UDC 621.315.592

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DETERMINATION IN MOBILITY OF NON-EQUILIBRIUM CARRIERS CONSIDERING MOTION VELOCITY DISTRIBUTION

The particularities of contact influence on processes of current rise in crystal at the expense of non-equilibrium charge were investigated. The procedure to determine carrier active mobility for the case of considerable asymmetry in their velocity distribution was developed

The mobility of charge carriers is one of the most important values that characterized the electric properties of semiconductors. This value determines such device qualities as sluggishness, frequency response, etc.

The value of mobility μ is defined as drift velocity υ_{dr} fall at the unit of external field strength E:

$$\mu = \frac{v_{\partial p}}{E} \qquad (1)$$

And drift velocity is realizes as such medium rate being equal for all carriers at which they transfer the same electric charge between contacts at distance l [1, 2]:

$$v_{\partial p} = \frac{l}{t} \qquad (2)$$

Where t is time to pass this distance for current rise carriers. If voltage U is applied to contacts we obtain:

$$\mu = \frac{l^2}{U \cdot t} \qquad (3)$$

The l and U appeared in this equation are the large-scale parameters and measure experimentally. Drift time t – large-scale parameter too, and owing to thermal motion this time is different for each carrier. Calculation of active number for value μ offers the main difficulty to define mobility and crystal conductivity σ:

$$\sigma = e n \mu . \qquad (4)$$

The selective approach both for carriers already located in element at the moment of field connection and carriers injected from contact was used in our work.

During the first test we studied equilibrium carriers, during the second one – non-equilibrium carriers because their energy is not ---- and does not depend on energy of sample crystal lattice. For equilibrium carriers already located in crystal at the moment of field connection the symmetric distribution in velocities is characteristic phenomenon (Fig. 1a). The group of particles has the medium velocity υ_0 with some quantity of slower and quicker participants.

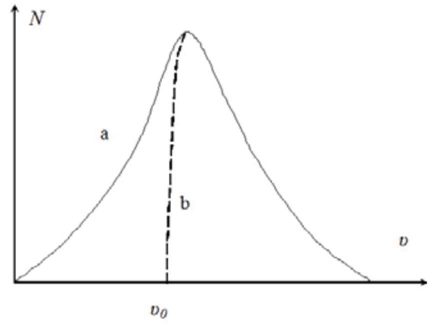

Fig. 1. **The distribution for N quantity of particles for different velocities υ in case of equilibrium (a) and injected (b) charge carriers**

When field of the corresponding polarity is connected they begin to move to cathode. The quicker particles reach cathode first. As their quantity is small (the right part of curve 1a) collector potential increases comparatively slowly. Then the basic group of carriers with velocity ~ υ_0 reaches cathode and potential of contact increases with maximum rate. The slower carriers reach cathode the latter (the left part of curve 1a) and collector potential again rises slowly. The time dependence of signal change is of S-shape [3, 4] and is shown in Fig. 2a.

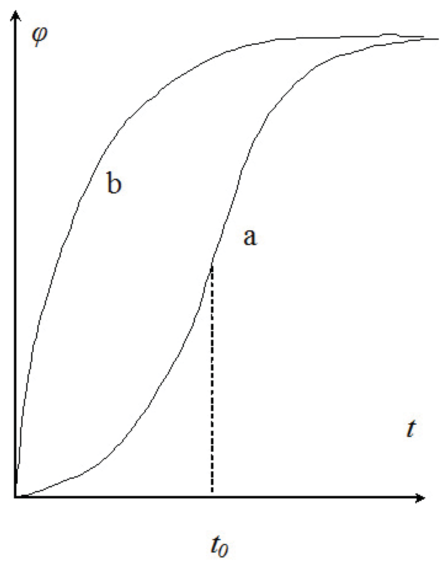

Fig. 2. **Increase of collector potential from the moment of field connection (t = 0) for equilibrium (a) and contact introduced (b) charge**

One should note that the shape of curve 2a is not the direct reflection of 1a distribution because of two reasons. Firstly, if the vector of additional velocity for carriers at the expense of field draw effect is equal in value and direction, then the vector of thermal velocity directed chaotically increases the variation in values of total velocity for each particle. Secondly, charge space distribution influences too. Independently on primary velocity the quick and slow charge carriers were located uniformly. As the result, the slower particles from distribution 1a at the moment of field connection can be located nearer to the probe and contributed quickly to raise of its potential $\varphi(t)$.

The shape of curve $\varphi(t)$ in Fig. 2a makes possible to determine the characteristic time of drift t_0 from inflection point at the moment when the basic number of charge carriers reach the probe. This parameter is observed as current forming value. The practical study of $\varphi(t)$ oscillograms gives the active value of mobility for equilibrium carriers.

The situation changes when non-equilibrium carriers entered crystal from the contact are observed. High-ohmic samples are usually investigated. It means that concentration of intrinsic charge n_0 is not high comparing with concentration of introduced charge Δn: $n_0 << \Delta n$. Non-equilibrium charge Δn just defines in this case the conductivity of crystal.

Moreover, the charge Δn should overcome energy barrier at metal-semiconductor boundary to enter the sample even for good ohmic contacts. The carriers with low velocities (and small energy too) cannot overcome the barrier. Especially as the presence of ohmic contact is the utmost situation. In practice the contacts to sample are more or less ohmic. This increases the height of barrier and decreases the portion of injected charge.

This is the cause that polarity of applied voltage is selected in such a way that polarity of external field was opposite to barrier field. Its height decreases simultaneously. But there is the limitation to apply the high injecting voltages. In this case the contribution of equilibrium carriers raises with arbitrary coordinate, the opposite collecting barrier, thermal effects influence at higher values of current. So, one cannot correct the emitter barrier. As result, the distribution in Fig. 1 for emitter contacted carriers is observed as curve 1b [5, 6].

We note that the transition from curve 2a to plot 2b can be the criteria for contact quality. This is of the special interest as the test procedure. But the parameters can not be always improved to reach the ideal shape of curve 2a. This is impossible if one needs to study the mobility in quantity-produced or operating device.

Let`s study the abscissa axis. The absolute value on vertical scale either in Figure 1 or in Fig. 2 was taken in arbitrary units comparing with the maximum value.

The changes in distribution of N particle number (Fig. 1b) are represented in curve of Fig. 2. The slow carriers are already absent. Large quantity of high-velocity carriers reach collector immediately. And signal increases quickly as shown in Fig. 2b.

Besides, curve 2b should be slightly shifted relatively to the origin of coordinates. Carriers located previously in crystal were distributed homogeneously along the volume. Part of them was located in the vicinity of contact to collector. So, curve 2a raises from the moment $t = 0$. On the contrary, all the added carriers at zero time locate from collector at distance equal to intra-probe one. And they need some time to overcome it. The graph 2b will be observed later. But probes are usually located rather nearer to each other and velocity of injected carriers is primarily high, practically this shift in curve 2b is observed comparative with thickness of oscillogram line and did not presented in Fig. 2.

The shape of dependence 2b hampers to determine value t_0 because there is no characteristic point in curve being evidently observed.

As criteria to look-up value t_0 we propose to search point on curve 2b where the square of inscribed rectangle would be the maximal. And both criteria to shape current will be taken into consideration (see equations 3 and 4): maximum number of participating carriers (vertical axis) and optimal short time of their motion (abscise line).

The task comes to geometric examination. And the axis of time is suitable to swing to the opposite way, i.e. to count off not from the moment of field connection but the opposite one – to the moment when equilibrium was attained. In this case the plot is completed between scales. We also note that traditionally used shape of plots 1 and 2 is mirror. In Fig. 1 from the left to the right we at first show the carriers with slow velocities, then – with higher ones. In Fig. 2, on the contrary, the high-rate carriers do their contribution, and then the insertion of charge with slow drift velocities is observed.

In Fig 3 one should search the point with maximal square of inscribed rectangle $S(t_0) = \varphi(t_0) \cdot t_0$. It is obvious that this point will tend to zero at the edges of plot when $\varphi \to 0$ or $t \to 0$ (dash-dot line $S(t)$). In operating point t_0 show the highest value.

For this point

$$\frac{dS(t)}{dt} = \frac{d}{dt}[\varphi(t) \cdot t] = 0 \qquad (5)$$

The shape of $\varphi(t)$ dependence is not prescribed. So,

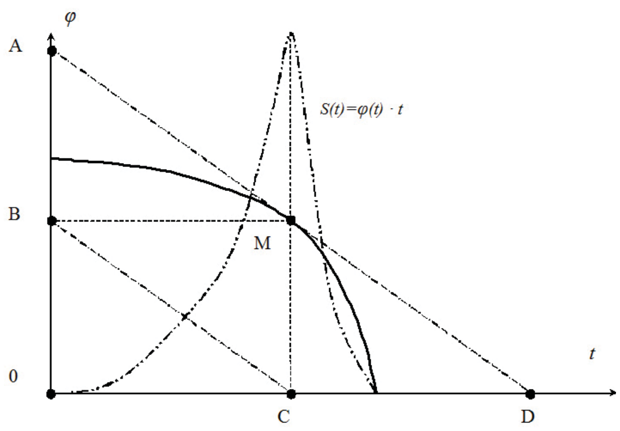

Fig. 3. The criteria to search operating point t_0 for non-equilibrium carriers

$$\frac{d\varphi(t)}{dt} \cdot t + \varphi(t) = 0 \qquad (6)$$

or $$\frac{d\varphi(t)}{dt} = -\frac{\varphi(t)}{dt}. \qquad (7)$$

The sign «–»has no physical meaning. It simply describes the fact that the value of function along vertical scale decreases with increase of the value along X-axis in the chosen reading system.

In equation (7) the left value is the slope of tangent line to plot $\varphi(t)$ in operation point. And the left value is the slope of diagonal in rectangle *OBMC*, inscribed in operating point. Or $\angle BCO = \angle ADO$. The straight lines *BC* and *AD* are parallel. As *CM* || *OB* and *BM* || *OD* in plotting, then the boxes *BCMA* and *BCDM* are parallelograms. So, *BC* = *AM* and *BC* = *MD*. Or *AM* = *MD*. The tangent line in operating point divides in two within the ranges of oscillogram changes.

The developed criteria to search the operating points for samples with non-ideal contacts are highly suitable to be applied in practice. For oscillograms obtained in real conditions and taking into account the particularities of carrier injection into crystal when the curves of shape 2b are observed one should choose such value of effective time for carrier drift between contacts t_0 when tangent line to plot $\varphi(t)$ divides in two in the point $t = t_0$.

We note that the present result was obtained without application of manifested appearance for function $\varphi(t)$. This means that the developed procedure is universal for wide class of smooth curves described the raise of collector potential ignoring the specificity of diffusion and recombination processes in crystal itself and depends only on changes of carrier dispersion in velocities when emitter contact was overcome.

The suggested model efficiently allows determining the transit time, and thus the carrier mobility from the distribution maximum (fig. 1b).

It should be pointed out that just because of the velocity distribution of the particles there is neither average nor typical mobility. It appears to be different depending on the carrier groups of different velocity intervals in Fig. 1b. Under this conditions, it is possible only to speak about some effective mobility value, which can adequately reflect the conditions of current transfer.

It is possible to get the calculation of the contribution of all the fractions from the range of possible velocities only by taking as the time of passing the distance between the emitter and the collector where

$$t = \frac{S}{\Delta t}, \quad (8)$$

S - is the area under the curve of the function $U(t)$ (fig. 2b) on the increasing curve section during the time Δt from the process start till the saturation beginning.

Graphically, it corresponds to the point of intersection on the graph with the side of an equivalent rectangle. Physically, this approach means that the model is accepted when all carriers are moving at the same drift speed. And the magnitude of this velocity provides the conductivity actually observed in accordance with (4, 1).

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The article is received in editorial 21.07.2013

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Abstract

The particularities of contact influence on processes of current rise in crystal at the expense of non-equilibrium charge were investigated. The procedure to determine carrier active mobility for the case of considerable asymmetry in their velocity distribution was developed.

Key words: the contacts, the current, the mobility, the crystals.

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ОПРЕДЕЛЕНИЕ ПОДВИЖНОСТИ НЕРАВНОВЕСНЫХ НОСИТЕЛЕЙ С УЧЁТОМ РАСПРЕДЕЛЕНИЯ СКОРОСТЕЙ ИХ ДВИЖЕНИЯ

Резюме

Изучены особенности влияния контактов на процессы формирования тока в кристаллах за счёт неравновесного заряда. Указан способ определения действующей подвижности носителей для случая значительной несимметрии их распределения по скоростям.

Ключевые слова: ток, контакты, кристаллы, подвижность

УДК 621.315.592

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ВИЗНАЧЕННЯ РУХЛИВОСТІ НЕРІВНОВАЖНИХ НОСІЇВ З УРАХУВАННЯМ РОЗПОДІЛУ ШВИДКОСТЕЙ ЇХ РУХУ

Резюме

Розглянуто особливості впливу контактів на процеси формування струму в кристалі за рахунок нерівноважного заряду. Вказано засіб визначення дієвої рухливості носіїв у випадку значної несіметрії їх розподілу за швидкостями.

Ключеві слова: струм, контакти, кристали, рухливість