THE CAPTURE OF HOLES BY EDGE DISLOCATIONS WITH PARTICIPATION OF OPTICAL PHONONS IN SEMICONDUCTORS

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The process of the capture of holes by edge charged dislocations accompanied with radiation of optical phonons is considered. It is shown that in the considered case the effective cross section of the capture sharplier depends on temperature compared with the coresssponding processes accompanied with radiation of acoustical phonons.

It is well-known that in the temperature below indoors the main channel of loosing energy in capture of holes in n-type semiconductors with charged edge dislocations is the interaction with acoustic phonons [1] Indeed, interaction of holes with optical phonons has an exponential small probability in this case $exp(-(\hbar\omega_0-E_D)kT)$, where E_D is the bound state energy of hole dislocations, $\hbar\omega_0$ is the energy of optical phonons if $\hbar\omega_0-E_D>>kT$. However, in capture process the levels with the energy $E_D\sim\hbar\omega_0$ can be arisen. Then in this case $\hbar\omega_0-E_D<<kT$ and the probability of transition of thermal electrons will not be exponentially small, though $\hbar\omega_0>>kT$

We shall investigate a capture process of holes by edge charged dislocations corresponding to the last situation.

For simplicity, let us suppose that the Read radius of separate dislocation is $R<<N_D^{-1/2}$ (N_D is the density of charged dislocations), i.e. the cylindrical regions arising around the edge charged dislocations do not intersect. The flux per unit of an isolated centre is determined by the expression [2]

$$j=\int d^3\bar{r}\,d\varepsilon d\varepsilon' F(\varepsilon,r)\rho(\varepsilon)w(\varepsilon,\varepsilon')P(U). \qquad (1)$$

Here ε and ε' are the kinetic energies of holes before and after emission of optical phonons, $F(\varepsilon,r)$ is the distribution function of the holes with the kinetic energy ε at the distance r from the axis of dislocation

$$\rho(\varepsilon) = \frac{8\sqrt{2\pi}\,m^{\frac{3}{2}}}{(2\pi\hbar)^3}\sqrt{\varepsilon} \qquad (2)$$

ρ is the density of the states, m is the effective mass of the holes, $w(\varepsilon,\varepsilon')$ is the probability of the transition of the holes per unit of time with spontaneous emission of phonons, $P(U)$ is the probability of the stick of the holes in the state with the energy U. In the case of edge charged dislocation

$$U = \frac{e^2 f}{4\pi\varepsilon\varepsilon_0 a}\ln\frac{R}{r} - \varepsilon' \qquad (3)$$

where ε_0 is the electric constant, ε is the dielectric constant of the semiconductor, a is the distance between the atoms along the axis of the dislocations, f is the coefficient of filling of charged dislocation by electrons.

The life time and the cross section of capture of holes in the field of the charged dislocation are determined by the expressions:

$$\begin{gathered}\tau^{-1}=N_D j/P\\ \sigma=j/P\langle U\rangle=1/N_D\langle U\rangle\tau\ ,\end{gathered} \qquad (4)$$

where P is the concentration of holes, $\langle U\rangle$ is the average thermal speed of holes.

Let us consider the situation, when in the valence zone the holes are distributed equilibriously and the interaction is going on with deformative optical phonons.

The probability of such interaction is determined by the formula [1]

$$W(\varepsilon,\varepsilon') = \frac{(2m)^{\frac{3}{2}}E_{op}^2}{4\pi\rho_0\omega_0\hbar^2}\left[N(\omega_0)\sqrt{\varepsilon+\hbar\omega_0} + \left(N(\omega_0)+1\right)\sqrt{\varepsilon-\hbar\omega_0}\right]. \qquad (5)$$

Here ρ_0 is the density of the crystal, $N(\omega_0)$ is the function of the distribution of optical phonons (in the considered case it is the Planck function), E_{op} is the constant of the optical potential of deformation. Putting (2)-(5) in (1) we obtain the expression for the cross section of the capture

$$\sigma_{op}=\frac{4mE_{op}^2 r_D^2}{3\sqrt{\pi}\,\hbar^4\rho_0}A\alpha^2\frac{(kT)^2}{mS_0^2\hbar\omega_0}exp(-1/\alpha), \qquad (6)$$

after a long but not difficult calculations.Here $r_D=(\varepsilon\varepsilon_0 kT/n_d)^{1/2}$ is the Debye radius of screening, $\alpha=e^2 f/8a\pi\varepsilon\varepsilon_0 kT$, n_d, is the density of donors in the volume, A is the numerical factor of the order of unit. Let us compare the formula (6) with the corresponding formula obtained in [3] for same conditions.

In this case

$$\sigma_{op}/\sigma_{ac} \sim (kT)^2/mS_0^2\hbar\omega_0\ . \qquad (7)$$

According to (7) σ_{op} is more sensitive to the change of temperature than σ_{ac}. In the end, let us estimate the characteristic temperature T_{char} when $\sigma_{op}/\sigma_{ac}\sim 1$ For the value of the parameters of the $n-$ Ge crystal: $W=(E_{op}/E_{ac})^2\sim 0,4$ (E_{ac} is the constant of the deformative potential), $mS^2\sim 0,4$K $\hbar\omega_o\sim 430$ K and the characteristic temperature is $T_{char}\sim 50$ K. Thus at the temperatures $T>>T_{char}$ the emission of optical phonons plays the leading role. However at $T<T_{char}$ the emission of acoustic phonons plays the leading role.

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OPTİK FONONLARIN İŞTİRAKI İLƏ YARIMKEÇİRİCİLƏRDƏ DEŞİKLƏRİN KƏNAR YÜKLÜ DİSLOKASİYALAR TƏRƏFİNDƏN ZƏBT OLUNMASI

İşdə optik fononların şüalandırılması ilə müşahidə olunan deşiklərin kənar yüklü dislokasiyalarla zəbt olunması prosesinə baxılmışdır. Göstərilmişdir ki, zəbt olunmanın effektiv kəsiyi baxılan halda, akustik fononların şüalanması ilə gedən uyğun proseslə müqayisədə temperaturdan daha kəskin asılı olur.

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ЗАХВАТ ДЫРОК КРАЕВЫМИ ДИСЛОКАЦИЯМИ В ПОЛУПРОВОДНИКАХ С УЧАСТИЕМ ОПТИЧЕСКИХ ФОНОНОВ

В работе рассмотрен процесс захвата дырок краевыми заряженными дислокациями с излучением оптических фононов. Показано, что сечение захвата от температуры зависит сильнее, чем в процессе с излучением акустических фононов.

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