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EFFECTS CONNECTED WITH INTERACTION OF CHARGE CARRIERS AND R-CENTERS BASIC AND EXITED STATES

The critical modes of illumination for samples with sensitization centers by exciting and quenching light were investigated. And the conditions when the spectral distribution of infrared quenching coefficient changed qualitatively have been founded. Disappearance of quenching shortwave maximum within the range of 1000 μm connected with photoexcitation of holes from R-centers under the high intrinsic conductivity. The anomalous shape of quenching curve without long-wave maximum in the range of 1400 μm was obtained. The observed dependence is explained by the decrease of quantum yield for infrared illumination.

Semiconductor crystals of cadmium sulphide with S- and R-centers were applied in the studies. When samples treated by visible light and intensive IR-illumination, their relaxation characteristics, lux-current dependencies, photocurrent spectral distribution and curve for quenching coefficient distribution corresponded to Bube-Rose model [1,2]. The dependence of quenching value on wavelength had two maxima within the range 1000-1400 μm, that certified the presence of R-centers excited states [2].

We investigated the change in quenching value under various intensities of applied light fluxes. All the measurements were carried out under the stationary conditions. The relaxation maintained in each point (up to 20 minutes) to avoid the processes described in [3, 4].

For $Q(L_g\ L_B)$ there is only one expression in literature [5] that requires to measure the variables such as free carriers and complicated considerably the calculations, made them low exact and practically unacceptable.

We used the dependence of IR-quenching value on intensities of applied light flows, being given earlier in [6]:

$$Q=\left[\left(1-\frac{\tau_p}{\tau_в}\right)+\frac{L_g\alpha'\beta'\tau_p}{{}_nL\ \alpha\beta\tau}\right]\cdot 100\% \qquad (1)$$

where Q - IR-quenching coefficient; τ_n, τ_p — lifetimes for nonequilibrium electrons and holes; $L_в$, L_g — the value for incident quanta of exiting and quenching light; α, α' — the part of photons absorbed by our sample; β, β' — quantum yields under exciting and quenching light treatment.

Expression (1) shows the dependence of optical quenching value on intensities of exciting $L_в$ and quenching L_g light. It should be noted that the mentioned ratio is valid for low intensities of quenching light and high levels of photoexcitation, when the changes in recombination centers occupation can not be taken into consideration.

The studies showed that under various intensity combinations the shortwave maximum occurred lower than long-wave one. This is explained by thermal supply of captured carriers. At the expense of photon absorption, the part of holes from the basic R-level shifted to excited R' one [2]. And the occupation of these levels with holes is determined by the corresponding maxima. For the same reason the first maximum (shortwave one) is more sensible to changes in each light intensities.

The lower intensity of quenching light at $L_в = const$, the lower Q becomes. And at lower intensities of intrinsic excitation this dependence shows evidently. At the same time the value of quenching coefficient increases with decrease of $L_в$ excitation at unchanging intensity of quenching light. The increase was higher if the applied intensities L_g were insignificant.

Experimental particularities of *Q* $(L_g,\ L_B)$ mentioned above confirm the validity of formula (1) in our case. There are some limits imposed during its derivation, and one was the following: all the holes knocked out of R — R' levels by light remain in valence band and decrease capturing to S — centers. But this supposition is not valid. Cross-section of holes capture by S- and R — centers are equal. The hole being newly photoexcited locates dimensionally near R' — center and most probably will be captured by it [7]. The similar, probably multiple, oscillations does not show on registered external parameters and lead to useless absorption of IR-light photons. Obviously this process can mask the dependence on intensity of IR-light.

As critical levels of illumination both by exciting and quenching light we will observe such light fluxes when in spectral allocation of quenching coefficient not only the mentioned numerical changes is seen at spectral distribution of quenching coefficient, but the qualitative changes become.

As it was noted previously, with increase of intrinsic excitation intensity and decrease of IR-light flux the value of quenching decreases in accordance to formula (1). The conditions, when shortwave maximum disappeared completely in curve of spectral distribution *Q (λ)* but long-wave maximum still presented, were created (Fig. 1a). Formula (1) can not be applied for such a case because tolerance limits made at its derivation were broken.

The processes took place in the case could be explained as follows. The lower the value L_g the lower the number of holes is knocked out of R-centers by IR-photons. Respectively, the lower number of holes enters the centers of quick recombination and the losses of main carriers (electrons) become lower. The value of coefficient *Q* estimates (through current) namely this relative decrease. The higher the intensity of intrinsic light and, respectively, the initial concentration of free electrons, the quickly their decrease by recombination becomes negligibly small. In the first place, the shortwave maximum *Q (λ)* disappears from the curve, because it is connected with holes release from basic state of R-centers, and charge concentration there is lower at the expense of thermal pumping to R’- states [2].

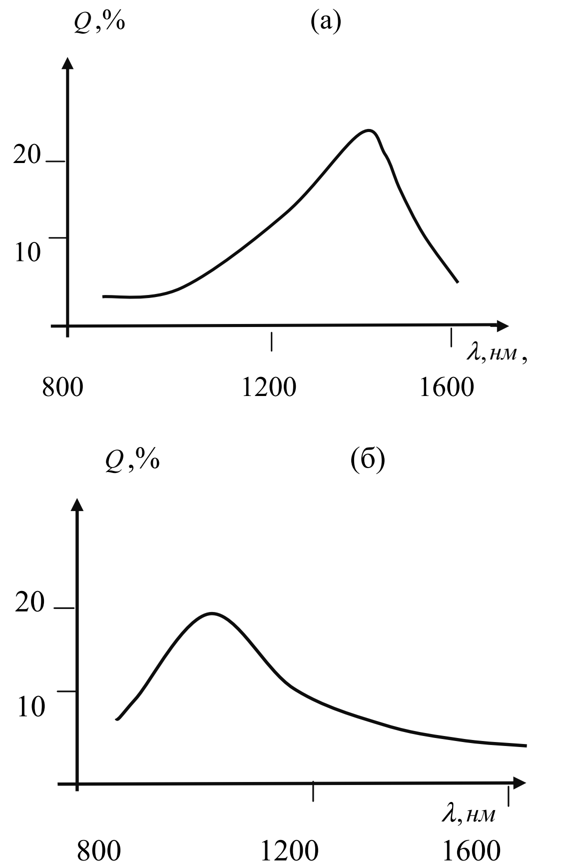

Figure 1. Qualitative changes in quenching. (a) — $L_в$ ” L_g; $L_g \rightarrow 0$; (б) — $L_в\uparrow$, L_g

At maximum flux of IR-light and maximum level of intrinsic excitation we observed the disappearance of long-wave maximum for photocurrent quenching (1300-1400 µm), whereas shortwave maximum *Q (λ)* within the range 950-1000 µm still remained (Figure 1b). This phenomenon was not described in literature previously.

The maximum levels of exposure were determined by the possibilities of experimental equipment. Within the maximum of sample photosensitivity (520-530 µm) the intensity of monochromatic light provided the illumination of order 5-6 lx.

In infrared part of spectrum we ran into the obstacle of equal raise in illumination within spectral regions of both maxima. The known procedures to control light flux by the width of monochromator output slit or by application of neutral light filter gave non-proportional values, because these regions were located far from each other (up to 400 µm). And we took up the procedure to vary the tube filament at rather narrow output slit of monochromator.

The assumptions of this procedure consist in the following: with increase of filament according to Wein law the spectrum of source emittance shifts slightly to shortwave part. As the result, illumination in near shortwave part of IR-spectrum increases somewhat quickly, than in long-wave part. In this case the greater influence gives the mechanisms to form *Q (λ)* maxima. Shortwave maximum of quenching always locates lower than long-wave one because of redistribution in captured holes concentration and it should disappear first at non-optimized ratio for exposure intensities.

The anomalous shape of *Q (λ)* curve (Fig. 1b) is explained as follows. In accordance with formula (1), the value of coefficient *Q* does not depend on intensity L_g itself but on product βL_g ‘ which includes the value of quantum yield. The authors [8] noted, that at some ratios of light flux intensities the value of quantum yield can quickly decrease for infrared illumination in the samples with R-centers. The magnitudes of order β’= 0,026ч0,072 [7] were registered experimentally. At such low values namely the decrease of β’ can be decisive factor even under the considerably high magnitudes in numerator (1).

The mechanism to explain the shape of Figure 1b dependence is suggested as follows. Under illumination by light with wavelength corresponded to activation energy of R’-centers (Figure 2), the number of free sites there increases. And decrease of thermally excited holes from R-level must raise. In its turn this leads to increase of free sites on these levels. As the result, the recurrent captures of holes to R’-centers increase, and quantum yield for IR-illumination becomes lower.

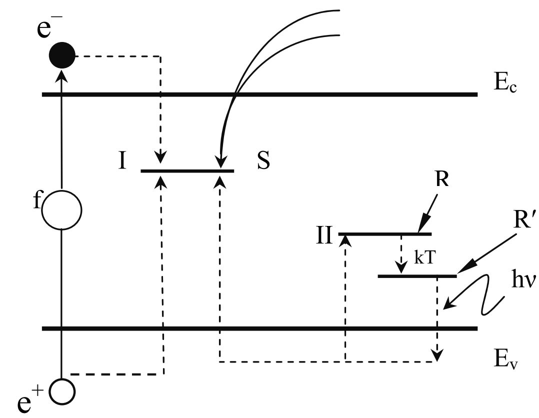

Figure. 2 Diagram for transitions of electrons and holes under considerable intensity of exciting light and infrared illumination.

We note that the described effect can be achieved for each specified temperature only within very narrow range of existing R-center concentration and applied intensities of intrinsic light and infrared illumination. The studies are carried out under the condition when only the intensity of intrinsic light changes in relation to the other three registered parameters. If the intrinsic excitation is considerably high, there is the great number of free holes in V-band. The additional charge knocked out from R-centers by IR-illumination does not significantly change their concentration, and in the end, the current flow. Besides, R-centers become strongly occupied by holes (probably, even $p_r \approx N_r$; $p_{r'} \approx N_{r'}$ [1]). Respectively small changes caused by

IR-photons are unable to influence the existed ratio of charge concentration on these centres. And the free places created there will be occupied immediately by holes from valence band.

If intensity of intrinsic light is sufficiently high, concentration of localized vacancies will be low too. In this case, there are a lot of sites on R-centres not occupied by holes before IR-light switched on. And IR-excitation can not change their number and the balance of capture — emptying processes considerably.

The studies carried out correspond to the movement along AB line of sketch figure 3.

Area 1 in Figure 3 shows the intensities when the standard Rose mechanism is carried out [1]. The families of *Q (λ)* curves were measured under such conditions and formula (1) was obtained for such light fluxes. During its derivation the authors made simplifications required the conditions $L_g \uparrow > L_в \uparrow$ [6], when collection of quanta of intrinsic and infrared light is incident on the sample, and the value of quenching light L_g is higher. And formula (1) can not be applied in area 2 in Figure 3 because of the abovementioned cause.

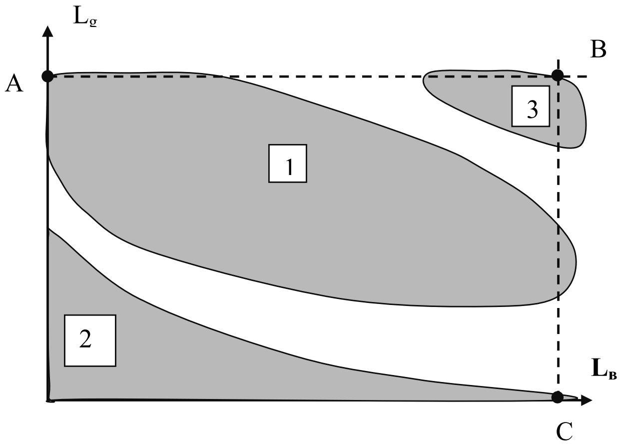

Figure 3. The shape of possible relationships between the intensities of exciting and quenching light: 1 — the area for photocurrent IR-quenching effect; 2 — the area for intensities without quenching; 3 — the area with anomalous quenching effect.

The quenching effect can not carry out because of the following three reasons:

I. Firstly, under low intrinsic excitation ($L_в \to 0$) the number of free nonequilibrium carrier pairs is found smaller than the value, that can provide their recombination only through S-centres (see Fig. 2);

II. Secondly, insignificant activation of holes from R-centres ($L_в \to 0$) L_g concealed almost completely by dissipation processes, captures to traps etc. These traps do not practically reach S-centres;

III. Small numbers of additional holes that however reach fast-recombination centres lead to small decrease of main carriers — electrons and practically do not influence on photocurrent change.

Let’s make the observation when the area 3 of Figure 3 can be reached along the line CB. This means that the level of intrinsic excitation is registered at the highest position and infrared flux increases gradually. At low L_g magnitudes the quenching does not occur because of the third reason for area 2. At middle L_g magnitudes the quenching can be observed but it is insignificant. This corresponds to range condition of area 1 in Figure 3, showed by curve in Figure 1a. For the higher intensities the mechanism of anomalous quenching described above becomes valid.

At that time the quenching maxima of *Q (λ)* dependence conduct differently. Shortwave maximum within the range 1000 µm can increase slightly at the expense of complete emptying in basic state of R-centers. Long-wave maximum (area of 1400 µm) can not appear even under these conditions because of the small magnitudes for quantum yield. The holes photoexcited from R’-states remain in R-centers areas at the expense of repeated captures and do not contribute to recombination on S-centers.

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Abstract

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Key words: quantum yield, spectral distribution, infrared illumination.

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ЭФФЕКТЫ, СВЯЗАННЫЕ СО ВЗАИМОДЕЙСТВИЕМ НОСИТЕЛЕЙ ЗАРЯДА С ОСНОВНЫМ И ВОЗБУЖДЁННЫМ СОСТОЯНИЕМ R-ЦЕНТРОВ

Резюме

Исследованы критические режимы освещения возбуждающим и гасящим светом образцов с центрами очувствления. Оределены условия, при которых спектральное распределение коэффициента инфракрасного гашения претерпевает качественные изменения. Исчезновение коротковолнового максимума гашения в области 1000нм связано с фотовозбуждением дырок с R — центров в условиях большой собственной проводимости. Определён аномальный вид кривой гашения без длинноволнового максимума в области 1400нм. Наблюдаемая зависимость объясняется уменьшением квантового выхода для инфракрасного излучения.

Ключевые слова: носители заряда, инфракрасное излучение, квантовый выход.

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Е. В. Бритавський, Ю. Н. Каракіс, М. І. Куталова, Г. Г. Чемересюк

ЕФЕКТИ, ПОВ'ЯЗАНІ ЗІ ВЗАЄМОДІЄЮ НОСІЇВ ЗАРЯДУ З ОСНОВНИМ І ЗБУДЖЕНИМ СТАНОМ R-ЦЕНТРІВ.

Резюме

Досліджені критичні умови засвітлення збуджуючим і гаснучим світлом зразків з центрами чутливості. Знайдені умови, при яких спектральний розподіл коефіцієнта інфрачервоного гасіння відчуває якісні зміни. Зникнення короткохвильового максимума гасіння в області 1000нм пов'язано з фотозбудженням дірок з R — центрів за умов більшої власної провідності. Розраховано аномальний вигляд кривої гасіння без довгохвильового максимума в області 1400нм. Спостерігаєма залежність пояснюється зменьшенням квантового виходу для інфрачервоного випромінювання.

Ключові слова: носії заряду, інфрачервоне випромінювання, квантовий вихід.