ENERGY RADIATION IN EXTERNAL ELECTRIC FIELD BY IMPURITY SEMICONDUCTOR

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It has been proved that an impurity semiconductor in an external electric field can become an energy irradiator with the definite frequency. Values of the frequency and external electric field, at which excited waves inside the semiconductor become instable, have been determined.

Vibration effects in semiconductors are associated with possibilities of practical use of the current instability phenomenon to produce high-frequency energy generators. Production of such devices first of all requires theoretical predictions. When arising vibrations of current carriers inside a semiconductor are instable, from the semiconductor the energy irradiation of the definite frequency begins [1]. Therefore theoretical investigations of the instability condition in concrete semiconductors are of special scientific interest. In this work we theoretically investigate conditions of the rise of instable waves inside a concrete semiconductor in the presence of an external constant electric field.

Let us consider a semiconductor with concentrations of electrons n_- and holes n_+ being placed in an external constant electric field. Moreover, in the semiconductor there are one-fold N and two-fold N_- negatively charged traps, and $N \succ\succ N_-$, $n_+ \prec\prec N, N_-, n_- \prec\prec N, N_-$ inequalities take place. Electrons are captured, and holes are emitted by one-fold charged traps through the Coulomb energy barrier. The thermal generation of electrons and hole capture occur without the barrier. Then concentrations $n_\pm$ and N_- are determined by equations:

$$\frac{\partial n_\pm}{\partial t} \pm div j_\pm = (\frac{\partial n_\pm}{\partial t})_{rec}; \frac{\partial N_-}{\partial t} = (\frac{\partial n_+}{\partial t})_{rec} - (\frac{\partial n_-}{\partial t})_{rec}; j_\pm = \pm(n_\pm \mu_\pm E \mp D_\pm \nabla n_\pm);$$

$$divJ = ediv(j_+ - j_-) = 0; (\frac{\partial n_+}{\partial t})_{rec} = \gamma_+(E) n_{1+} N - \gamma_+(0) n_+ N_-; (\frac{\partial n_-}{\partial t})_{rec} = \gamma_-(0) n_{1-} N_- - \gamma_-(E) n_- N \quad (1)$$

$$(\frac{\partial n_-}{\partial t})_{rec} = \gamma_-(0) n_{1-} N_- - \gamma_-(E) n_- N$$

Here and henceforth $j_\pm$ are densities of flows of electrons and holes, $\gamma_-(0)$ is the coefficient of electron emission by two-fold negatively charged traps in the absence of an electric field, $\gamma_+(E)$ is the coefficient of hole emission by one-fold negatively charged traps in the presence of an electric field. For electrons and for holes concentrations $n_{1\mp}$ are determined from the stationary condition, i.e. $(\frac{\partial n_\mp}{\partial t})_{rec} = 0$ and $\gamma_\mp(E) = \gamma_\mp(0)$. We restrict ourselves to one-dimensional problem, i.e. directions of the wave vector $\vec{k}$ and electric field $\vec{E}_0$ are either parallel or anti-parallel.

Assuming that

$$n_\pm(x,t) = n_\pm^0 + \Delta n_\pm(x,t); N_-(x,t) = N_-^0 + \Delta N_-(x,t); E(x,t) = E_0 + \Delta E(x,t) \quad (2)$$

and introducing the following characteristic frequencies of capture and emission by equilibrium centers

$$\nu_- = \gamma_-(E_0)N_0;\nu_+ = \gamma_+(0)N_-^0;\nu_+^E = \gamma_+(E_0)N_0;\nu_-^1 = \gamma_-(E_0)n_-^0 + \gamma_-(0)n_{1-};$$

$$\nu_+^1 = \gamma_+(0)n_+^0 + \gamma_+(E_0)n_{1+};n_{1+} = \frac{\gamma_+(0)n_+^0 N_-^0}{\gamma_+(E_0)N^0};n_{1-} = \frac{\gamma_-(E_0)N^0}{\gamma_-(0)N_-^0} \quad (3)$$

we can characterize dependences of coefficients of electron capture and hole emission by the following dimensionless parameters:

$$\beta_+^\gamma = 2\frac{d\ln\gamma_+(E_0)}{d\ln(E_0^2)};\beta_-^\gamma = 2\frac{d\ln\gamma_-(E_0)}{d\ln(E_0^2)} \quad (4)$$

Supposing $(\Delta n_\pm, \Delta N_-, \Delta E) \sim e^{i(kx-\omega t)}$ and substituting (2) into (1) with consideration for (3)-(4), we get the dispersion equation to determine the frequency of energy irradiation from the semiconductor of the following form [2]:

$$\omega^3 + (\omega_1 + i\omega_2)\omega^2 + (\omega_3^2 + i\omega_4^2)\omega - \nu\omega_4^2 = 0 \quad (5)$$

Here

$$\nu = \nu_+^1 + \nu_-^1;\omega_1 = \frac{k(\sigma_+^\mu \nu_- - \sigma_-^\mu \nu_+)}{\sigma^\mu};\nu_\pm = \mu_\pm E_0;\sigma_\pm^\mu = en_\pm^0\mu_\pm^0\beta_\pm^\mu;\beta_\pm^\mu = 1 + 2\frac{d\ln\mu_\pm(E_0)}{d\ln(E_0^2)};$$

$$\sigma^\mu = \sigma_+^\mu + \sigma_-^\mu;\omega_2 = \frac{\sigma_+^\gamma\nu_+^E - \sigma_-^\gamma\nu_-}{\sigma^\mu};\omega_3^2 = \frac{\sigma_-^\gamma\nu_-\nu_+^1 - \sigma_+^\gamma\nu_+^E\nu_-^1\frac{\mu_+}{\mu_-}}{\sigma^\mu}; \quad (6)$$

$$\omega_4^2 = \frac{\sigma_-^\gamma\nu_- k\nu_+ + \sigma_+^\gamma\nu_+^E k\nu_-}{\sigma^\mu};\sigma_\pm^\gamma = en_\pm\mu_\pm\beta_\pm^\gamma.$$

Exact solutions of (5) in the general form are extremely cumbersome and therefore we restrict ourselves to cases, which are feasible on test. Let us present vibration frequencies as [3]

$$\omega = \omega_0 + i\gamma \text{ and } \gamma \prec\prec \omega_0 \quad (7)$$

Separating real and imaginary parts of Equation (5) with consideration for (7) we get the following two equations:

$$\omega_0^3 + \omega_1\omega_0^2 - 2\omega_0\omega_2\gamma + \omega_3^2\omega_0 - \omega_4^2\gamma - \nu\omega_4^2 = 0 \quad (8)$$

$$3\omega_0\gamma + 2\omega_0\omega_1\gamma + \omega_2\omega_0^2 + \omega_3^2\gamma + \omega_4^2\omega_0 = 0 \quad (9)$$

From Equations (8)-(9) it is seen that values of ω_0 and γ depend on values and signs of characteristic frequencies $\omega_1, \omega_2, \omega_3$. We consider the case

$$\omega_3^2 \succ 0, \omega_1 \prec 0, \omega_2 \prec 0 \text{ and } \omega_0 \succ \frac{\omega_3^2}{2|\omega_1|} \quad (10)$$

Then from (8)-(9) we get

$$\omega_0^3 - \omega_1\omega_0^2 + 2\omega_0\omega_2\gamma - \omega_4^2\gamma - \nu\omega_4^2 = 0 \quad (11)$$

$$3\omega_0\gamma - 2\omega_1\gamma - \omega_2\omega_0 + \omega_4^2 = 0 \quad (12)$$

The vibration inside the semiconductor is growing (i.e. instable) as $\gamma \succ 0$. Then (12) has the appearance

$$\omega_0 = \frac{2\omega_1}{3} \text{ and } \omega_4^2 = \frac{2\omega_1\omega_2}{3} \quad (13)$$

Substituting values of ω_0 and ω_4^2 from (13) into (11) we obtain

$$\gamma = \nu + \frac{4}{27}\cdot\frac{\omega_1^3}{\omega_4^2} \quad (14)$$

From (14) it is seen that the value of γ can substantially vary depending on the validity of the following inequalities: 1)$\nu \succ \frac{4}{27}\cdot\frac{\omega_1^3}{\omega_4^2}$ and 2)$\nu \prec \frac{4}{27}\cdot\frac{\omega_1^3}{\omega_4^2}$.

Then the frequency of energy irradiation from the semiconductor takes on the value $\omega_0 = \frac{2\omega_1}{3}$ and the condition $\omega_0 \succ\succ \gamma$ is wholly satisfied when the external electric field is determined from

$$\omega_4 \succ \frac{1}{\sqrt{2}}\nu \tag{15}$$

Positiveness of ω_3^2 leads to

$$\frac{n_-}{n_+}\cdot\frac{\nu_-}{\nu_+^E}\cdot\frac{\nu_+^1}{\nu_-^1}\cdot\frac{\beta_-^\gamma}{\beta_+^\gamma}\cdot\frac{\mu_-}{\mu_+} \succ 1 \tag{16}$$

Condition (16) of energy irradiation from an impurity semiconductor with frequency (15) at possible experimental conditions is wholly satisfied inasmuch as $\beta_-^\gamma \succ \beta_+^\gamma ; \mu_- \succ \mu_+$, and $\nu_- \succ \nu_+^E$ and $\nu_+^1 \sim \nu_-^1$.

Dependences of mobility $\mu_\pm^0$ on an electric field are determined versus the current carrier scattering. In the case of scattering by acoustic vibrations of the lattice $\mu_\pm \sim E^{-1/2}$ and $\frac{d \ln \mu_\pm}{d \ln E_0^2} = -\frac{1}{2}$, and in the case of scattering by lattice optical vibrations $\frac{d \ln \mu_\pm}{d \ln E_0^2} \approx \frac{1}{2}$.

To evaluate dimensionless parameters $\beta_\pm^\gamma$ it is needed to determine the Coulomb potential around negative impurities. However, inasmuch as $\mu_- \succ\succ \mu_+$ and $\nu_+^1 \sim \nu_-^1$ in the case of $n_-^0 \geq n_+^0$ condition (16) is fulfilled. Thus, in impurity semiconductors, being considered by us, (for example, gold-doped germanium, *GeAu*) at the definite constant electric field, an instable wave arises. In these conditions the semiconductor becomes a source of energy irradiation of the definite frequency and with the definite wave growth increment inside the semiconductor.

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AŞQARLI YARIMKEÇİRİCİNİN ELEKTRİK SAHƏSİNDƏ ENERJİ ŞUALANDIRMASI

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İsbat olunmuşdur ki, xarici elektrik sahəsində yerləşən aşqarlı yarımkeçirici müəyyən tezliklə enerji şualandırır. Yarımkeçiricinin daxilində yayılan dalğalar dayanıqsız olduqda tezliyin xarici elektrik sahəsinin qiymətindən asılılığı təyin edilmişdir.

ИЗЛУЧЕНИЕ ЭНЕРГИИ ПРИМЕСНЫМ ПОЛУПРОВОДНИКОМ В ЭЛЕКТРИЧЕСКОМ ПОЛЕ

РАСУЛ НИДЖАТ ХОССЕЙН, ГАСАНОВ Э.Р.

Выявлено, что примесный полупроводник, помещенный во внешнее электрическое поле, может стать излучателем энергии с определенной частотой. Определены значения частоты и внешнего электрического поля, при которых возбужденные волны внутри полупроводника становятся неустойчивыми.