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EXTERNAL BIAS INFLUENCE ON TRANSMISSION PROCESSES IN NONIDEAL HETEROJUNCTION

Optimum conditions for nonequilibrium positive charge accumulation and storages are determined. The maximal charge accumulation speed for a sample, which basic cadmium sulfide layer is obtained by liquid electrohydrodynamical spraying (LEHDS) method in the air, is achieved at small negative biases (-0.3 V), and for a sample obtained by vacuum deposition method - at any negative or zero bias. The speed reduction of nonequilibrium charge ejection (optimum storage conditions) located on capture centers in RSC for a case when sensor obtained by LEHDS method in the air realizes at any negative bias, and for a sample obtained by vacuum deposition — at $V = -0{,}4V$.

For a long time the attention of the researchers was given to studying CdS-Cu_2S nonideal heterojunction which can be applied for original effective converters of the optical and X-ray image into an electric signal creation, as it was convincingly shown [1]. At the same time, processes of emission and accumulation of nonequilibrium charge which determine the basic characteristics of converter in such structure are investigated insufficiently.

A lot of the phenomena in CdS-Cu_2S heterojunction are anyhow determined by the form of potential barrier on heteroboundary. In this connection it is expedient to investigate processes in accumulation and emission of nonequilibrium charge under the influence of external bias applied to heterojunction.

Let's consider the influence of external bias on the character of the photoconverter signal (j_{sc}) increase. The signal increase processes were investigated at continuous sensor excitation by light source with λ=520 nm. At the investigation in character of the signal recession, the sample was initially illuminated by powerful flash of white light (without external bias). The signal registration was made on the pulse values at the oscillograph screen under illumination of converter by light-emitting diode IR-pulses. Pulses registration was made without external bias.

Simultaneously with investigation of the samples obtained by liquid electrohydrodynamical spraying (LEHDS) method in the air (samples of group No 1), the samples obtained by vacuum evaporation method (samples of group No 2) were investigated too.

The measurements experimental results are submitted in fig. 1 and 2.

Figures show the curves for signal increase under samples excitation by light with λ = *520* nm at different applied bias for typical samples of groups No 1 and No 2 , accordingly. It is seen, that various stationary values of short circuit current, and, hence, the different accumulated stationary hole charge on traps in RSC (fig. 1—2) correspond to different applied biases.

On the basis of fig. 1 and 2 we constructed the dependence of charge accumulation speed on value of external bias (fig. 3). The analysis of the curves obtained show, that charge accumulation speed decreases sharply in the region of positive biases and on the abscissa cuts off the voltage about 1 V, that approximately corresponds to barrier height φ_0 in CdS-Cu_2S heterojunction. For the samples obtained by LEHDS method the cutoff voltage is some less that can be caused by the greater degree of structure imperfection in comparison with the samples obtained by vacuum evaporation method.

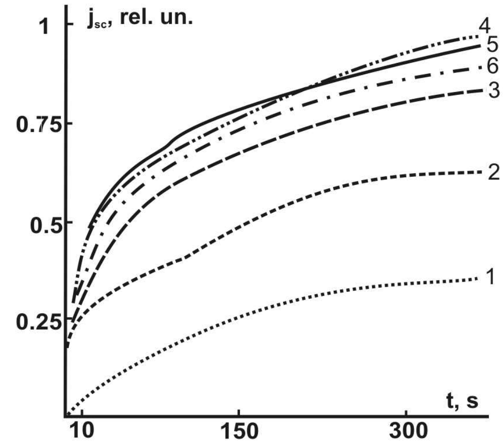

Fig. 1. The curves of *(j_{sc})* signal dependence on time of samples excitation by light with λ=520 nm at different values of applied external bias. The sample was obtained by LEHDS method in the air (group No 1): 1 (+1 V), 2 (+0,6 V), 3 (+0,3 V), 4 (-0,3 V), 5 (-0,5 V), 6 (-0,9 V)

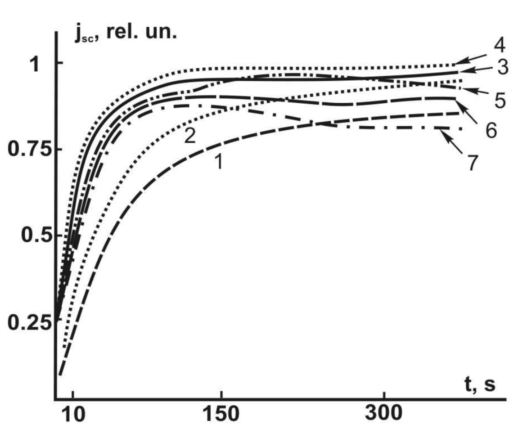

Fig. 2. The curves of *(j_{sc})* signal dependence on time of samples excitation by light with λ=520 nm at different values of applied external bias. The sample was obtained by vacuum evaporation method (group No 2): 1 (+0,9 V), 2 (+0,6 V), 3 (+0,3 V), 4 (+0,1 V), 5 (-0, I V), 6 (-0,4 V), 7 (-0,9 V)

Let's pay attention to the fact that with reduction of positive bias the value of signal increase speed raises, reaches the maximal values at small negative biases, and decreases again at high values of negative bias (fig. 3).

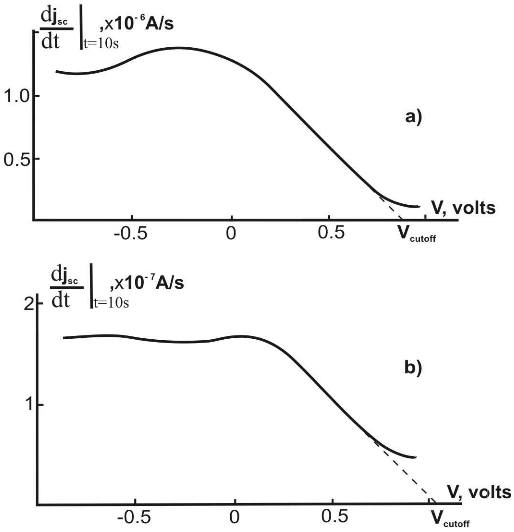

Fig. 3. Dependence of the charge accumulation speed (a derivative j_{sc} on time) on voltage of external bias for samples of groups No 1 - (a) and No 2 - (b)

Let's observe the influence of external bias value on accumulation, and, hence, on current transfer of charge in RSC of CdS-Cu_2S heterojunction.

Conditions of current transfer and recombination on CdS-Cu_2S heterojunction heteroboundary are determined by a kind of $\varphi(x)$ function which describes the behavior of potential barrier in heterojunction RSC. As it was already noted, this is connected with, the fact that the short circuit current (j_{sc}) generated by IR-light in Cu_2S is determined not only by the intensity of illumination, the quantum yield and the collecting factor in Cu_2S but also by the ratio between speed of surface recombination for free electron being generated by light in Cu_2S, and their drift speed in heteroboundary (formula 1).

$$j_{sc} = j_{sc}^{0}\frac{\mu_n \frac{1}{q}\frac{d\varphi}{dx}\Big|_{x=0}}{\mu_n \frac{1}{q}\frac{d\varphi}{dx}\Big|_{x=0} + S_\delta}. \tag{1}$$

For unlighted heterojunction, the potential $\varphi(x)$ depends only on bias V and is expressed by the formula

$$\varphi(x) = (\varphi_0 - qV)\left(1 - x/W\right)^2 + qV + \Delta F_0, \tag{2}$$

where φ_0 – heterojunction barrier height, W – RSC width,

ΔF_0 — depth of occurrence for Fermi level in cadmium sulfide quasi-neutral region.

When heterojunction is illuminated, minor carriers (holes) generated in wideband cadmium sulfide are captured in RSC on the traps there which concentration is equal N_t. Because of zones curvature in RSC, distribution of the localized charge along axis x is determined by expression (3).

$$\Delta p(x) = \Delta p_0 \exp\left[\frac{\varphi_0}{kT}\left(\frac{W-x}{W}\right)\right]. \tag{3}$$

The solving of Poisson equation (4)

$$\frac{d^2\varphi}{dx^2} = \frac{\rho(x)}{\varepsilon\varepsilon_0}, \tag{4}$$

where

$$\rho(x) = q\left[N_d + \Delta p(x) - n(x)\right] \tag{5}$$

at external bias in view of expression (3) and (5) allows to receive dependence of potential barrier for illuminated heterojunction on coordinate:

$$\varphi(x) = \frac{\varphi_0 - qV}{1 + \frac{\Delta p_0}{\alpha N_d}}\left[1 + \frac{x^2}{W^2} + \left(\frac{2\Delta p_0}{\alpha N_d} - 2\right)\frac{x}{W} +, \right.$$
$$\left. + \frac{2\Delta p_0}{\alpha^2 N_d}\left(e^{\alpha} e^{-\alpha\frac{x}{W}} - 1 - \alpha\right)\right] + \Delta F_0, \tag{6}$$

where $\alpha = \frac{\varphi_0 - qV}{kT}$.

Expressions (2) and (6) show that external bias qV influences essentially on the form of potential barrier and, hence on the value $\frac{d\varphi}{dx}\Big|_{x=0}$ which determines short circuit current.

It is obvious, that current transfer in investigated structure is determined by concentration of nonequilibrium charge located in RSC. We shall consider the current dynamics at different external biases. As at heterojunction illumination simultaneously with charge accumulation emission takes place, for the simplicity let's observe the case of decay relaxation (when stimulating light is cut off).

Experimental curves for current value dependence on time, passed after end of sensor excitation by flash of white light and the speed of current decrease (a derivative $\frac{dj_{sc}}{dt}\Big|_{t=10s}$) are given in fig. 4 and 5, accordingly, at different values of external bias.

Thermal ejection (fig. 6, transition 1) does not depend on bias V. Direct tunneling (transition 2) weakly depends on V, but two-level tunneling process with the subsequent recombination (transition 3) and tunnel-jumping recombination process (transition 4) depend on the applied external bias. At $V \rightarrow \varphi_0/q$ the recombination in the way 3 becomes considerable, that results in high jsc drop speed for a typical sample of group No 1 (fig. 4, and fig. 5, a). In this sample cadmium sulfide was obtained by LEHDS method with the subsequent pyrolysis in the air that results in strongly developed surface and the crystallite sizes being smaller than 0,5 microns.

Cadmium sulfide for samples of group No 2 was obtained by vacuum dispersion method. Its crystallite size is the order more, but the density defects is much lower. This causes low speed of signal drop (fig. 4, b), and can be connected with the fact that process (4) does not contribute essentially the recombination.

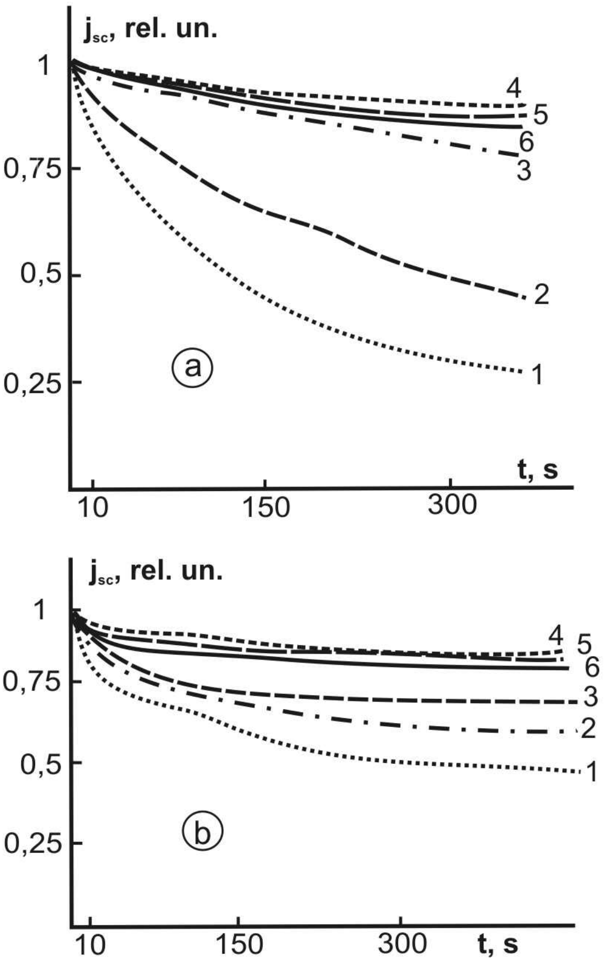

Fig. 4. Dependence of signal j_{sc} value on time after sample excitation by white light pulse at different bias values. For typical sample of group No 1 — a and for sample of group No 2 — b: 1 (+0,9 V), 2 (+0,5 V), 3 (+0,2 V), 4 (-0,2 V), 5 (-0,5 V), 6 (-0,9 V)

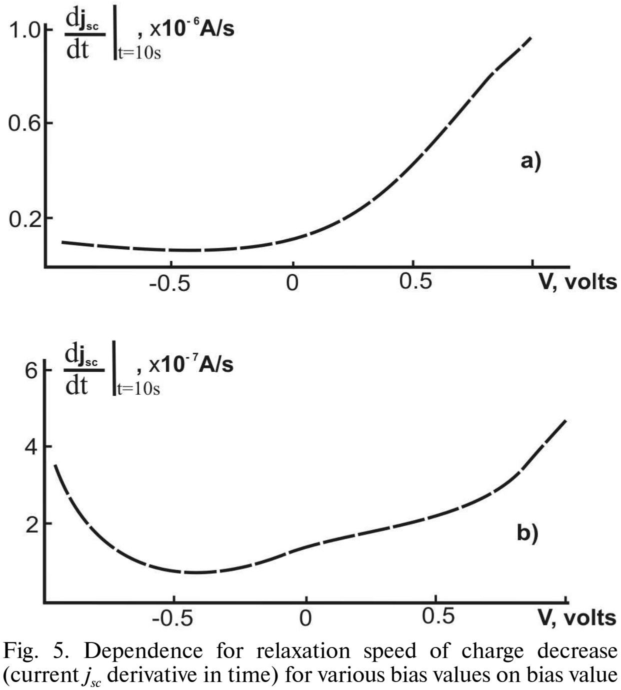

Fig. 5. Dependence for relaxation speed of charge decrease (current j_{sc} derivative in time) for various bias values on bias value for samples of group No 1 — a and No 2 — b

Let's observe the influence of external bias on hole emission mechanisms (fig. 6).

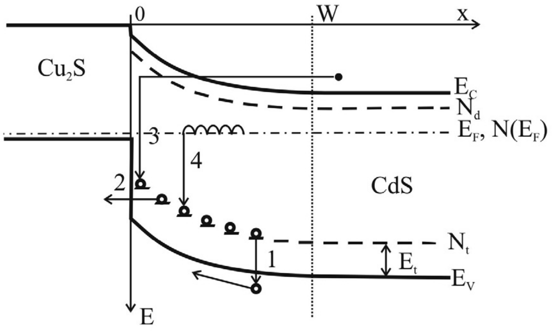

Fig. 6. Mechanisms to remove holes captured on traps out of CdS-Cu_2S heterojunction RSC. 1 — thermal emission into the valence band; 2 — direct hole tunneling from trap centers into Cu_2S valence band; 3 — free electron two-level tunneling from CdS quasi-neutral region into RSC and the subsequent recombination with nonequilibrium hole; 4 — tunnel-jumping recombination

In homogeneous materials tunnel-jumping mechanism on the located states is usually observed at rather low temperatures [2]. At the same time, for barrier structures, concentration of free carriers which determines thermal activation current, at small biases ($V << \varphi_0/q$) is too small, that makes jumping conductivity mechanism the basic one even at rather high temperatures. Cadmium sulfide obtaining by LEHDS method and formation of CdS-Cu_2S heterojunction by vacuum deposition method, results in formation of significant amount of defects in transient region. At defects concentration 10^{18}-10^{21} sm^{-3} quasi-continuous density of states N(E) appears in RSC by which current transfer can be carried out.

With the increase of positive bias, the energy position of Fermi level $E_F(x)$ in all points x is increased, hence, the states density, near the Fermi level $N(E_F)$ increases, and tunnel-jumping recombination speed in a way 4 raises. However, as it was earlier mentioned, for a sample obtained by vacuum deposition method, the absolute values $N(E_F)$ are lower, that's why this process cleared weakly. At high negative biases, because of barrier form changing for the sample of group No 2 hole tunneling into Cu_2S V-zone increase, but for sample of group No 1 this effect is less noticeable, this can be connected with high barrier width, or the presence of deep centers (fig. 5, a, b).

Let's turn back now to the process of current signal increase in heterojunction at photoexcitation. The rate of nonequilibrium charge increase in heterojunction RSC will be determined by expression (7):

$$\frac{dp_t}{dt} = f - p_t\bar{v}S_{pt}P_v\exp\left[-\frac{E_t}{kT}\right] - p_t\bar{v}S_{pt}P_vD_1(x) - p_t\bar{v}S_{nt}n_0D_2(x) - p_t\bar{v}'S_{nr}N(E_F), \tag{7}$$

where f — the generation function that has constant value; $\bar{v}'$ — average thermal speed of carriers; S_{pt} and S_{nt} — holes and electrons capture cross section; P_v — effective state density in CdS valence band; n_0 — free electrons concentration in quasineutral CdS region; S_{nr} — capture cross section of electron by recombination center on interface boundary; $N(E_F)$ state density in vicinity of Fermi level; $D_1(x)$, $D_2(x)$ – transparency factors of barriers corresponded to direct hole tunneling from traps centers into Cu_2S valence band and two-level free electron tunneling from CdS quasineutral region into RSC with subsequent recombination with nonequilibrium hole; $\overline{v'}$ — effective thermal speed of carriers at jumping conductivity ($\overline{v'} = R'w$, where w — probability of a jump for the most probable length R').

Generation function f and thermal ejection do not depend on voltage bias. At the high positive biases, as in the case of excitation absence, charge accumulation speed decreases essentially because of two-level recombination intensity growth (transition 3) and tunnel-jumping recombination (transition 4). Therefore, according to the formula (3.1), dp_t/dt thus decreases, that results in experimentally observed $\left.\frac{dj_{sc}}{dt}\right|_{t=10s}$ reduction (fig. 3). At $V \to \varphi_0/e$ recombination barrier for process (2) disappears and recombination in this way becomes so high, that charge accumulation on centers N_t practically does not occur, i. e. $\Delta p = 0$ and the profile $\varphi(x)$ does not change, and hence j_s current value does not change too. However, at $V \to \varphi_0/e$ the part of voltage decays on series resistance of cadmium sulfide layer.

From above-stated follows, that for the optimization of accumulation information process (the maximal charge accumulation speed) for sample of group No 1 (cadmium sulfide obtained in the air) it is possible to apply low negative bias, and for sample of group No 2 (cadmium sulfide obtained in vacuum) — any negative or zero biases (fig. 3). The optimum conditions for information storage (located nonequilibrium charge ejection minimal speed) realize at any negative biases for sample of group No 1, and for sample of group No 2 at $V = -0{,}4V$ (fig. 5). Process of the accelerated informative charge ejection from RSC (for both variants to produce heterojunction), can be carried out by applying positive bias at value of about 1 V.

CONCLUSION

Optimum conditions for nonequilibrium positive charge accumulation and storages are determined. The maximal charge accumulation speed for a sample, which basic cadmium sulfide layer is obtained by liquid electrohydrodynamical spraying (LEHDS) method in the air, is achieved at small negative biases (-0.3 V), and for a sample obtained by vacuum deposition method - at any negative or zero bias. The speed reduction of nonequilibrium charge ejection (optimum storage conditions) located on capture centers in RSC for a case when sensor obtained by LEHDS method in the air realizes at any negative bias, and for a sample obtained by vacuum deposition — at $V = -0{,}4V$.

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ВПЛИВ ЗОВНІШНЬОГО ЗМІЩЕННЯ НА ПЕРЕХІДНІ ПРОЦЕСИ В НЕІДЕАЛЬНОМУ ГЕТЕРОПЕРЕХОДІ

Визначено оптимальні умови для нагромадження і збереження нерівноважного позитивного заряду. Максимальна швидкість нагромадження заряду для зразка, базовий шар сульфіду кадмію якого отриманий методом електрогідродинамічного розпилення рідини (ЕГДРР) у повітрі, досягається при невеликих негативних зсувах (–0.3 В), а для зразка, отриманого вакуумним осадженням — при будь-яких негативних зсувахабо нульовому зсуві. Зменшення швидкості викиду локалізованого на центрах захоплення в ОПЗ нерівновагого заряду (оптимальні умови збереження) для випадку одержання сенсора методом ЕГДРР у повітрі здійснюється при будь-яких негативних зсувах, а для зразка, отриманого вакуумним осадженням — при $V = -0{,}4V$.

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ВЛИЯНИЕ ВНЕШНЕГО СМЕЩЕНИЯ НА ПЕРЕХОДНЫЕ ПРОЦЕССЫ В НЕИДЕАЛЬНОМ ГЕТЕРОПЕРЕХОДЕ.

Определены оптимальные условия для накопления и хранения неравновесного положительного заряда. Максимальная скорость накопления заряда для образца, базовый слой сульфида кадмия которого получен методом электрогидродинамического распыления жид кости (ЭГДРЖ) на воздухе, достигается при небольших отрицательных смещениях (–0.3 В), а для образца, полученного вакуумным осаждением – при любых отрицательных или нулевом смещении. Уменьшение скорости выброса локализованного на центрах захвата в ОПЗ неравновесного заряда (оптимальные условия хранения) для случая получения сенсора методом ЭГДРЖ на воздухе осуществляется при любых отрицательных смещениях, а для образца, полученного вакуумным осаждением – при $V = -0{,}4V$.