CAPTURE OF CARRIERS ON SCREENED COULOMB CENTRE

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Some aspects of theory of the capture of free carriers on screening Coulomb potential in semiconductors are analyzed. It is established that with the decrease the screening radius the capture cross section drastically decreases and for $r_S \le a_B^*$ it equals to zero. It is shown that in the case of the small r_S the diffusion theory becomes unapplicable.

For the correct consideration of the kinetic, photoelectrical and optical phenomena in semiconductors and semiconductor structures it is necessary to take into account the capture of carriers on attracting centres. Such centres in semiconductors are, for example, the shallow impurities, the potential of which is considered usually as Coulomb one. The capture on Coulomb centre in semiconductors was first considered by Lax [1] and was corrected in [2,3]. The various aspects of the carrier capture problem in semiconductor structure were considered in connection with the investigations of low dimensional systems [4,5]. However, the potential of a charged impurity in real semiconductors may be considered as purely Coulomb one only in the weak doping case ($N_D^{-1/3} a_B^* << 1$, where N_D is the shallow impurities concentration, a_B^* - the effective Bohr radius).

In [3] in the case of a high impurity concentration, when distance between centres $L_D \approx N_D^{-1/3}$ becomes comparable with radius essential for capture $r_T = e^2/\chi kT$, it was supposed that the capture occurs on impurity potential fluctuations wells. But a correct account of the capture demands a correct choice the form of attracting potential. Actually, with increasing of impurity concentration it is necessary to take into account the screening of Coulomb potential of the charged impurities by free carriers. On this view the Coulomb potential must be substituted by screening Coulomb potential, i.e.

$$U(r) = (e^2/\chi r)\exp(-r/r_s) \qquad (1)$$

In (1) r_S is the Debye screening radius and it must by be chosen as $r_S = \chi E_F/(6\pi n e^2)$ in degenerate case and as $r_s = \sqrt{\chi kT/(4\pi n e^2)}$ in the nondegenerate case, where $E_F = \hbar^2 k_F^2/2m^*$, $k_F = (4\pi n^2)^{1/3}$, χ is dielectric constant and n is free carrier concentration.

In this work we consider the capture of free carriers on potential of the form (1) and discuss some essential details of this problem.

Similarly to Coulomb potential case the capture radius is determined from the equation

$$E = (e^2/\chi r)\exp(-r/r_S) \qquad (2)$$

where E is the total energy of carrier.

To calculate the capture cross section (CCS) we use-the following expression [3]:

$$\sigma = (\pi^2\hbar^2)/(2kTm^*)\left[\int_{-\infty}^{0} \exp(E/kT)B^{-1}(E)\,dE\right]^{-1} \qquad (3)$$

where

$$B(E) = \int \varepsilon\tau_\varepsilon^{-1}\rho(\varepsilon)\delta[E-\varepsilon-U(r)]d\varepsilon d^3r \qquad (4)$$

$$\rho(\varepsilon) = 8\sqrt{2}\pi(2\pi\hbar)^{-3}m^{*3/2}\varepsilon^{1/2}, \tau(\varepsilon) = l_0(m^*/2\varepsilon)^{1/2},$$
$$l_0 = (\pi\hbar^4\rho_0)/(2m^{*3}E_C^2) \qquad (5)$$

E_C is the deformation potential constant, ρ_0 is the crystal density, m^* is the carrier effective mass.

For $B(E)$ in this case we have:

$$B(E) = 4mr^3E^2J(x)/3\pi l_0\hbar^3 \qquad (6)$$

$$J(x) = 2x^3 + 12x(1+x-e^{-x}) + 3x^2(e^{-x}-1)e^x \qquad (7)$$

where $x = r_1/r_S$, r_1 is the root of equation (2) for a given screening length r_S.

Substituting (6) and (7) into (3) for CCS we obtain an expression:

$$\sigma_0/\sigma = 2(kT)^{-2}(e^2/\chi r_S)^3\int_0^{\infty}\exp[(-E/kT)/(E^2J(x)]dE \qquad (8)$$

where $\sigma_0 = (4\pi/3l_0)\cdot(e^2/\chi kT)$ is the CCS in the Coulomb case.

The results of numerical calculation at T=4,2 K for GaAs (curve 1) and Ge (curve 2) with parameters m^*=0,067 m_0, χ=12,5 and m^*=0,082m_0, χ =16, correspondingly, are shown in fig.1.

It is easy to show that when $r_S \to \infty$ from (8) for CCS Coulomb potential case can be obtained. However, the screened potential (1) as distinct from Coulomb one has a

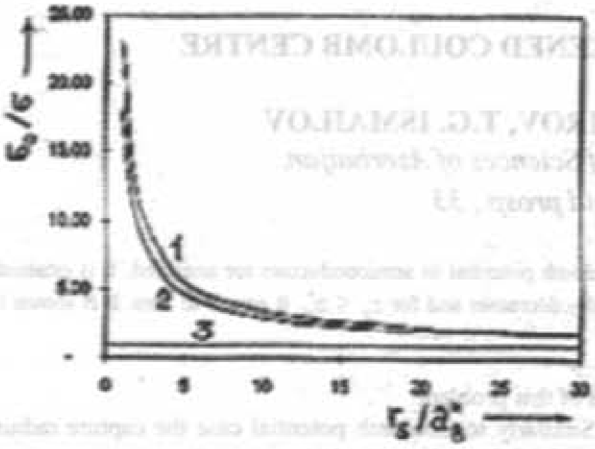

Fig. 1. Dependence of σ_s/σ on screening radius r_s/a_B^*:
1 - for GaAs; 2 - for Ge; 3 - Coulomb potential case.

finite number of bond states and when $r_s = a_B^*$ has not any bond states, they pass into continuous zone [7,8]. It is obvious that in the absence of bond states, CCS is equal to zero. As it is seen from fig.1 the method used in [6] gives the decrease for CCS no more than in 20 and 25 times for Ge and GaAs, correspondingly, when $r_s = a_B^*$.

This indicates that the method used in [2] and in this work for CCS calculation becomes unacceptable at small screening lengths, when the discrete states number are small. In this case the capture process can not be considered as a diffusion lowering through energetic states of impurity.

Note that in the high impurities concentration case, when $l_D \leq 4\ a_B^*$ in semiconductors at low temperatures Mott transition takes place. This phenomena also due to disappearing of all bond states of impurity potential for $r_s \leq a_B^*$. The equality of CCS to zero when $r_s \leq a_B^*$ may be considered as a one of the reasons of Mott transition in semiconductors.

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YÜKDAŞIYICILARIN EKRANLAŞMIŞ KULON MƏRKƏZLƏRİNƏ TUTULMASI

Yarımkeçiricilərdə sərbəst yükdaşıyıcıların ekranlaşmış Kulon potensialına tutulma nəzəriyyəsinin bə'zi aspektləri təhlil edilmişdir. Müəyyənləşdirilmişdir ki, ekranlaşma radiusunun azalması ilə tutulmanın effektiv kəsiyi kəskin azalır və $r_s \leq a_B^*$ olduqda sıfra bərabər olur. Göstərilmişdir ki, ekranlaşma radiusunun kiçik qiymətlərində diffuzion nəzəriyyə tətbiqedilməzdir.

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ЗАХВАТ НОСИТЕЛЕЙ НА ЭКРАНИРОВАННЫЙ КУЛОНОВСКИЙ ЦЕНТР

Проанализированы некоторые аспекты теории захвата свободных носителей на экранированный Кулоновский потенциал в полупроводниках. Установлено, что с уменьшением радиуса экранировки сечение захвата существенно уменьшается и равняется нулю при $r_s \leq a_B^*$. Показана неприменимость диффузионной теории для расчета сечения захвата при малых радиусах экранировки.

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