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PECULIARITIES IN PHOTOEXCITATION OF CARRIERS FROM DEEP TRAPS

This work is devoted to the studies in nuances of the processes proceeding at excitation of charge carriers from bound state to current conducting one. The effect for infrared quenching of photocurrent was used as the method to investigate the mechanism of trap injection from R-centers. It was shown that after photoexcitation the hole could recurrently and spontaneously return to the source center. The anomalously low quantum yield for IR-light, and also the change in spectral distribution of quenching coefficient on applied field and light intensity point out this.

At excitation from local center by, for example, light, the non-equilibrium carrier does not take part in current flow straight away. In dependence on the magnitude of applied electric field and temperature it remains during some time in the vicinity of this center. And it, of course, pays to decrease its energy coming back to the trap. This is promoted by the change of trap charge state after the act of excitation. Such oscillations of release-capture, probably repeated, do not observe anyway in electric current, registered from the outside, because the coordinate of such charge carriers does not change. Owing to the above mentioned cause, these stages of excitation remained not studied.

As the method of investigation we chose the effect of current infrared quenching. In our opinion, such approach has several advantages.

First of all, if the studied crystals saturated with S- and R-centers to the sufficient degree, the distance between them is not large. In this case the holes, dislodged out of slow recombination centers by IR-light, come only several translations of crystal lattice and get at R-centers distributed uniformly, the capture lengths are more or less standardized. In the usual situation these processes are concealed by scattering, accidental capture at traps, foreign recombination channels etc.

Besides, the specificity of IR-quenching allows to operate independently both the parameters of current-forming intrinsic light and the intensity and spectral content of IR-light responsible for current release exceptionally.

At last, the effect of IR-quenching allows to pick up and investigate the mechanism of carriers ejection from one specific class of centers, whereas in usual case one has to deal with the whole spectrum of traps which processes of trap depletion dazzled each other.

The mentioned specificities of IR-quenching make it the sensitive and flexible procedure to study the details in photoexcitation of extrinsic carriers.

The quantum yield β for monochromatic long-wave light is determined directly in experiments. We proceeded from the fact that namely this parameter defined, from one hand, the number of appeared free carriers, and from the other hand, the number of photons consumed for this. The difference in them is just connected with carriers recurrences, waste for current formation, to the source center.

At the same time, the investigation in changes taking place with the quenching itself under influence of external factors is of great interest. As the external influence we will consider the change in intensity both of exciting and quenching light irrespective of each other, and also the change in applied voltage and operating temperature.

The overall experimental results for the behaviour of quenching coefficient Q under the changes in values of light fluxes are presented in Figure 1.

As the basic results, the curve 2, measured at the same intensities of intrinsic and quenching light both in case 1a and in case 1b, was taken. In the left part of Figure (1a) it is shown, how the value Q changes under variation of exciting light at unchanged quenching one. On the contrary, in Figure 1b the intensity of exciting light for the reference curve was fixed and the intensity of quenching light changed.

All the plots in Figure 1 were obtained under stationary conditions. In each point, rather long relaxation (up to 7—10 min.) was delayed to avoid the processes of photocurrent adjustment [1].

First of all, let's note, that the short-wave maximum (Fig. 1) was found to be below the long-wave one at any combinations of intensities. This is explained by thermal pumping of captured carriers. At the expense of photon absorption, the part of holes from the ground R-level transits to the excited R'. And occupation of these levels by holes just defines the corresponding maxima. For this reason, as follows form Figures 1*a* and 1*b*, the first maximum (short-wave) is found to be more sensitive to the changes in intensities of each light. In this connection, namely it was chosen to determine β value (see Figure 3).

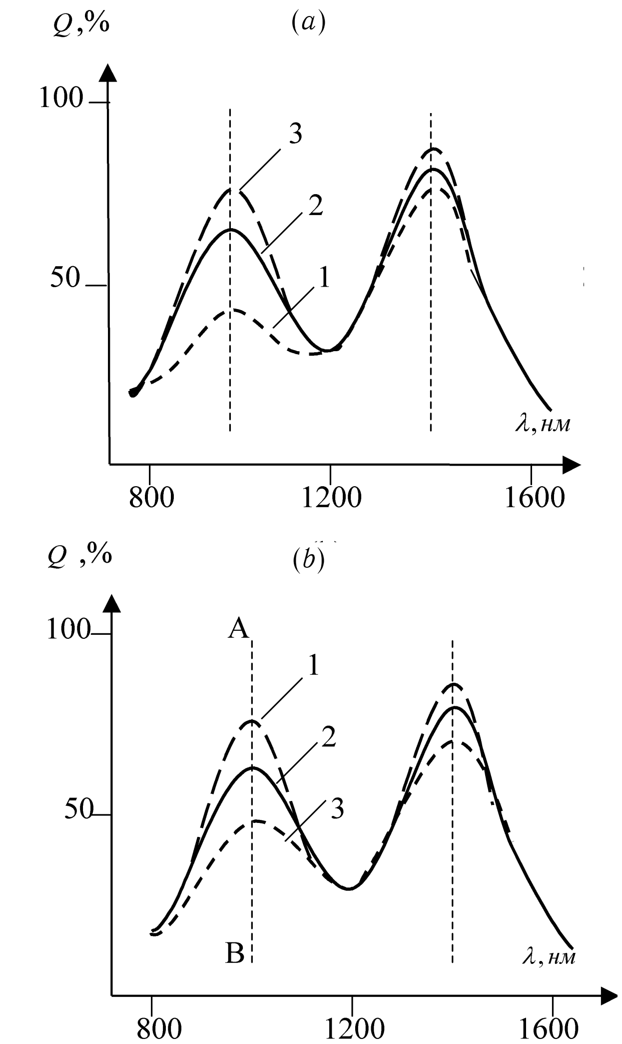

Fig. 1. Dependence of quenching value on intensities of applied light: *a*) $L_г = \text{const}$; $L_{в1} > L_{в2} > L_{в3}$; *b*) $L_в = \text{const}$; $L_{г1} > L_{г2} > L_{г3}$

As it is observed in Figure 1*b*, the lower the intensity of quenching light at $L_b = \text{const}$, the lower the value Q. And for the lower intensities of internal excitation, this is observed strikingly. One managed to create situations experimentally, when short-wave maximum disappeared at all.

At the same time, under the invariable intensity of quenching light (see Figure 1*a*), the value of quenching light increases as the decrease in excitation L_b. And this increase is observed to be higher if the applied intensities $L_г$ negligible.

In Figure 2, the curve «*a*» is measured under the same conditions as the basic curves of Figure 1*a*, *b*. The sample at that time was supplied with the voltage 50 V. As it is observed from the Figure, the decrease in this voltage steps down both $Q(\lambda)$ maxima. And such behaviour was characteristic for all combinations of $L_г$ and L_b.

And as it was previously, the second maximum was found to be higher than the first one, which is connected with the described thermal pumping between centers of slow recombination. With the decrease in applied voltage, we observe the increase in this change (see Figure 2).

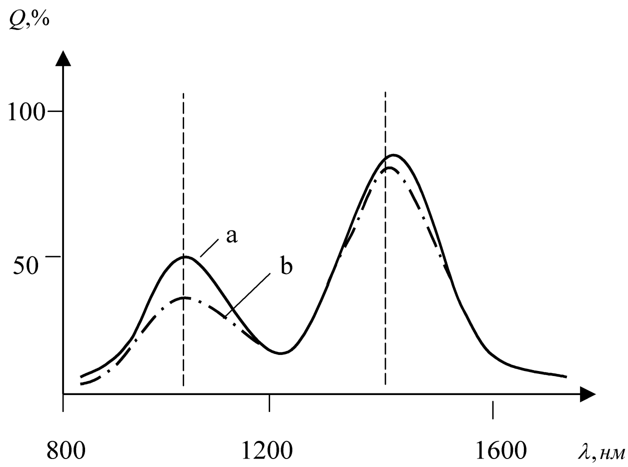

Fig. 2. Dependence of quenching value on the applied electric field: *a*) the sample is supplied with 50 V; *b*) the sample is supplied with 30 V

To define quantum yield of IR-quenching we used the formula adopted out of the paper [2]:

$$Q = \left[\left(1 - \frac{\tau_p}{\tau_n}\right) + \frac{L_г \alpha \beta \tau_p}{L_в \alpha' \beta' \tau_n}\right] \cdot 100\%, \qquad (1)$$

where Q — coefficient of IR-quenching, τ_n, τ_p — lifetimes of non-equilibrium electrons and holes; $L_в$, $L_г$ — the number of exciting and quenching light quanta dropped; α, α' — the parts of these phonons, absorbed in our sample; β, β' — quantum yields under light excitation and quenching.

The dependence (1) was derived under condition of considerable luminous fluxes of exciting and quenching light, and the intensity of quenching light is higher than the intensity of exciting one.

The form for absorption coefficient Q in formula (1) is not suitable for experimental processing. So we transform the denominator of the 2nd component in formula (1) with due regard for:

$$n = L\alpha\beta, \qquad (2)$$

where n — concentration of charge generated by intrinsic light; and the meaning of L, α, β corresponds to formula (1).

At that time we use

$$j = \sigma E; \ \sigma = en\mu. \qquad (3)$$

Taking into account that

$$j = \frac{I}{S}; \ E = \frac{U}{l}, \qquad (4)$$

where I — current flowing under action of exciting light only; and $l = 1,2$ mm — sample length between contacts; $S = 1$ mm^2 — cross-section of sample, we obtain

$$L_в \alpha' \beta' = I(в) D; \qquad (5)$$

where the constant $D = \frac{l}{US\mu e}$; in our case is

$$D = 7.14 \cdot 10^{21} \cdot A^{-1}\ \text{м}^{-3}. \qquad (6)$$

After the mentioned transformations, formula (1) with account of (5)—(6) allowed to determine the coefficient β by the slope angle of curve $Q(L_e)|_{I(в)}$.

In Figure 3, the experimental dependencies of coefficient Q on intensity of quenching light with wavelength 1100 nm at fixed fluxes of exciting light are presented. One can say that the view of Figure 3 corresponds to the section of plot 1*b* along *AB* line.

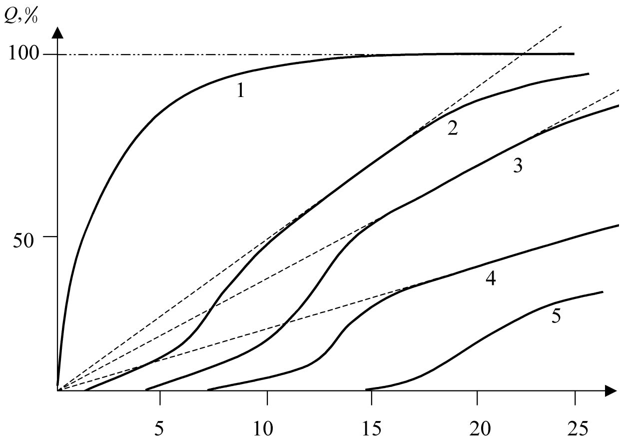

Fig. 3. Dependence of quenching value on the number of infrared photons being incident on sample surface at the registered excitation level: 1. $I_в = 1.2$ lx; 2. $I_в = 2.6$ lx; 3. $I_в = 4.25$ lx; 4. $I_в = 9.8$ lx; 5. $I_в = 19.4$ lx

As it is observed from this Figure, the plots did not have the linear section in the case when intensity of exciting light was too low (curve *1*) and too high (curve *5*) in comparison with intensity of quenching light. Obviously, the conditions for derivation of formula (1) were not kept for these curves. The area of linear dependence was observed by us for curves *2—4* within the range of quenching light intensity $(12—25) \cdot 10^{15}$ $c^{-1}mm^{-1}$ at intensities of exciting light from 2,6 up to 9,8 lx.

It is observed that as the increase in intensity of exciting light, the slope of plots 2—4 in the linear section decreased. The extrapolation of linear sections for curves *2—4* was found at the origin of coordinates in Figure 3.

In correspondence with formula (1) this means that the first component in square brackets, at values $L_e = 0$, is also equal to $1 - \frac{\tau_p}{\tau_n} = 0$. In this case it follows that $\tau_p \approx \tau_n$, i. e. the lifetime of free holes corresponds approximately to the lifetime of free electrons. Unfortunately, we failed to extend the changes in ratio for lifetimes at different intensities of intrinsic and exciting light. In the subsequent calculations we consider $\frac{\tau_p}{\tau_n} = 1$. In the account of this and the dependencies (5), (6), the formula (1) takes the form

$$Q = \left[\frac{L_e \alpha}{I(в) D} \beta\right] \cdot 100\%. \qquad (7)$$

The coefficient α was determined by spectrophotometer SF-26 at wavelength 1100 nm. At first, the mica substrate was inserted into the spectrophotometer, and it was the same as for investigated samples, and the intensity of output flux $\alpha_1 I_0$ was measured. Then, at the same conditions, the crystal transmission together with substrate $\alpha_2 I_0$ was measured. The reflection of infrared light is practically absent. So, the transmission coefficient is defined by formula

$$\alpha = \frac{\alpha_1 I_0 - \alpha_2 I_0}{\alpha_1 I_0}. \qquad (8)$$

Within the ranges of spectrophotometer output slit from 0,5 up to 0,7 mm, the value $\alpha = 0{,}96$ was obtained. At the account of this, it was determined: for curve *2* in Figure 3 — $\beta_2 = 0{,}026$; for curve *3* in Figure 3 — $\beta_3 = 0{,}049$; for curve *3* in Figure 3 $\beta_4 = 0{,}072$.

The value β is observed to remain anomalously low in the whole area of the applied photoexcitation intensities. And the coefficient of light absorption at that time is close to 1. This means that for the final release of each hole from R-center, a few tens of IR-photons are consumed. The hole returns multiply to the source level, until the applied fields will entrain it outside the limits of capture cross-section. The changes of Q with the intensities of both light fluxes and with field, observed above, indirectly confirm the same.

Some increase in β with photocurrent raise, and then, the intensity of intrinsic light we connect with increase in R-centers occupation. At that time the probability of carriers ejection increases and the possibility of recurrent trapping decreases.

Thus, we showed that within the ranges of applied combination for exciting factors — temperature, field and intensities of internal and quenching light, when the lifetimes of non-equilibrium carriers with both signs are found approximately equal, the calculated magnitude for quantum yield value is within the range [0,026—0,072]. This, equally with lux-ampere and field dependence of Q, points to the presence of phase in charge excitation from deep traps being not studied previously — before they take part in current transfer, they can multiply return to the source center.

References

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ОСОБЕННОСТИ ФОТОВОЗБУЖДЕНИЯ НОСИТЕЛЕЙ С ГЛУБОКИХ ЛОВУШЕК

Работа посвящена изучению процессов, протекающих при возбуждении носителей заряда из связанного в токопроводящее состояние. Использовался эффект инфракрасного гашения фототока как инструмент исследования механизма выброса дырок с R-центров. Показано, что после фотовозбуждения дырка может многократно спонтанно возвращаться на исходный центр. На это указывает аномально низкий квантовый выход для ИК-света, а также изменение спектрального распределения коэффициента гашения от приложенного поля и интенсивности света.

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ОСОБЛИВОСТІ ФОТОЗБУДЖЕННЯ НОСІЇВ ІЗ ГЛИБОКИХ ПАСТОК

Робота присвячена вивченню процесів, що протікають при збудженні носіїв заряду зі зв'язанного в струмопровідний стан. Використовувався ефект інфрачервоного гасіння фотоструму, як інструмент дослідження механізму викиду дірок з R-центрів. Показано, що після фотовозбудження дірка може багаторазово спонтанно повертатися на вихідний центр. На це вказує аномально низький квантовий вихід для ІЧ випромінювання, а також зміна спектрального розподілу коефіцієнта гасіння від прикладеного поля і інтенсивності світла.