INTERNAL OSCILLATIONS OF CURRENT CARRIER CONCENTRATIONS IN IMPURITY SEMICONDUCTORS

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The unstable wave in semiconductors with defined deep traps at the presence of external constant electric and strong magnetic fields has been theoretically investigated. The wave frequency and increment are found. The variation interval of magnetic field and critical value of electric field at which the instability inside of semiconductor appears, have been defined.

Introduction.

Redistribution of electric charges in impurity semiconductors leads to the appearance of unstable waves inside of the semiconductor. The current carriers are trapped (recombination) or generated in the dependence on external electric field value at the presence of deep impurities (traps). Generation increases the number of electric charges but trapping decreases the number of carriers. These processes occur with different probability and as a result the wave with defined frequency takes place in semiconductor. Frequency of these waves essentially depends on electric field value.

If the appearing wave propagates only inside of the crystal and doesn't go out (i.e. current oscillations are absent), then such instable state is called internal instability [1-2].

Internal instability theory in impurity semiconductors.

In this paper we theoretically investigate the instable waves inside of impurity semiconductor at the presence of external constant electric field and strong magnetic one (i.e. when $\mu_\pm \mathrm{H} > C$, C is light speed, $\mu_\pm$ are mobilities of holes and electrons correspondingly, H is magnetic field strength). The single-charged deep traps by N number and double-charged ones by N_- one are in the semiconductor with electron concentration n_- and hole concentration n_+. Then main equations of our problem have the following form [1]:

$$\frac{\partial n_\pm}{\partial t} + div\vec{j}_\pm = \left(\frac{\partial n_\pm}{\partial t}\right)_{rec}$$

$$\gamma_-(0)n_{1-}\mathrm{N}_- - \gamma_-(\mathrm{E})n_-\mathrm{N} = \left(\frac{\partial n_-}{dt}\right)_{rec}$$

$$\left(\frac{\partial n_+}{\partial t}\right)_{rec} = \gamma_+(\mathrm{E})n_{1+}\mathrm{N} - \gamma_+(0)n_+\mathrm{N}_- \qquad (1)$$

$$\frac{\partial \mathrm{N}_-}{\partial t} = \left(\frac{\partial n_+}{\partial t}\right)_{rec} - \left(\frac{\partial n_-}{\partial t}\right)_{rec}$$

$$div\vec{J} = e\,div(\vec{j}_+ - \vec{j}_-) = 0$$

$$\vec{j}_\pm = \pm n_\pm\mu_\pm\vec{\mathrm{E}} + n_+\mu_{1-}[\vec{\mathrm{E}}\vec{\mathrm{H}}]n_\pm\mu_{2\pm}\vec{\mathrm{H}}(\vec{\mathrm{E}}\vec{\mathrm{H}}) - D_\pm\nabla n_\pm \mp D_{1\pm}[\nabla n_\pm \mathrm{H}] - D_{2\pm}\vec{\mathrm{H}}(\nabla\vec{n}_\pm\vec{\mathrm{H}})$$

$\mu_\pm$ are ohmic mobilities, $\mu_{1\pm}\mathrm{H}$ are Hall mobilities, $\mu_{2\pm}\mathrm{H}^2$ are focusing mobilities of electrons and holes correspondingly; $\gamma_\pm(\mathrm{E}), \gamma_\pm(0)$ are coefficients of trapping and emission of holes and electrons at the presence of electric field $\gamma_\pm(\mathrm{E})$ and without it $\gamma_\pm(0)$. Dependencies of these coefficients on magnetic field strength can be essential only in quantizing magnetic fields which aren't considered in this work. We investigate longitudinal waves for which oscillating field is $\Delta H=0$, .

Supposing

$$\begin{aligned} &n_\pm(\vec{r},t) = n_\pm^0 + \nabla n_\pm(\vec{r},t) \\ &\vec{\mathrm{E}} = \vec{\mathrm{E}}_0 + \nabla\vec{\mathrm{E}}(\vec{r},t) \\ &\mathrm{N}_- = \mathrm{N}_-^0 + \nabla\mathrm{N}_-(\vec{r},t) \\ &(\nabla n_\pm, \nabla\mathrm{E}, \nabla\mathrm{N}_-) \sim l^{(\vec{\kappa}\vec{r} - \omega t)} \end{aligned} \qquad (2)$$

we linearize the system (1) and obtain the equations of the following form:

$$\begin{cases} \mathrm{A}_-\Delta n_-(\vec{r},t) + \mathrm{A}_+\Delta n_+(\vec{r},t) = 0 \\ \mathrm{B}_-\Delta n_-(\vec{r},t) + \mathrm{B}_+\Delta n_+(\vec{r},t) = 0 \end{cases} \qquad (3)$$

The explicit dependencies $\mathrm{A}_\pm, \mathrm{B}_\pm$ on equilibrium values of $n_\pm^0, \mathrm{E}_0, \mu_\pm^0, \mathrm{H}$ are easy found at linearization of equations (1) taking into account (2) and that's why we won't write them here. At the investigation of waves inside of the semiconductor the wave vector $\vec{\kappa}$ is obtained in the following form:

$$\mathrm{K}_x = \frac{\pi}{L_x}m_x; \quad \mathrm{K}_x = \frac{\pi}{L_y}m_y;$$

$$\mathrm{K}_z = \frac{\pi}{L_z}m_z; \quad m_{x,y,z} = 1,2,3.....$$

Taking into consideration (3) the dispersion equation takes the form

$$A_-B_+ - A_+B_- = 0, \text{ i.e. } \omega_+^3 + \Gamma_1\omega^2 + \Gamma_2^2\omega + \Gamma_3^3 = 0 \quad (4)$$

where

$$\Gamma_1 = \frac{\sigma_+^\mu u_- - \sigma_-^\mu u_+}{\sigma^\mu}K_x + \frac{\sigma_+ u_{1-} + \sigma_- u_{1+}}{\sigma}K_y + i\frac{\sigma_+^\gamma \nu_+^E - \sigma_-^\gamma \nu_-}{\sigma^\mu} = \Gamma_{10} + ^i\Gamma_1'$$

$$\Gamma_2^2 = \frac{\sigma_-^\gamma \nu_- \nu_+^-}{\sigma^\mu} - \frac{\sigma_+^\gamma \nu_+^E \nu_-' \mu_-}{\mu_+\sigma^\mu} + i\frac{\sigma_+^\gamma \nu_+^E u_- + \sigma_-^\gamma \nu_- u_+}{\sigma^\mu}K_x +$$

$$+ i\frac{\sigma_+^\gamma \nu_+^E K_y}{\sigma\sigma^\mu}\left(\sigma_+ u_{1-} - \frac{\sigma_- u_{1+}\mu_-}{\mu_+}\right) + i\frac{\sigma_-^\gamma \nu_- K_y}{\sigma\sigma^\mu}\left(\frac{\sigma_+ u_{1-}\mu_+}{\mu_-} - \sigma_- u_{1+}\right) = (\Gamma_{20})^2 + i(\Gamma_2')^2$$

$$\Gamma_3^3 = -K_x\nu\frac{\sigma_+^\gamma \nu_+^E u + \sigma_-^\gamma \nu_- u_+}{\sigma^\mu} - \frac{\sigma_+^\gamma \nu_+^E \nu K_y}{\sigma\sigma^\mu}\left(\sigma_+ u_{1-} - \frac{\sigma_- u_{1+}\mu_-}{\mu_+}\right) - \frac{\sigma_-^\gamma \nu_- \nu K_y}{\sigma\sigma^\mu}\left(\frac{\sigma_+ u_{1-}\mu_+}{\mu_-} - \sigma_- u_{1+}\right) \quad (5)$$

$$\sigma = \sigma_- + \sigma_+;\ \sigma^\mu = \sigma_-^\mu + \sigma_+^\mu;\ \sigma_\pm^\mu = en_\pm\mu_\pm\left[1 + \frac{d\ln\mu_\pm}{d\ln(E_0^2)}\right];$$

$$\sigma_\pm = en_\pm\mu_\pm;\ u_\pm = \mu_\pm E_0;\ u_{1+} = \mu_{1+}E_0;$$

$$\mu_\pm = a\left(\frac{C}{H}\right)^2 \cdot \frac{1}{\mu_\pm^0};\quad \mu_{1+} = \sqrt{2}\frac{C}{H};\quad \mu_{2+} = b\mu_\pm^0;\quad a \sim b \sim 1 \quad [2].$$

$\nu_- = \gamma(E_0)N$ is frequency of electron trapping

$\nu_+^E = \gamma_+(E_0)N$ is frequency of hole emission

$\nu_+ = \gamma_+(E_0)N_-^0$ is frequency of hole trapping

$$n_{1-} = \frac{n_-^0 N_0}{N_-^0};\qquad n_{1+} = \frac{n_+^0 N_-^0}{N_0};$$

$\nu_-^1 = \gamma_-(E_0)n_-^0 + \gamma_-(0)n_{1-}$ is <<combined>> frequency of electron trapping and emission y non-equilibrium traps.

$\nu_+^э = \gamma_+(0)n_+^0 + \gamma_+(E_0)n_{1+}$ is <<combined>> frequency of hole trapping and emission by non-equilibrium traps $\nu = \nu_+' + \nu_-'$.

The solving of dispersion equation for obtaining of frequency taking into account (5) is too intricate problem and so we solve the equation (4) in the following way:

Supposing $\omega = \omega_0 + \iota\gamma$, where

$$\gamma \ll \omega_0 \quad (6)$$

we obtain from (4) the following two equations

$$\begin{cases} \omega_0^3 + \Gamma_{10}\omega_0^2 - 2\Gamma_1^э\omega_0\gamma + \Gamma_{20}^2\omega_0 - (\Gamma_2')^2\gamma + \Gamma_3^3 = 0 \\ 3\omega_0^2\gamma + 2\omega_0\Gamma_{10}\gamma + \omega_0^2\Gamma_1' + (\Gamma_{20})^2\omega_0 = 0 \end{cases} \quad (7\text{-}8)$$

Designating $X = \frac{C}{\mu H} = \frac{H_{char}}{H}$ and comparing values $\Gamma_{10}, \Gamma_1^4, \Gamma_{20}^2, \left(\Gamma_2^1\right)^2$ from (7-8) taking into account (6) we obtain

$$\begin{cases} \omega_0^3 + \Gamma_{10}\omega_0^2 - (\Gamma_2')^2\gamma - \Gamma_3^3 = 0 \\ 3\omega_0^2\gamma + 2\omega_0\Gamma_{10}\gamma + (\Gamma_2^1)^2\omega_0 = 0 \end{cases} \quad (9\text{-}10)$$

From (10) we find:

$$\gamma = -\frac{(\Gamma_2^1)^2}{3\omega_0 + 2\Gamma_{10}} \quad (11)$$

Substituting (11) into (9) we obtain the equation for obtaining ω_0:

$$\omega_0^4 + \frac{5}{3}\Gamma_{10}\omega_0^3 + \frac{2}{3}\Gamma_{10}^2\omega_0^2 - \Gamma_3^3\omega_0 - \frac{2}{3}\Gamma_{10}\Gamma_3^3 + \frac{1}{3}(\Gamma_2')^4 = 0 \quad (12)$$

Under condition

$$2\Gamma_{10}\Gamma_3^3 = (\Gamma_2^1)^2 \ldots \quad (13)$$

the solutions of equation (12) have the following forms:

$$\omega_0 = -\frac{5}{3}\Gamma_{10} \quad (14)$$

$$\gamma = \frac{1}{3}\frac{(\Gamma_2^1)^2}{\Gamma_{10}} \quad (15)$$

At obtaining of solutions (14-15) we consider the region of frequency variation

$$\omega_0 >> \frac{3}{2}\frac{\Gamma_3^3}{\Gamma_{10}^2} \quad (16)$$

Under condition (6) we find the variation range of external magnetic field as follows:

$$H << H << \left(\frac{5\kappa_y u_-}{V_-}\cdot\frac{L_x}{L_x}\right)^{1/2} H_{char} \quad (17)$$

It is easy to check that if (16) is correct then the magnetic field value satisfies to following the inequality:

$$H >> H_{char}\left(\frac{L_y}{L_x}\cdot\frac{\mu_-}{\mu_+}\right)^{1/4} \quad (18)$$

If (17) and (18) are correct then we obtain the variation range of electric field:

$$E_0 >> \frac{V_- L_y}{10\pi\mu_-}\left(\frac{L_y}{L_x}\right)^6\cdot\left(\frac{\mu_-}{\mu_+}\right)^2 \quad (19)$$

The internal instability appears in cubic crystal under the following condition:

$$E_0 >> E_{char} = \frac{V_- L}{10\pi}\cdot\frac{\mu_-}{\mu_+}$$

and magnetic field variates in following interval:

$$H_{charr}\left(\frac{\mu_-}{\mu_+}\right)^{1/4} << H << H_{char}\cdot\frac{5\mu_- E_0 L\pi}{\nu - L}$$

where L is size of cubic crystal.

One can analyze the solution of equation (12) in several cases, i.e. at different variations of frequency ω_0 as the function of $\Gamma_{10}, \Gamma_{10}^1, (\Gamma_{20})^2$. We confine ourselves by the detail investigation of the equation (12) because of volume limitation of this paper.

Conclusion.

Thus, the instable wave with frequency (14) and increment (15) at the variation of external electric field (19) when magnetic field variates in interval (20) will propagate in semiconductors with given traps.

Oscillation values of physical values can be presented in the following form:

$$(\Delta n_\pm, \Delta E, \Delta N) \sim e^{i(\vec{k}\vec{r}-\omega t)} \sim e^{-iwt} \sim e^{-i\omega_0 t}\cdot e^{\gamma t} \sim$$
$$\sim A_0\, e^{\gamma t}\, cos(\omega_0 t + \varphi_0) = B(t)\, cos(\omega_0 t + \varphi_0) \quad (21)$$

where A_0 is initial amplitude, φ_0 is initial phase.

It is seen from (21) that amplitude oscillations of carrier concentration and electric field in considered semiconductors depend on time. The exact form of this dependence requires the solving of nonlinear differential equations.

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AŞQAR YARIMKEÇİRİCİLƏRDƏ CƏRƏYAN DAŞIYICILARI KONSENTRASİYASININ DAXİLİ RƏQSLƏRİ

Xarici elektrik və güclü maqnit sahəsində yerləşən dərin talalı yarımkeçiricilərdə yaranan dalğaların dayanıqsızlığı nəzəri olaraq tədqiq edilmişdir. Dalğaların tezlikləri və inkrementləri tapılmışdır. Yarımkeçiricinin daxilində yaranan dalğaların dayanıqsızlığına uyğun xarici elektrik və maqnit sahələrinin kritik qiymətləri hesablanmışdır.

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ВНУТРЕННИЕ КОЛЕБАНИЯ КОНЦЕНТРАЦИИ НОСИТЕЛЕЙ ТОКА В ПРИМЕСНЫХ ПОЛУПРОВОДНИКАХ

Теоретически исследована неустойчивая волна в полупроводниках с определенными глубокими ловушками при наличии внешнего постоянного электрического и сильного магнитного полей. Найдены частота и инкремент волны. Определены интервал изменения магнитного поля и критические значения электрического поля, при которых начинается неустойчивость волны внутри полупроводника.

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