Semiconductor Physics, Quantum Electronics & Optoelectronics, 2021. V. 24, No 3. P. 248-254.

Semiconductor physics

Non-recombination injection mode

A.Yu. Leyderman[1], **R.A. Ayukhanov**[2], **R.M. Turmanova**[2], **A.K. Uteniyazov**[3,*], **E.S. Esenbaeva**[3]

[1]*Physical-Technical Institute of SPA "Physics-Sun", Uzbekistan Academy of Sciences, Uzbekistan, 100084, Tashkent, Chingiz Aytmatov str., 2B*
[2]*Research Institute of Semiconductor Physics and Microelectronics under National University of Uzbekistan named after Mirzo Ulugbek, Uzbekistan, 100057, Tashkent, Yangi Olmazor str., 20*
[3]*Karakalpak State University named after Berdakh, Uzbekistan, Republic of Karakalpakstan, 230012 Nukus, Abdirov str., 1*
[*]*E-mail: abat-62@mail.ru*

Abstract. A new type of injection regime is considered – non-recombination one, which can be realized in the forward direction of the current in structures of the p-n-n^+ type under conditions of opposite directions of ambipolar diffusion and drift of non-equilibrium carriers. This is possible only if the accumulation at the n-n^+ junction is stronger than the injection through the p-n junction, *i.e.*, the concentration of carriers at the boundary of the n-base with the n-n^+ junction is higher than their concentration at the boundary of the n-base with the p-n junction. In this mode, the dependences of the current on the voltage of the type $J \sim V$, and then $J \sim V^2$ appear. Experimentally, such a behavior of the current-voltage characteristic is observed for the Al–Al_2O_3–CdTe structure.

Keywords: non-recombination injection mode, accumulation of charge carriers at the n-n^+ junction, ambipolar diffusion, drift of carriers.

https://doi.org/10.15407/spqeo24.03.248
PACS 72.10.-d, 73.61.Ga, 73.40.Sx

Manuscript received 24.04.21; revised version received 24.06.21; accepted for publication 18.08.21; published online 26.08.21.

1. Introduction

Injection processes in semiconductor structures began to be studied back in the 50s of the recent century, as soon as the first p-n junctions and devices based on them were created – diodes, triodes, and then photocells, LEDs and many others [1–6]. Over the next years of research, the main injection modes were identified, in which operation of these devices usually occurs – diffusion modes and drift mode. In the former (diffusion) mode, the main role is played by diffusion of non-equilibrium carriers and their recombination, and, in the latter one – by the drift of non-equilibrium carriers and their recombination [7, 8]. These two types of injection modes have been well studied; many articles, reviews, and even monographs have been written about them [9–11]. The purpose of this work is to describe one more injection mode, in which the main role will be played by diffusion and drift of non-equilibrium carriers, while their recombination will be negligible.

2. Theoretical model and calculation

It is well known that the processes of relaxation of excitation for a semiconductor are described by a system of equations, which under stationary conditions for an n-semiconductor consists of:

1. Current equations:

$$J_n = q\mu_n nE + D_n \frac{dn}{dx}, \quad (1)$$

$$J_p = q\mu_p pE + D_p \frac{dp}{dx}, \quad (2)$$

moreover

$$J = J_n + J_p. \quad (3)$$

2. Equations for conservation of the number of free carriers:

$$\frac{dJ_n}{dx} = -qU \ , \tag{4}$$

$$\frac{dJ_p}{dx} = qU \ . \tag{5}$$

3. Poisson's equation

$$\frac{\varepsilon}{4\pi q}\frac{dE}{dx} = p + N_d - n \ . \tag{6}$$

Here, J_n and J_p are the current densities for electrons and holes, J is the total current density, μ_n and μ_p – mobility of electrons and holes, respectively, D_n and D_p are the diffusion coefficients for electrons and holes, respectively, q is the electron charge, n and p are the concentrations of electrons and holes, E is the electric field, ε – dielectric constant, N_d – concentration of doping shallow donors, U – rate of recombination of non-equilibrium carriers, which under stationary conditions in an n-semiconductor containing no impurities other than doping donors is the same for electrons and holes.

We will consider just this situation, when the rate of recombination of non-equilibrium carriers U obeys the classical Shockley–Read statistics, *i.e.*, recombination occurs through simple singly charged traps with the concentration of N_R, with $N_R << N_d$ and, therefore, is absent in Poisson's equation (6).

Under the considered stationary conditions, excluding from the system (1)–(6) the currents of electrons J_n and holes J_p, one can obtain the differential equation, which is the basic equations of the problem (see [11] for more details):

$$\frac{d}{dx}\left[D_{eff}\frac{dp}{dx}\right] - v_a\frac{dp}{dx} - U = 0 \ . \tag{7}$$

This equation describes the spatial distribution of non-equilibrium carriers, which is established as a result of action of ambipolar processes of carrier transport by diffusion and drift.

Here,

$$D_{eff} = \frac{D_n D_p}{D_n n + D_p p}(n + p) \tag{8}$$

is the ambipolar diffusion coefficient,

$$v_a = \frac{J}{q}\frac{\mu_n \mu_p}{\left(\mu_n n + \mu_p p\right)^2}(n - p) \tag{9}$$

is the ambipolar drift velocity,

$$E = \frac{\dfrac{J}{q\mu_n} - \dfrac{kT}{q}\left(b\dfrac{dn}{dx} - \dfrac{dp}{dx}\right)}{bn + p} \tag{10}$$

is the electric field, k – Boltzmann constant, T – temperature, $b = \mu_n/\mu_p$ – ratio of the electron and hole mobilities.

We emphasize once again that in the Poisson equation (6) there are no deep ionized impurity centers (for example, adherent centers), as well as N_R recombination centers, since their concentration, as usual, is considered as low, much less than the concentration of shallow doping N_d donors. Under these conditions, from (6) the quasi-neutrality condition follows:

$$n \approx p + N_d \ . \tag{11}$$

In this case, from (8) and (9) one can obtain simpler expressions for the ambipolar diffusion coefficient and the ambipolar drift velocity:

$$D_{eff} = \frac{D_n D_p \left(2p + N_d\right)}{\left(D_n + D_p\right)p + D_n N_d} \ , \tag{12}$$

$$v_a = \frac{J}{q}\frac{\mu_n \mu_p N_d}{\left[\mu_n N_d + \left(\mu_n + \mu_p\right)p\right]^2} \ . \tag{13}$$

It should be emphasized that the expressions for D_{eff} and v_a will become more complicated, if new terms appear in the Poisson equation describing the presence of deep charged impurities.

We want to dwell on the double injection processes occurring in the p-n-n^+ structure (Fig. 1a) under conditions of opposite directions of ambipolar diffusion and drift, as a result of which recombination of non-equilibrium carriers in the n-base can be suppressed, and realized will be the regime that we will call as the non-recombination injection one. These opposite directions are possible only under conditions of a positive sign of the concentration gradient $\frac{dp}{dx} > 0$, when accumulation of carriers at the n-n^+ isotype junction is stronger than the injection through the p-n junction and, accordingly, the carrier concentration at the n-n^+ junction is higher than that of the p-n junction: $p(d) > p(0)$ (Fig. 1b).

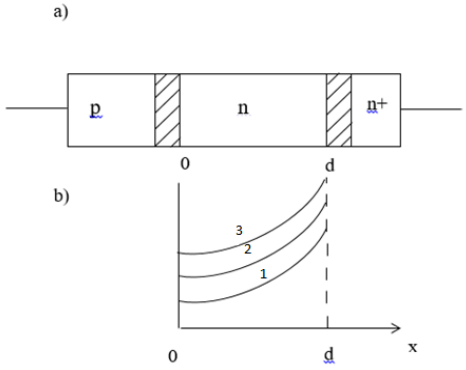

Fig. 1. Scheme of the p-n-n^+ structure (a) and the distribution of concentration inherent to injected carriers in the n-base under conditions of predominance of accumulation at the n-n^+ junction $p(d) > p(0)$ (b). Curve numbers correspond to currents $J_1 < J_2 < J_3$.

It is under these conditions, due to mutual compensation of diffusion and drift flows, a situation arises when generation-recombination processes play a less significant role than diffusion and drift, and the main equation of problem (7) takes the form:

$$\frac{d}{dx}\left[D_{eff}\frac{dp}{dx}\right]-v_a\frac{dp}{dx}\approx 0. \quad (14)$$

In order to calculate the voltage V on the base of this structure, it is necessary to take the integral of the electric field $E(x)$:

$$V=\int_0^d E dx, \quad (15)$$

where d is the length of the base.

Note that earlier, under conditions of opposite directions of ambipolar diffusion and drift, the effect of injection depletion was predicted theoretically [12] and then experimentally realized on many materials (see, for example, [1, 13]). This effect is realized not only under conditions of a high injection level, but also with the obligatory presence of a high concentration of adherent centers or other impurity centers with a large asymmetry of the electron and hole capture coefficients, which changes the Poisson equation (6). It is under these conditions that the opposite directions of diffusion and drift lead to suppression of recombination of non-equilibrium carriers, as a result of which the concentration of non-equilibrium carriers can decrease according to the law $p \sim \exp(-Jax)$, and the I–V characteristic of the type $V \sim \exp(Jad)$ appears (a is a parameter depending only on material properties). This effect is similar to the results considered in this work by the fact that it can also be realized practically under conditions of non-recombination injection mode.

As usual, assuming, that in the expression for the electric field (10) the current component prevails over the Dember one and taking into account the quasi-neutrality condition (11), one can rewrite (15) in the form:

$$V\approx\frac{J}{q\mu_n}\int_0^d\frac{dx}{(b+1)p+N_d}. \quad (16)$$

Under conditions of a low injection level, when $p < N_d$, from (16) one obtains:

$$V\approx\frac{Jd}{q\mu_n N_d}, \quad (17)$$

i.e.,

$$J\approx\frac{q\mu_n N_d V}{d}. \quad (18)$$

Thus, under low injection conditions, we have unusual ohmic voltage across the base of the structure. In this case, we do not need to use the ambipolar diffusion coefficient and the ambipolar drift velocity, which, under conditions $p < N_d$, can be easily obtained from (12) and (13):

$$D_{eff}\approx D_p, \quad (12a)$$

$$v_a\approx\frac{J}{qbN_d}. \quad (13a)$$

It is much more difficult to carry out studies under conditions of a high injection level, when $p > N_d$, and the ambipolar diffusion coefficient (12) and the ambipolar drift velocity (13) take the following forms:

$$D_{eff}\approx\frac{2bD_p}{b+1}, \quad (19)$$

$$v_a=\frac{J}{q}\frac{\mu_n\mu_p N_d}{(\mu_n+\mu_p)^2 p^2}. \quad (20)$$

In this case, the main equation of problem (14) takes the form:

$$\frac{d^2p}{dx^2}-\frac{v_a}{D_{eff}}\frac{dp}{dx}=0, \quad (21)$$

where

$$\frac{v_a}{D_{eff}}=\frac{JA}{p^2}, \quad (22)$$

moreover

$$A=\frac{N_d}{2qD_n(b+1)}. \quad (23)$$

We can represent $\frac{d^2p}{dx^2}$ as $\frac{d}{dp}\left(\frac{dp}{dx}\right)$ and rewrite equation (21) in the form:

$$\frac{d}{dp}\left(\frac{dp}{dx}\right)-\frac{JA}{p^2}=0. \quad (24)$$

The first integral of this equation:

$$\frac{dp}{dx}=-\frac{JA}{p}+C_1, \quad (25)$$

where C_1 is an arbitrary constant.

It must be remembered that the case $\frac{JA}{p}>C_1$, *i.e.* $\frac{dp}{dx}<0$, corresponds to the usual situation when in the p-n-n^+ structure $p(0) > p(d)$ directions of ambipolar diffusion and drift coincide and recombination cannot be neglected. We are interested in the case when $\frac{dp}{dx}>0$ and, therefore, $C_1>\frac{JA}{p}$ and $\frac{dp}{dx}\approx C_1$. Integrating (25) again, we get:

$$p=C_1x+C_2, \quad (26)$$

where C_2 is an arbitrary constant.

The constants C_1 and C_2 are determined from the conditions on the boundaries of the base with the p-n junction at the point $x = 0$ and with the n-n^+ junction at the point $x = d$:

for $x = 0$, $p(0) = C_2$,

for $x = d$, $p(d) = C_1 d + p(0)$, (27)

and correspondingly,

$$C_1 = \frac{p(d) - p(0)}{d}. \quad (28)$$

To determine the voltage across the base, one can continue to use expression (15), which, under conditions of the high injection level, takes the form:

$$V \approx \frac{J}{q\mu_n (b+1)} \int_0^d \frac{dx}{p}. \quad (29)$$

Using the expression for the concentration distribution (26) and the values of the constants (27) and (28), we obtain:

$$V = \frac{Jd}{q\mu_n (b+1) p(d)}. \quad (30)$$

Since we carried out the calculation using only the current component of the electric field, *i.e.*, in the expression (10), the Dember terms $\left(b\frac{dn}{dx} - \frac{dp}{dx}\right)$ were discarded, this unambiguously means that we assume p-n and n-n^+ junctions to be imperfect (not ideal) (see [14, 11] for more details). Accordingly, the concentration of electrons at the base boundary with the n-n^+ junction at the point $x = d$:

$$n(d) = \sqrt{\frac{Jn_n}{qV_p^*}}, \quad (31)$$

where V_p^* is the so-called rate of leakage of holes from the base through the barrier of the n-n^+ junction to the n^+-region (see [11]). Taking into account that $n_n = N_d$ and due to the high injection level $p(d) = n(d)$, using (30) and (31), we obtain the final expression for the dependence $J(V)$ in the form:

$$J = \frac{q\mu_n^2 (b+1)^2 N_d}{V_p^* d^2} V^2. \quad (32)$$

This current-voltage characteristic is similar to the well-known quadratic characteristic

$$J = \frac{9}{8} \frac{q\mu_n \mu_p \tau_p N_d}{d^3} V^2 \quad (33)$$

obtained from an equation of the type (7) under conditions of neglecting diffusion with the comparable contribution from the processes of recombination of non-equilibrium carriers and their drift, which is determined by the processes of ohmic relaxation of the space charge. However, it should be emphasized that the I–V characteristic (32) differs from (33) in independence from the lifetime of non-equilibrium carriers τ_p (since we assumed that the contribution of recombination is negligible) and a weaker dependence on the base length d.

4. Experiment and comparison with theory

The dependence of the $J \sim V^2/d^2$ type obtained in this work should be characteristic of structures with a not very long base ($d/L \approx 3$) under conditions of opposite directions of ambipolar diffusion and drift of non-equilibrium carriers. This situation, apparently, takes place under certain conditions in the Al–Al_2O_3–p-CdTe–Mo structure.

As it has been repeatedly noted in previous works [15, 16], the investigated Al–Al_2O_3–p-CdTe–Mo structure has a number of unique properties, in particular, it has good rectifying properties. As it has been shown in [15], the structure under consideration is a MOS structure in which CdTe has p-type conductivity, and the Al_2O_3 oxide can be considered as a wide-gap material of the n-type, so that the structure under study can be considered as R_{Oh}–n^+-p-R_{Oh} structure. Consideration of current transport in this structure with a long base ($(d/L) \approx 5\ldots7$) within the framework of the injection theory taking into account the possibility of recombination through complex pair complexes made it possible to obtain good agreement between theory and experiment [16].

Further, more thorough studies showed that the metal contact of Al with an n^+-semiconductor is not ideally ohmic, but may have a slight bending of the bands at the metal–n^+-semiconductor boundary, for example, due to creation of a blocking contact of the n^+-semiconductor with the metal. As a result, a small space charge arises at the boundary of the n^+-semiconductor with the metal. A scheme of the structure under study is shown in Fig. 2.

The I–V characteristic of this structure with a thin n^+-layer under conditions when plus (+) is applied to the Al contact and minus (–) is applied to the opposite Mo contact is shown in Fig. 3.

This I–V characteristic is completely beyond the description of the classical theory of current transport in p-n-structures. It can be seen that all I–V characteristics are power-law; therefore, the voltage across the base is decisive, and the voltage across the n^+-p junction and

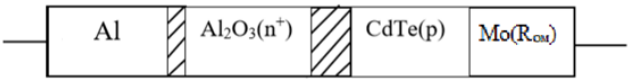

Fig. 2. Scheme of Al–Al_2O_3–p-CdTe–Mo structure. Areas of space charges metal n^+-semiconductor and n^+-p junction are dashed.

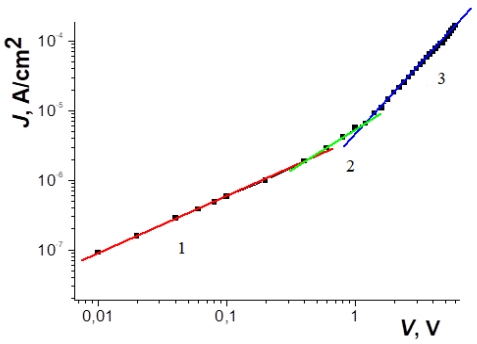

Fig. 3. Current-voltage characteristic of type $J \sim V^{\alpha}$ with different slopes in a double logarithmic scale: α = (0.84, 1, 2) for the regions 1 to 3, respectively.

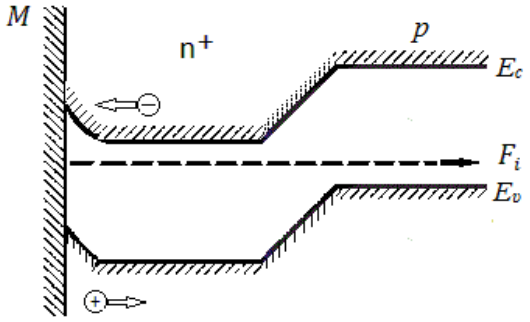

Fig. 4. An approximate energy diagram of the metal–n^+-p semiconductor structure, the n^+-layer plays the role of a base.

at the n^+-semiconductor–metal boundary does not play any significant role and can be neglected. It can be seen from the figure that the structure under study has first the $J \sim V$ dependence, and then $J \sim V^2$. Apparently, this behavior of the I–V characteristic can be explained, if we take into account that, as noted above, the metallic contact of the n^+-semiconductor with Al is not ohmic, but weakly injects holes (see Fig. 4). Then the holes will enter the n^+-semiconductor, significantly affecting the processes occurring in it. Since at the same time electrons arrive from the side of the n^+-p junction, ambipolar processes occur in the n^+-region, which are similar to the usual processes with double injection. Thus, when we apply "plus" to the Al contact, and "minus" – to the opposite Mo contact, in the n^+-layer there are contrary movements of electrons coming from the n^+-p junction and holes diffusing from the near-contact layer of n^+-metal. As a result, ambipolar processes develop, and an electron-hole plasma appears. Moreover, since there are, of course, there are more electrons at the boundary of n^+-base with n^+-p junction than holes at the n^+-semiconductor–metal contact, and due to the quasi-neutrality condition, electrons and holes tune to each other, eventually a concentration gradient $\frac{dn}{dx} > 0$ (and, respectively, $\frac{dp}{dx} > 0$) appears.

Since the movement of electrons occurs from the boundary with the n^+-p junction towards the metal contact, and holes diffuse towards them, moving from the contact with the metal, we realize the first requirement of the theory – the opposite directions of diffusion and drift of non-equilibrium carriers.

Since the n^+-layer is rather thin, the second condition is also easily fulfilled – the ratio d/L is small $(d/L) \approx 3$, we have $(d/L) \approx 1\ldots1.5$. And finally, under these two conditions, the change of the current-voltage characteristic $J \sim V$ to $J \sim V^2$, which is predicted by the theory, is realized. These three points suggest that, apparently, this course of the current-voltage characteristic is well described by the above theory.

5. Conclusions

Thus, the work considers the processes of double injection occurring in the p-n-n^+ structure under conditions of opposite directions of ambipolar diffusion and drift, as a result of which the recombination of non-equilibrium carriers in the n-base can be suppressed, and the regime will be realized, which we called the non-recombination injection mode. It has been shown that under these conditions, due to mutual compensation of diffusion and drift flows, a situation arises when generation-recombination processes play a less significant role than diffusion and drift, and current-voltage characteristics of the type $J \sim V$ and then $J \sim V^2$ type appear. It is proved that in the Al–Al_2O_3–CdTe structure this non-recombination injection mode is apparently realized. The course of the current-voltage characteristic is explained by the fact that the metal contact with the n^+-semiconductor is not ideally ohmic, but has a slight bending of the band gaps at the metal–n^+-semiconductor boundary due to creation of a blocking contact of the n^+-semiconductor with the metal at this boundary. Then this contact will not be ohmic, but will be a weakly injecting (hole) contact. As a result, ambipolar processes will occur in the n^+-region, which will lead to the appearance of power-law dependences of the $J \sim V$ and $J \sim V^2$ type.

It is necessary to emphasize that the characteristic $J \sim V^2$ is very widespread and can appear in semiconductor structures for a variety of reasons, although there is a very widespread misconception to always associate it with the so-called drift regime of ohmic relaxation, which is described by the I–V characteristic of type (33) under the conditions of "long" base ($d/L > 10$) and has a cubic dependence on the length of the base of the type $J \sim V^2/d^3$, and this dependence is very rarely observed in practice. Meanwhile, the dependence of the $J \sim V^2$ type is easily realized in structures of the p-n-n^+ type under conditions with a not very long base (d/L = 3…7), the presence of a minimum in the distribution of the concentration of free carriers in the base and imperfect p-n and n-n^+ contacts, and it can also appear in the non-recombination injection mode.

References

1. Sze S.M., Ng Kwok K. *Physics of Semiconductor Devices*. 3rd ed. Wiley, 2006.
2. Seeger K. *Semiconductors Physics*. Springer-Verlag Berlin Heidelberg, 2004. https://doi.org/10.1007/978-3-662-09855-4.
3. Sharma R.K., Rawal D.S. (Eds). *The Physics of Semiconductor Devices*. Proc. IWPSD 2017. Springer, 2019. https://doi.org/10.1007/978-3-319-97604-4.
4. Fonash S.J. *Solar Cell Device Physics*. Academic Press, 2010.
5. Grundmann M. *The Physics of Semiconductors*. *An Introduction Including Nanophysics and Applications*. Springer-Verlag Berlin Heidelberg, 2010. https://doi.org/10.1007/978-3-642-13884-3.
6. Vikulin I.M., Kurmashev Sh.D., Stafeev V.I. Injection-based photodetectors. *Semiconductors*. **42**, No 1. P. 112–117. https://doi.org/0.1007/s11453-008-1016-y.
7. Lampert M.A., Mark P. *Current Injection in Solids*. Academic Press, New York & London, 1970.
8. Zyuganov A.N., Svechnikov S.V. *Contact-Injection Phenomena in Semiconductors*. Naukova dumka, Kiev, 1981 (in Russian).
9. Baron R., Mayer J.W. Ch. 4. Double Injection in Semiconductor. *Semiconductors and Semimetals*. 1970. **6**. P. 201–313. https://doi.org/10.1016/S0080-8784(08)62633-2.
10. Rosenberg L.M., Lampert M.A. Double injection in the perfect insulator: Further analytic results. *J. Appl. Phys.* 1970. **41**, No 2. P. 508–521. https://doi.org/10.1063/1.1658705.
11. Adirovich E.I., Karageorgy-Alkalaev P.M., Leyderman A.Yu. *Current of Double Injection in Semiconductors*. Sov. Radio, Moscow, 1978 (in Russian).
12. Leyderman A.Yu., Karageorgy-Alkalaev P.M. On the theory of sublinear current-voltage characteristics of semiconductor structures. *Solid State Commun.* 1978. **27**, No 4. P. 339–341. https://doi.org/10.1016/0038-1098(78)90529-X.
13. Peculiarities of the current–voltage characteristic of *n*-GaP–*p*-$(InSb)_{1-x}(Sn_2)_x$ heterostructures. *Techn. Phys. Lett.* 2020. **46**, No 11. https://doi.org/10.1134/s1063785020110279.
14. Fletcher N.H. General semiconductor junction relations. *J. Electron*. 1957. **2**, No 6. P. 609–610. https://doi.org/10.1080/00207215708937064.
15. Uteniyazov A.K., Ismailov Q.A. Effect of ultrasound irradiation on the electro-physical properties of the structure of Al–Al_2O_3–CdTe. *Semiconductor Physics, Quantum Electronics & Optoelectronics*. 2019. **22**, No 2. P. 165–170. https://doi.org/10.15407/spqeo22.02.165.
16. Uteniyazov A.K., Leyderman A.Yu., Ayukhanov R.A., Esenbaeva E.S., Gafurova M.V. Features of current transport in Al–Al_2O_3–*p*-CdTe–Mo structure. *Semiconductor Physics, Quantum Electronics & Optoelectronics*. 2020. **23**, No 4. P. 339–345. https://doi.org/10.15407/spqeo23.04.339.

Authors and CV

Ada Yu. Leyderman (1936–2021) defended her PhD thesis in Physics and Mathematics (Semiconductor Physics) in 1964 at the Physical-Technical Institute of Academy of Sciences of Uzbekistan, she defended her thesis of Doctor of Science (DcS) in Physics and Mathematics (Semiconductor Physics) in 1989 at the Leningrad Politechnical Institute (Saint-Petersburg, Russia). She was a chief researcher in the Laboratory of Crystal Growth, Physical-Technical Institute of Academy of Sciences of Uzbekistan. A.Yu. Leyderman was awarded with the order "Dustlik". She was the author of over 170 publications, 3 patents, 6 textbooks. The area of her scientific interests included injection and photoelectric phenomena in semiconductors and in semiconductor structures based on them, interaction of impurities and defects in semiconductors, self-organization processes and synergetic phenomena in semiconductors with impurities and defects.
https://orcid.org/0000-0001-7133-0806.

Ayukhanov Rashid Akhmetovich. Doctor of Science in Physics and Mathematics, professor, Leading Researcher at the Physical-Technical Institute of Scientific Production Association "Physics-Sun", the Academy of Sciences of the Republic of Uzbekistan.
Research interests: processes of current transfer in low-dimensional structures; polariton effects in bulk crystals and low-dimensional structures; photoelectric phenomena in semiconductors and in low-dimensional structures. Publications: 32 articles. E-mail: alia52@bk.ru

Uteniyazov Abatbay Kurbaniyazovich. PhD in Physics and Mathematics, Associate Professor at the Department of Semiconductor Physics of Karakalpak State University, Nukus, Uzbekistan. Authored over 60 publications and 3 textbooks
Research interests: injection and photoelectric phenomena in semiconductors and semiconductor structures based on them.
https://orcid.org/0000-0003-0705-0425.
E-mail: u.abat1962@gmail.com

Turmanova Raymash Maxmutovna. Basic doctoral student of the 1st year. Ministry of Higher and Secondary Education of the Republic of Uzbekistan, Research Institute of Semiconductor Physics and Microelectronics at the National University of Uzbekistan. E-mail: raymashmaxmutovna@gmail.com

Esenbaeva Elmira Seytjanovna. Applicant, assistant of the Department of Semiconductor Physics, Karakalpak State University, Nukus, Uzbekistan. Author of more than 10 scientific papers.
E-mail: esenbaeva_3187@mail.ru

Режим нерекомбінаційної інжекції

A.Yu. Leyderman, R.A. Ayukhanov, R.M. Turmanova, A.K. Uteniyazov, E.S. Esenbaeva

Анотація. Розглянуто новий тип інжекційного режиму – нерекомбінаційний, який може бути реалізований у прямому напрямку струму в структурах p-n-n^+ типу в умовах протилежних напрямків амбіполярної дифузії та дрейфу нерівноважних носіїв. Це можливо лише в тому випадку, якщо накопичення на n-n^+ переході сильніше, ніж інжекція крізь p-n перехід, тобто концентрація носіїв на межі n-база – n-n^+ перехід перевищує їх концентрацію на межі n-база – p-n перехід. У цьому режимі з'являються залежності величини струму від напруги типу $J \sim V$, а потім $J \sim V^2$. Експериментально така поведінка вольт-амперної характеристики спостерігається для структури Al–Al_2O_3–CdTe.

Ключові слова: режим нерекомбінаційної інжекції, накопичення носіїв заряду на n-n^+ переході, амбіполярна дифузія, дрейф носіїв заряду.