathrm{T}}{en_0}\overrightarrow{\nabla n}+\Lambda_0\overrightarrow{\nabla T}\varphi\frac{\vec{E}_0\vec{E}'}{E_0{}^2} \tag{9}$$

$\Lambda_0' = 2\frac{E_0^2}{\Lambda_0}\frac{d\Lambda'}{d\left(E_0^2\right)}$; $\varphi = \frac{2E_0^{\ 2}}{\Lambda_0}\frac{d\Lambda}{d\left(E_0^{\ 2}\right)}$, $\vec{k} -$ is wave vector, $\omega -$ is wave frequency.

Signing the recombination frequencies $\nu(E_0) = (N - N_-)^0 \gamma(E_0)$ and discharging frequencies $\nu(0) = n_1\gamma(0)$ we'll determine $n', N -$ from (6) and obtain

$$N'_- = An' + An_0\frac{\vec{E}_0\vec{E}'}{E_0^{\ 2}}; \qquad A = \frac{\nu(E_0)}{\nu(0) - i\omega}$$

$$n' = \psi n_0 + 2\frac{\vec{E}_0\vec{E}'}{E_0^{\ 2}} + i\frac{n_0 k u_0}{R} \times \frac{2\left(\vec{E}_0\vec{E}'\right)}{E_0^{\ 2}}; \quad R = -i\omega - i\left(\vec{k}\vec{H}\right) - k^2 D + \nu(E_0) - \nu(0)A$$

$$\psi = \frac{\nu(0)A - \nu(E_0)}{R} \tag{10}$$

Putting (10) in (9) we'll obtain the vector equation for $\vec{E}'$ of the following type:

$$\vec{E}' = i\frac{\Lambda_0^{/} c}{\omega}\left[\vec{k}\left(\overrightarrow{\nabla T}\vec{E}'\right) - \vec{E}'\left(\overrightarrow{\nabla T}\vec{k}\right)\right] - \Lambda_0'\beta\left[\overrightarrow{\nabla T}\mathrm{H}_0\right]\frac{\vec{E}_0\vec{E}'}{E_0^{\ 2}} - i\frac{c^2}{4\pi\sigma\omega}\left[\vec{k}\left(\vec{k}\vec{E}'\right) - k^2\vec{E}'\right] +$$

$$+ \Lambda_0\overrightarrow{\nabla T}\varphi\frac{\vec{E}_0\vec{E}'}{E_0^{\ 2}} + \frac{\mathrm{T}}{e}\vec{\nabla}\left[\psi\frac{\vec{E}_0\vec{E}'}{E_0^{\ 2}} + i\frac{\vec{k}\vec{u}_0}{R}\frac{\vec{E}_0\vec{E}'}{E_0^{\ 2}}\right] \tag{11}$$

$\vec{u}_0 = \mu\vec{E}_0$ - is charge-drift velocity.

In order to solve the vector equation (11) we'll choose the coordinate system

$$\vec{E}_0 = \vec{i}E_{0x},\ \vec{\mathrm{H}}_0 = \vec{k}\mathrm{H}_{0z},\ \overrightarrow{\nabla T} = \vec{j}\nabla_y \mathrm{T} \tag{12}$$

$\vec{i}, \vec{j}, \vec{k} -$ are unit vectors on coordinate axes. With consideration of (12) from (11) we'll gain the following three equations for projections of electric field upon axes E_x', E_y', E_z'

$$\left[1 - i\frac{\omega(y)}{\omega} - i\frac{\omega_y^{\ 2} + \omega_z^{\ 2}}{4\pi\sigma\omega} - i\frac{\mathrm{T}k_x}{lE_0}\left(\psi + i\frac{k_x u_0}{R}\right)\right]E_x' +$$

$$+\left[\frac{\omega_x\omega_y}{4\pi\sigma\omega} + \frac{\omega(x)}{\omega}\right]E_y' + i\frac{\omega_x\omega_z}{4\pi\sigma\omega}E_z' = 0 \qquad \mathrm{I}$$

$$\left[i\frac{\omega_x^{\ 2}}{4\pi\sigma\omega} - \frac{E_T}{E_0}\varphi\right]E_x' + \left[1 + i\frac{2\omega_y^{\ 2}}{4\pi\sigma\omega} + i\frac{\omega_x^2 + \omega_z^2}{4\pi\sigma\omega}\right]E_y' +$$

$$+ i\frac{\omega_y\omega_z}{4\pi\sigma\omega}E_z' = 0 \qquad \mathrm{II}$$

$$i\frac{\omega_x\omega_z}{4\pi\sigma\omega}E'_x+i\left[\frac{\omega_y\omega_z}{4\pi\sigma\omega}+\frac{\omega(z)}{\omega}\right]E'_y+\left[1-i\frac{\omega(y)}{\omega}+i\frac{\omega_z^2}{4\pi\sigma\omega}\right]E'_z=0 \quad \text{III}$$

We'll write the equations I, II, III in the following signs

$$\begin{cases} a_1E'_x+b_1E'_y+c_1E'_z=0 & I \\ a_2E'_x+b_2E'_y+c_2E'_z=0 & II \\ a_3E'_x+b_3E'_y+c_3E'_z=0 & III \end{cases} \quad (13)$$

For the non-zero solutions of *I, II, III* the following is required:

$$\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}=a_1b_2c_3+b_1c_2a_3+c_1a_2b_3-c_1b_2a_3-a_1c_2b_3-b_1a_2c_3=0 \quad (14)$$

In (13) the following signs were accepted: $\omega_x=ck_x,\ \omega_y=ck_y,\ \omega_z=ck_z$

$\omega(y)=-c\Lambda'_0k_y\nabla_y\mathrm{T},\ \omega(x)=-c\Lambda'_0k_x\nabla_y\mathrm{T},\ \omega(z)=-c\Lambda'_0k_z\nabla_y\mathrm{T}$

$\omega_{x,y,z}$ - are appropriate frequencies of electromagnetic waves upon coordinate axes, and $\omega(x),\omega(y),\omega(z)$ are frequencies of the thermomagnetic waves upon coordinate axes.

Solution (13) in general is very huge and consequently we'll investigate distribution of the thermomagnetic waves upon separate coordinate axes.

Let's review the case of $k_y=k_z=0,\ k_x\neq0$ then from (13) after simple calculation we'll obtain equation which determines the frequency of the spreading upon x waves;

$$y^4+\left[1+i\frac{\nu(E_0)-\nu(0)\omega(x)\varphi}{k_xu_0}-i\left(\frac{c}{u_0}\right)^2\frac{k_xu_0}{4\pi\sigma}\right]y^3+\left(\frac{c}{u_0}\right)^2\left[\frac{\omega(x)}{4\pi\sigma}-\frac{\nu(E_0)}{4\pi\sigma}+i\frac{k_xu_0}{4\pi\sigma}\right]y^2+$$

$$+\left(\frac{c}{u_0}\right)^2\left[\frac{\omega(x)-\nu(0)}{c}+i\frac{\omega(x)}{4\pi\sigma}\frac{\nu(E_0)}{k_xu_0}\right]y+\left(\frac{c}{u_0}\right)^2\frac{\nu(0)}{\nu}\frac{\omega(x)}{k_xu_0}\left(\frac{k_xD}{u_0}+i\right)=0 \quad (15)$$

Hereby, $y=\dfrac{\omega}{k_xu_0}$. Considering that $y=y_0+iy_1$ and $y_1<<y_0$ from (15) we will determine y_0 and y_1

$$y_0=\frac{\omega_0}{k_xu_0};\quad y_1=\frac{\omega_1}{k_xu_0};\quad \omega_0=k_xu_0y_0,\ \omega_1=k_xu_0y_1$$

Upon simple calculation from (15) we will obtain

$$\omega_0^{(1)}=k_xu_0\frac{\psi_1}{\psi};\ \omega_0^{(2)}=-k_xu_0\frac{\psi_1+\psi^2}{\psi};\quad \omega_1^{(1)}=-k_xu_0\frac{d_1\psi_1}{d\psi};\ \omega_1^{(2)}=k_xu_0\frac{d_1}{d}\frac{\psi_1+\psi^2}{\psi}$$

$$d_1=\frac{\omega(x)\nu(E_0)}{4\pi\sigma k_xu_0};\ \psi=(1+d_1)\left(\frac{u_0}{c}\right)^2\frac{2\pi\sigma}{k_xu_0}\frac{4\pi\sigma}{\omega(x)\nu(E_0)};\quad \psi_1=\frac{1}{2}\left(\frac{u_0}{c}\right)^2\frac{\omega(x)-\nu(0)}{k_xu_0}\frac{\nu(0)}{\nu(E_0)}\frac{k_xD}{u_0} \quad (16)$$

Conclusion

We can easily see from (16) that at $\omega(x) > \nu(0)$ the wave with frequency $\omega_0^{(2)}$ with increment is thermomagnetic. Instability of this wave corresponds the value of electric field $E_0 > \frac{\nu(E_0)}{k_x \mu_0}$. When the frequency of heat changeover of electrons $\nu(0) > \omega(x)$ the wave distributed through the outward electric field E_0 is recombining and increasing with increement $\omega_1^{(1)}$. Consequently, in semiconductors with increments Ge with alloy gold Au appearance of instable thermomagnetic waves is possible. This wave interacts with the recombination wave. In certain conditions the recombination wave may make weaker the thermomagnetic waves.

References

[1] V.V. Shchennikov and S.V. Ovsyannikov, Solid State Commun. 121 No. 6 (2002) pp 323-7

[2] S.V. Ovsyannikov and V.S. Vladimir, Physica : B Condensed Matt. 34 No.1-4 (2004) pp-190-4

[3] T. Okashita *et al.. J. Phys. Soc. Jpn.* 67 (1998), p. 67

[4] E.R. Gasanov, M.F. Novruzov. “Current hesitations at the temperature gradient, power field and magnetic field in solids”, “The Physical Institute of the Azerbaijan National Academy of Sciences, Transactions, No.5”, Baku, 2005, 176-179.

[5] E.R. Gasanov, M.F. Novruzov. “Current hesitations in the conducting medium in case of thermomagnetic waves”, “Proceedings devoted to 60th anniversary of the Institute of Physics of the National Academy of Sciences of Azerbaijan, collection of articles Physics-2005”, Baku, 2005, 235-236.

[6] E.R. Gasanov., R.R. Huseynov., M.F. Novruzov “Energy generation and amplitude of thermomagnetic waves in the conducting medium”, “Third International Conference on Technical and Physical Problems in Power Engineering”, May 29-31, 2006, Ankara, Turkey.

[7] N.N. Bogolyubov, Y.A. Mitropolsky “Asymptotic methods in the non-linear hesitations theory”, Moscow, 1963, page 36- 94.

[8] V.L. Bonch-Bruevich, I.P. Zvyagin, A.G. Mironov “Blast instability in semiconductors”, “Science”, Moscow, 1972, 126-194