CURRENT TRANSPORTATION PROCESSES IN p-n-n+ - STRUCTURES UNDER SATURATION OF RECOMBINATION RATE

Abat K. Uteniyazov  
*Karakalpak State University, Uzbekistan*, a_uteniyazov@karsu.uz

A Leyderman  
1*Physical-Technical Institute of SPA “Physics-Sun”, Uzbekistan Academy of Sciences, Uzbekistan*, a_uteniyazov@karsu.uz

M Nsanbaev  
*Nukus State Pedagogical Institute*, a_uteniyazov@karsu.uz

Sh Annayeva  
*Karakalpak State University*, a_uteniyazov@karsu.uz

Follow this and additional works at: https://uzjournals.edu.uz/karsu

Part of the Biology Commons, Chemistry Commons, Mathematics Commons, and the Physics Commons

**Recommended Citation**

Uteniyazov, Abat K.; Leyderman, A; Nsanbaev, M; and Annayeva, Sh (2021) "CURRENT TRANSPORTATION PROCESSES IN p-n-n+ - STRUCTURES UNDER SATURATION OF RECOMBINATION RATE," *Karakalpak Scientific Journal*: Vol. 4 : Iss. 2 , Article 2.  
Available at: https://uzjournals.edu.uz/karsu/vol4/iss2/2

This Article is brought to you for free and open access by 2030 Uzbekistan Research Online. It has been accepted for inclusion in Karakalpak Scientific Journal by an authorized editor of 2030 Uzbekistan Research Online. For more information, please contact sh.erknov@edu.uz.
CURRENT TRANSPORTATION PROCESSES IN p-n-n⁺ - STRUCTURES UNDER SATURATION OF RECOMBINATION RATE

Abstract

In the article, the model of the recombination of non-equilibrium carriers through a pair recombination complex of the donor-acceptor pair type is studied under conditions when the concentration of such paired complexes changes (decreases) during the excitation of the material. Also, the article describes that the injection into the p-n-n⁺ - structure can lead to fundamental changes in the distribution of the concentration of free carriers, especially, to the appearance of a periodic term depending on the concentration of the sample length (instead of the usual exponential dependence).

**Keywords:** recombination, donor-acceptor pairs, a decrease in the concentration of recombination centers, periodic distribution of the concentration of non-equilibrium carriers.

In [1], we considered the regime of double injection in the p-n-n⁺ -structure under the conditions of recombination proceeding through a pair impurity complex of the donor-acceptor pair type. It was shown that under conditions leading to a change in the concentration of one of the components of such a complex (for example, donors), the total number of actively working recombination complexes changes, which inevitably leads to inhibition (suppression) of the recombination rate and the appearance of a distribution of the concentration of nonequilibrium carriers in the n-base of the type:

\[ p = \frac{1}{\alpha}(N_k + A \cos \omega x + B \sin \omega x), \quad (1) \]

Where \( \alpha \) – is the parameter responsible for the decrease in the concentration of effectively working recombination complexes (regardless of the specific mechanism of their degeneration), \( A \) and \( B \) are constants determined by the conditions at the boundaries of the n-base with p-n and n-n⁺ - transitions (see
Figure 1a), $N_R$ – the concentration recombination complexes, and $\omega$ – the frequency of the emerging periodic distribution of carriers is:

$$
\omega = \sqrt{\frac{\alpha}{L_\alpha}},
$$

where $L_\alpha = \sqrt{\tau_\alpha D_p}$ – is the new diffusion length, which is now determined not as usual by the lifetime of minority carriers $\tau$, but by the time of intracomplex exchange $\tau$ (see Figure 1b).

As can be seen from (1), the distribution of the concentration of nonequilibrium carriers is now described by trigonometric functions (instead of the usual exponential ones), which unambiguously indicates the onset of self-organization processes in the structure under study. The purpose of this work is to consider the I–V characteristic under such conditions.

**Fig. 1.** Scheme of the $p$-$n$-$n^+$ structure (a) and the band diagram of a semiconductor with paired recombination complexes (b). The solid lines show $\tau$, the time transitions within the complex.

As can be seen from (1), the distribution of the concentration of nonequilibrium carriers is now described by trigonometric functions (instead of the usual exponential ones), which unambiguously indicates the onset of self-organization processes in the structure under study. The purpose of this work is to consider the I–V characteristic under such conditions.
To calculate the total I - V characteristic of the structure under study (see Figure 1a), we need to calculate the total voltage drop across it:

\[ V = V_{p-n} + V_{n-n^+} + V_T + V_D, \]  

(3)

where \( V_{p-n} \) and \( V_{n-n^+} \) - the voltage drop across the p-n and n-n\(^+\) - junctions, respectively, and the \( V_T + V_D \) - total voltage drop across the n-base of the structure, which is determined by the field \( E \):

\[ V_T + V_D = \int_0^d E \, dx, \]  

(4)

where

\[ E = E_J + E_D, \]  

(5)

and under high injection conditions \( p > N_d \)

\[ E_J = \frac{J}{q \mu_n (b+1) p}, \quad E_D = -\frac{kT}{q} \frac{b-1}{b+1} \frac{dp}{dx} \]  

(6)

moreover, the second term in (5) is the part of the field responsible for the appearance of the so-called Dember component of the voltage drop, which is caused only by the difference in the mobility of electrons and holes \((b = \frac{\mu_e}{\mu_p})\) and is usually small.

Since the processes of rearrangement of recombination paired complexes under consideration can be significant only in structures with a sufficiently long base \((\frac{d}{L_p} > 5 \div 10)\), then undoubtedly the most important will be the voltage drop across the base, determined by the field \( E_J \):

\[ V = \frac{J}{q \mu_n (b+1) p} \int_0^d dx. \]  

(7)

Using (1), we rewrite (7) in the form:
\[ V_T = \frac{J}{q \mu_n (b+1)} \int_0^d \frac{dx}{N_R^2 + A \cos \omega x + B \sin \omega x}. \]

(8)

From the analysis of solution (1) carried out in [1], we know that there are more periodic terms, so we can use an approximate formula for division and represent (8) in the form:

\[ V = \frac{J}{q \mu_n (b+1)} \left[ \int_0^d \frac{dx}{N_R^2} - \int_0^d \frac{(A \cos \omega x + B \sin \omega x)dx}{N_R^2} \right]. \]

(9)

Integrating (9), we obtain an expression for the voltage drop across the base in the form:

\[ V = \frac{J\omega d}{q \mu_n (b+1) N_R} \left[ 1 - \frac{A}{\omega d N_R} \sin \omega x + \frac{B}{\omega d N_R} (\cos \omega d - 1) \right]. \]

(10)

It can be seen from (10) that the first term gives an ohmic dependence \( V \sim J \), and the periodic terms are responsible only for a certain addition. It should be emphasized that this is an approximate solution (transition \( \alpha = 0 \) to the usual solution is impossible).

For further analysis, we need specific boundary conditions to determine the constants \( A \) and \( B \). Considering that the processes under consideration occur at sufficiently high levels of excitation, we can assume that the \( p-n \) and \( n-n^+ \)-transitions will no longer be ideal, i.e. for them the following conditions will be valid (see, for example, [2]):

\[ J = \frac{q V_n^+ p^2(0)}{p_n}, \quad p(0) = \sqrt{\frac{Jp_n}{q V_n^+}} \]

(11)

for a \( p-n \)-junction.

\[ J = \frac{q V_p^+ n^2(d)}{n_n}, \quad n(d) = \sqrt{\frac{Jn_n}{q V_p^+}} \]

(12)

for \( n-n^+ \)-transition.

Here, \( n_n = N_d \) – the concentration of shallow doping donors that determine the conductivity of the \( n \)-base, \( p_n \) – the initial concentration of holes in the \( n \)-base, \( V_n^+ \) –
the rate of leakage through the $p$–$n$- junction of electrons from the $n$-base to the heavily doped $p$-region, $V_{p}^*$ – and the rate of leakage of holes from the $n$-base to the heavily doped $n^*$–region.

Using (1), (11) and (12) we find constants $A$ and $B$:

$$A = \alpha a_1 \sqrt{J} - N_R,$$

$$B = \frac{\alpha(a_2 - a_1 \cos \omega d)\sqrt{J} - N_R(1 - \cos \omega d)}{\sin \omega d},$$

where $a_1 = \sqrt{\frac{p_n}{qV_n^*}}$, $a_2 = \sqrt{\frac{n_n}{qV_p^*}}$.

Using (13) and (14), we obtain from (10) the final expression for the dependence $V(J)$ in the form:

$$V = \frac{J\alpha d}{q\mu_n(b + 1)N_R} \left\{ 1 - C_1 - C_2 \sqrt{J} \right\},$$

where $C_1 = \frac{2[1 - \cos(\omega d)]}{\omega d \sin \omega d}$, $C_2 = \frac{\alpha(a_1 + a_2)[1 - \cos(\omega d)]}{\omega d N_R \sin(\omega d)}$.

Thus, the obtained I - V characteristic has a proportional addition to the ohmic dependence $\sqrt{J}$. It should be remembered that this term, due to the periodic addition in the concentration distribution (1), is always less than the main term, which depends directly on the length of the base $d$.

However, if it is something around 20%, this may be sufficient for a noticeable change in the shape of the I – V characteristic.

**References**
