საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 2, №4, 2008
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 2, no. 4, 2008

Physics

Possible Variations of Impulse Scattering Mechanisms at Transverse Runaway of Hot Electrons

Nana Metreveli, Zaur Kachlishvili, Fridon Chumburidze, Beka Bochorishvili

I. Javakhishvili Tbilisi State University

(Presented by Academy Member T. Sanadze)

ABSTRACT. The possibility of variation of impulse scattering mechanisms depending on the heating field at transverse runaway (TR) of hot electrons is considered in quasi-elastic scattering approximation. The correspondent normalization factors that determine the TR threshold values are calculated. *© 2008 Bull. Georg. Natl. Acad. Sci.*

Key words: *transverse runaway, impulse scattering, hot electrons, quasi-elastic scattering, scattering on dipoles.*

The transverse runaway of current carriers of semiconductors occurs at certain combination of energy and momentum scattering mechanisms and at certain threshold value of the applied electric field E_x, when drastic increase of the internal total electric field takes place due to growth of Hall field E_y [1].

In mutually perpendicular electric and magnetic fields the symmetric part of the distribution function in quasi-elastic scattering approximation has the following form [3]:

$$f_0(x) \propto \exp\left\{-\int \frac{dx}{1+\alpha\theta(x)}\right\}, \tag{1}$$

where $x \equiv \dfrac{\varepsilon}{k_0 T}$ is dimensionless energy, k_0 is Boltzmann constant, $\alpha \equiv \left(\dfrac{E}{E_0}\right)^2$, $E_0 \equiv \sqrt{3}\,\dfrac{k_0 T}{e\left(l_0 \tilde{l}_0\right)^{1/2}}$, E –internal total electric field; $\theta(x)$ – the so-called heating function and it shows the degree of deviation of the system from the equilibrium state:

$$\theta(x) \equiv \frac{x^{\frac{t+s}{2}}}{1+\eta x^t}, \tag{2}$$

where $\eta \equiv \left(\dfrac{H}{H_0}\right)^2$, H is the magnetic field, $H_0 \equiv \dfrac{\left(2mc^2 k_0 T\right)^{1/2}}{e l_0}$, c – the speed of light, t and s – exponents of the energy dependences of free path length according to impulse and energy respectively. Their values for each mechanism of scattering are known and are given in table [2].

$$l(x) = l_0 x^{\frac{t+1}{2}}, \quad \tilde{l}(x) = \tilde{l}_0 x^{\frac{s+1}{2}}. \tag{3}$$

In all earlier works (for instance [3–9]), the energy dependence of free path length according to impulse and energy was assumed to be determined by one scattering mechanism. Sometimes this is not always true and the number of cases of impulse scattering is due to respectively several synchronized mechanisms. In this case, the energy dependences are expressed as follows:

$$l^{-1} = \sum_i l_i^{-1} \quad \text{and} \quad \tilde{l}^{-1} = \sum_k \tilde{l}_k^{-1}, \tag{4}$$

where l_i and $\tilde{l}_k$ are the free path lengths at *i* and *k* mechanisms according to impulse and energy respectively (*i* and *k* designate the types of defects).

Considering the complex form of function (1), it is important to evaluate the limits of the applied fields when one of the mechanisms dominates over others and to define the critical value of the electric field when a change of the scattering mechanism takes place.

Let us consider the combination when t=1 and s=–1, i.e. the impulse is scattered by dipoles and the energy on deformative acoustic phonons. At scattering by diploes, the impulse relaxation time is expressed as [10]:

$$\tau = \frac{3}{8\pi}\cdot\frac{1}{\Gamma(5/3)}\cdot\frac{\hbar^3 q\chi^2}{mR_0^2 e^4 N_k}, \tag{5}$$

where N_k is the impurity concentration, R_0 – the average distance between the doped atoms, q – wave vector, χ – the environment dielectric permeability.

According to expressions (3) and (5), we can write:

$$H_0 = \frac{\sqrt[3]{(3\pi N_k)/4}}{\Gamma(5/\ )}\frac{m^{3/2}e^3}{\hbar^2\chi^2}\sqrt{\frac{2c^2}{k_0 T}} \tag{6}$$

$$E_0 = \sqrt{\frac{6\Gamma(3/2)}{\pi\rho k_0 T}}\cdot\sqrt[6]{\frac{4}{3}N_k}\cdot\frac{m^2 eE_1}{\hbar^3}, \tag{7}$$

where ρ is the density of the material, $E_1 \approx 10eV$ – the crystal constant [10].

Let us evaluate the electric fields at which dipole scattering takes place. In this case, the field is limited from above, since de Broglie wavelength λ decreases at increase of the electric field and when it becomes less than dipole arm d, the dipole scattering mechanism t=3 switches to the scattering by ions t=3, as the wave “penetrates” into the dipole and takes it as separate ions. Under these conditions the following condition is imposed on the electric field.

$$\frac{m}{\hbar^2}\bar{\varepsilon} < \frac{2\pi^2}{d^2}, \tag{8}$$

which assumes quite complicated form when the average energy is calculated according to equation (1).

The critical value of the electric field E^*, above which the ionized pair of donors is taken for different ions, can be expressed as:

$$E_x^* = E_0\sqrt{\frac{A_0 - 1}{1+\Phi(A_0-1)\Gamma^2\left(\frac{5}{2}\right)}}, \tag{9}$$

where $A_0 = \dfrac{4\pi^2\hbar^2}{3mk_0 Td^2}$, $F(x) = \int_x \dfrac{dx}{1+\alpha\theta(x)}$.

Further increase of the electric field above E_x^* values leads to transition of donor scattering to the scattering on ions. At this, the type of energy scattering stays the same and the energy still dissipates on deformative acoustic phonons.

At impulse dissipation on ions, the relaxation time is expressed as [11, 12]:

$$\frac{1}{\tau_i} = \frac{\pi N_i z^2 e^4}{\chi^2 x^{3/2}\sqrt{2m}}\ln\left(\frac{8mxR_0^2}{\hbar^2}\right), \tag{10}$$

where z is the ionization degree. Correspondingly, for normalization factors we have:

$$H_0 = \frac{\pi e^3 m^{1/2} c}{\sqrt{2}k_0^{3/2}\chi^2}N_i z^2 T^{-3/2}, \tag{11}$$

$$E_0 = \sqrt{\frac{3N_i m^3}{\rho}}\frac{eE_1}{\chi\cdot\hbar^2}. \tag{12}$$

Thus, the effect of TR as well as values of normalization factors of electric and magnetic fields and consequently the TR threshold value of the electric field depend on the scattering mechanisms. Depending on the heating field, variations of scattering mechanisms may take place. Because of it, it is necessary to define, which mechanism is dominant in the region of the fields under consideration.

ფიზიკა

იმპულსის გაბნევის მექანიზმის ცვლილების შესაძლებლობა ცხელი ელექტრონების განივი გაქცევისას

ნ. მეტრეველი, ზ. ქაჩლიშვილი, ფ. ჭუმბურიძე, ბ. ბოჭორიშვილი

ი. ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი

(წარმოდგენილია აკადემიკოს თ. სანაძის მიერ)

ნაშრომში კვაზიდრეკადი გაბნევების მიახლოებაში გამოკვლეულია იმპულსის გაბნევის მექანიზმის ცვლილების შესაძლებლობა ცხელი ელექტრონების განივი გაქცევისას (გგ) გამაცხელებელ ველზე დამოკიდებულებით და გამოთვლილია შესაბამისი მანორმირებელი მამრავლები, რომლებიც განსაზღვრავენ გგ ზღურბლურ მნიშვნელობას.

REFERENCES

1. *З.С. Качлишвили* (1980), ЖЭТФ, **78**: 1955.
2. *Z.S. Kachlishvili* (1976), Phys. stat. sol.(a), **33:**15.
3. *З.С. Качлишвили, Н.К Метревели* (2000), ФТП, **34**, 10:1159.
4. *Z.S. Kachlishvili, N.K.Metreveli* (2001), Bull. Georg. Acad. Sci., **163**, 2: 256.
5. *З.С. Качлишвили, Н.К. Метревели, Ф.Г. Чумбуридзе* (2002), Письма в ЖТФ, **28**, 18: 67.
6. *Н.К.Метревели, З.С. Качлишвили, Ф.Г. Чумбуридзе, Л.Т. Цкипури* (2003), Письма в ЖТФ**, 29,** 6: 63**.**
7. *N. K. Metreveli, B. G. Bochorishvili, Z. S. Kachlishvili* (2006), Bull. Georg. Acad. Sci., **173:** 277.
8. *N. K. Metreveli, Z.S. Kachlishvili, B. G. Bochorishvili* (2007), International Journal of Modern Physics, **B 21**, 10: 1715.
9. *N.K. Metreveli, Z.S. Kachlishvili, B.G. Bochorishvili* (2008), J. Physica, **B**: 595.
10. *А.А. Церцвадзе* (1969), ФТП, **3**: 409.
11. *В.Л. Бонч-Бруевич, С.Г. Калашников* (1990), Физика полупроводников, Москва, 672 с.
12. *V.N. Abakumov, V.I. Perell, I.N. Yassievich* (1991), Modern Problems in Condensed Matter Sciences, North-Holland, 375 p.

Received October, 2008