RECOMBINATION OF HOLES IN DISLOCATION CENTRES IN AN ELECTRIC FIELD

Z.A. VELIEV, N.A. KARDASHBEKOVA
Nakhchyvan State University,
The Azerbaycan Republic, Nakhchyvan, University campus

Recombination of holes in an electric field in the semiconductors with edge charged dislocations is studied in the paper. It is shown that the effective cross section of the capture decreases with growth of the strength of the electric field.

The cross section of capture of holes by charged edge dislocations in the presence of external strong electric field is considered with allowance for interaction of carriers with acoustical phonons [3].

However, in the presence of strong electric fields interaction of holes with optical phonons begins to take the most important role in the recombination process. The presented work is devoted to the process of recombination of holes interacting with both acoustical and optical phonons in the presence of strong external electric fields.

The question is investigated with the method developed in [1-3]. The temperature of the lattice is considered considerably low ($kT << \hbar\omega_0$, T is the thermodynamical temperature of the crystal, $\hbar\omega_0$ is the energy of the optical phonon). Therefore, only the processes with radiation of an optical phonon can be taken into account. We shall suppose that the potential fields do not cross, i.e. each center acts as an isolated center. As in pure semiconductors the function of distribution of charge carriers is formed in the result of their collision with the oscillations of a lattice. The energy gained with minority carriers per length of free running in a weak electric field is small, i.e. $e\xi l >> \hbar\omega_0$, formation of the function of distribution is realized with collision of holes with acoustical phonons.

The method of calculation of distribution function in such fields has been described in [4]. If the intensity of the electric field increases, then the energy $e\xi l$ becomes comparable with $\hbar\omega_0$. Non-elastic collisions of charge carriers accelerated by the field with the lattice when optical phonons are emitted begin to take a great role in the formation the distribution function. As the result of these collisions of the distribution function becomes asymmetrical and it is pulled along the field and the growth of the average energy carriers decelerates with growth of the field intensity. In very strong electric fields ($e\xi l >> \hbar\omega_0$), collisions of minority carriers with the oscillations of the lattice get an elastic character again [4].

The cross section of the capture in radiation of an optical phonon by a hot carrier is calculated from the general formula

$$\sigma = \frac{\int W(E, E')f(E)\rho(E)\rho'(E')dEdE'}{N_D < v > \int f(E)\rho(E)dE} \qquad (1)$$

Here $W(E, E')$ is the probability of transition of a free carrier with the energy E to the bound state to the dislocation center with the energy of bound E' per unit of time in the result of radiation of an optical phonon $\hbar\omega_0(E' = E - \hbar\omega_0)$, $f(E)$ is the distribution function of hot holes in the valence band. .The functions $\rho(E)$ and $\rho'(E')$ describe the full density of the state in the band and in the dislocation center, respectively.

The magnitude is determined with the formula

$$\rho(E) = \int \rho(\varepsilon)\delta\left(E' - \varepsilon + U_0 \ln\frac{r}{R}\right)d\varepsilon d^3\bar{r} = \left(\frac{\pi U_0}{2kT}\right)^{3/2} R2L\rho(T)e^{-\frac{2|E|}{U_0}} \qquad (2)$$

Here $\rho(E)$ is the density of the state in the valence band, $\rho(T) = \rho(E)$ at $E = kT$; L is the length of the dislocation, R is the Read radius of the edge dislocation, $U_0 = e^2 f / 4\pi\varepsilon\varepsilon_0 a$, f is the coefficient of filling of dislocations of electrons, e is an elementary charge, a is the distance between atoms along the dislocation line, ε is the dielectric constant of the crystal, ε_0 is the electric constant.

We carry the calculations in the limiting cases of week and strong electric fields. In weak electric fields when $kT_h << \hbar\omega_0$, transitions occur in the bound state with the energy $E' \sim \hbar\omega_0$.

In this case

$$\rho'(E') \approx \rho'(\hbar\omega_0)$$

$$\sigma_{op.} = \frac{5\pi\sqrt{\pi}A}{2} \cdot \frac{m^2 r_D^2 E_{on}^2 \varepsilon^2}{\rho_0 \hbar^2 e^2} \cdot \frac{\hbar\omega_0}{mS^2}(kT)^2 \cdot \rho'(\hbar\omega_0) \cdot \frac{\alpha^2 \exp\left(-1/\alpha\right)}{\mu^{3/2} U\left(\frac{3}{2}; \frac{5}{2} + \mu; \mu\right)} \qquad (3)$$

Here $\alpha = e^2 f / 4\pi\varepsilon\varepsilon_0 akT$, $\mu = (\xi/\xi_{char})^2$, ξ is the intensity of the electric field

$$\xi_{char} = (6mkT)^{1/2} \cdot (mE_c)^2 kT / \pi e\rho_0 S^2 \hbar^4 ,$$

A is the numeral multiplier of unit order, $U(x,\ y,\ z)$ is the Cummer degeneracyon hypergeometric function.

In strong electric fields when $kT_h \geq \hbar\,\omega_0$ the main contribution to σ_{op} is given by captures of carriers the higher excited levels of the dislocation centre with the bound energy $E' = \Delta$ (Δ determiners the position of the discrete levels in the dislocation well, i.e in the dislocation well the discrete energy levels correspond to the negative values of the total energy $|E| \leq \Delta$). The magnitude of Δ is determined from the condition $|grad\ E| = 0$ at $z = R_0(\xi)$, where

$$\Delta = 2\alpha kT \cdot \begin{cases} 1 + \ln(e\xi R_0 / 2\alpha kT), \text{ at } a/f \leq r \leq R_0 \\ \sqrt{\dfrac{\pi}{2}} \ln\left(\dfrac{3\alpha kT}{er_D\xi}\sqrt{\dfrac{\pi}{2}}\right) + \dfrac{er_D\xi}{2\alpha kT} \ln\left(\dfrac{3\alpha kT}{e\xi r_D}\sqrt{\dfrac{\pi}{2}}\right), \text{ at } r \geq R_0 \end{cases} \tag{4}$$

$$R_0 = \begin{cases} 2\alpha kT/e\xi \quad , \text{at, } a/f \leq r \leq R_0, \\ r_0 \ln(3\alpha kT/er_D\xi), \text{ at } \quad r \geq R_0 \end{cases} \tag{5}$$

After the not complicated calculations we have the following exspression for σ_{op}.

$$\sigma_{op}(\varepsilon) = \frac{5\sqrt{2}D}{\pi} \cdot \frac{kT}{mS_o^2} \cdot \left(\frac{\hbar\omega_0}{\Delta}\right)^{3/2} \cdot \frac{E_{op}^2 m^3 r_D^2}{\hbar^4 r_D} \alpha^2 \exp\left(-1/\alpha\right) \tag{6}$$

Here D is the numerical multiplier of unit order. The limits of strong and weak electric fields are determined with the expression $\mu \sim 1$, so that for the crystal n-Ge when $m \sim 10^{-31}$kg, $\varepsilon = 16$, $n_d \sim 10^{19}\mu^{-3}$, $10^{-2} \leq f < 1$, $S \sim 10^3 m/S$, the magnitude $\xi_{char} \sim 10^5 V/m$. It means that in the fields $\xi_{char} < 10^5 V/m$ the formula (3) takes place, but in the filds $\xi_{char} > 10^5 V/m$. the formula (6) does.

The temperature dependences of the cross section of the capture are described with formulaes

$$\sigma_{op}(\xi) / \sigma_{op}(0) \sim (kT)^{-1} \exp \cdot \left(-\frac{\Delta}{2kT} + \frac{1}{\alpha}\right)$$

$$\sigma_{op}(\xi) / \sigma_{op}(0) \sim \Delta^{-3/2} \exp \cdot \left(-\frac{\Delta}{2kT}\right)$$

As is seen from these formulaes the cross section of the capture intensely decreases with growth of the electric field strength.

[1] Z.A. Veliev FTP. 1983, v.17, N7, p.1351-1353.

[2] Z.A. Veliev FTP. 1999, v.33, N11, p.1300-1302.

[3] Z.A. Veliev FTP. 1983, v.17, N12, p.1436-1337.

[4] V.N. Abakumov, V.I. Perel, I.N. Yassiewich. FTP, 1978, v.12, N1, p.3-32.

Z.Ə. Vəliyev, N.A. Qardaşbəyova

ELEKTRİK SAHƏLƏRİNDƏ DISLOKASİYA MƏRKƏZLƏRİNDƏ DEŞİKLƏRİN REKOMBİNASİYASI

İşdə kənar yüklü dislokasiyalı yarımkeçiricilərdə xarici elektrik sahələrində deşiklərin rekombinasiyası öyrənilmişdir. Göstərilmişdir ki, elektrik sahəsinin intensivliyinin artması ilə zəbt olunmasının effektiv kəsiyi azalır.

З.А. Велиев, Н.А. Гардашбекова

РЕКОМБИНАЦИЯ ДЫРОК НА ДИСЛОКАЦИОННЫХ ЦЕНТРАХ В ЭЛЕКТРИЧЕСКОМ ПОЛЕ

В данной работе изучена рекомбинация дырок в дислокационных центрах во внешних электрических полях. Показано, что с ростом напряженности электрического поля эффективное сечение захвата дырок уменьшается.

Дата поступления: 20.11.2000

Редактор: Ф.М. Гашимзаде