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SIGNAL RELAXATION IN IMAGE SENSOR BASED ON NONIDEAL HETERO JUNCTIONS

V. A. Smyntyna, V. A.Borschak, A. P. Balaban

I. I. Mechnikov Odessa National University, 2 Dvoryanskaya St., 65026 Odessa, Ukraine,
E-mail:borschak_va@mail.ru

Аннотация

РЕЛАКСАЦИЯ СИГНАЛА В СЕНСОРЕ ИЗОБРАЖЕНИЯ НА ОСНОВЕ НЕИДЕАЛЬНОГО ГЕТЕРОПЕРЕХОДА

В. А. Смынтына, В. А. Борщак, А. П. Балабан

Исследованы процессы релаксации неравновесного заряда в барьерной области неидеального гетероперехода. Сенсор на основе такого гетероперехода даже при комнатной температуре может достаточно долго хранить скрытое изображение, так как оно сформировано неравновесным зарядом, захваченным на глубокие ловушки в области пространственного заряда, где имеется значительный рекомбинационный барьер.

Исследование релаксации сигнала после выключения возбуждающего света было выполнено в четырех точках сенсора. Установлено, что в разных точках сигнал убывает с одним и тем же характерным временем релаксации, однако сильно отличается по абсолютной величине. Это свидетельствует о том, что неоднородность сенсора по фоточувствительности вызвана существенным изменением вдоль поверхности концентрации ло-вушечных центров с одними и теми же параметрами, определяющими вероятность термического выброса.

Анотація

РЕЛАКСАЦІЯ СИГНАЛУ В СЕНСОРІ ЗОБРАЖЕННЯ НА БАЗІ НЕІДЕАЛЬНОГО ГЕТЕРОПЕРЕХОДУ

В. А. Сминтина, В. А. Борщак, А. П. Балабан

Досліджено процеси релаксації нерівноважного заряду в бар'єрній області неідеального гетероперехода. Сенсор на базі такого гетеропереходу навіть при кімнатній температурі може досить довго зберігати сховане зображення, тому що воно сформовано нерівновагим

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зарядом, захопленим на глибокі пастки в області просторового заряду, де мається значний рекомбінаційний бар'єр. Дослідження релаксації сигналу після вимикання збудливого світла було виконано в чотирьох точках сенсора. Установлено, що в різних точках сигнал убуває з тим самим характерним часом релаксації, однак сильно відрізняється по абсолютній величині. Це свідчить про те, що неоднорідність сенсора по фоточутливості викликана істотною зміною уздовж поверхні концентрації пасткових центрів з тими самими параметрами, що визначають імовірність термічного викиду.

Nonequilibrium charge relaxation processes in the barrier zone of nonideal heterojunction have been studied. Sensor based on nonideal heterojunctions is capable of a rather long-term storage of a latent image even at room temperature, since the image is formed by the nonequilibrium charge stored at deep traps in the space-charge region where a considerable recombination barrier is present. The signal relaxation after the exciting light switching-off was studied in four points of the sensor. The signal has been found to decrease at the same characteristic relaxation time but to differ considerably in absolute value at different points. This fact evidences that the sensor photosensitivity unhomogene-ity is caused by substantial variation of the trapping center concentration over the surface, the parameters defining the thermal emission probability being the same.

A nonideal heterojunction is known to be in equilibrium and nonequilibrium states [1, 2]. In the first-mentioned one, it has a low sensitivity to IR light and, respectively, a low short-circuit current value (I) while the nonequilibrium state is high-sensitive to IR light and is characterized by a high I . The transition from the equilibrium state to the nonequilibrium one occurs under short-wavelength light due to trapping and accumulation of the nonequilibrium photogenerated charge at deep trapping centers in the space-charge region (SCR) of the nonideal heterojunction. After the exciting irradiation is over, the system returns of course to the equilibrium state sooner or later. The relaxation time defines obviously the data storage duration in an optical sensor based on a nonideal heterojunction as well as the possibility to accumulate the signal under prolonged exposures by weak light, thus, it defines actually the maximum sensitivity of the sensor under study. Thus, a detailed study of the emission processes of the charge trapped in the SCR as well as of effects of external factors (temperature, bias, etc.) on those processes is of importance.

It has been found in experiment that a sensor based on a nonideal heterojunction is capable of a rather long-term storage of a latent image even at room temperature, since the image is formed by the nonequilibrium charge stored at deep traps in the space-charge region where a considerable recombination barrier is present that hinders the recombination of the trapped charge with free carriers. Nevertheless, the relaxation of the nonequilibrium charge occurs in the SCR and may be defined by various mechanisms (Fig. 1). Those include: thermal emission (Fig. 1, 1), the direct hole tunneling to the interface states (Fig. 1, 2), the two-step tunneling followed by recombination (Fig. 1, 3).

The short-circuit current of a nonideal heterojunction is defined by an expression depending heavily on the electric field strength at the heterojunction interface [2] that, in turn, is defined by the trapped charge kinetics. It is impossible to solve analytically the kinetic equation encompassing all the above-mentioned mechanisms of the nonequilibrium charge relaxation. Therefore, the consideration of the charge removal mechanisms out of SCR is restricted here by thermal emission only to obtain the preliminary estimation results.

Let the concentration of trapped holes be constant at the zero time moment. This situation may be realized, e.g., at high intensity illumination by short-wavelength light when all the traps are filled and $P_t(t=0) = N_t$. The absence of the heterojunction photocapacity increase at increasing exciting light intensity is an experimental evidence of the mentioned situation. A typical nonideal heterojunction

CdS- C u_2S was considered as a model. The short-circuit current relaxation was calculated under the above assumptions for different values of the trapping center parameters (concentration, depth, capture cross-section).

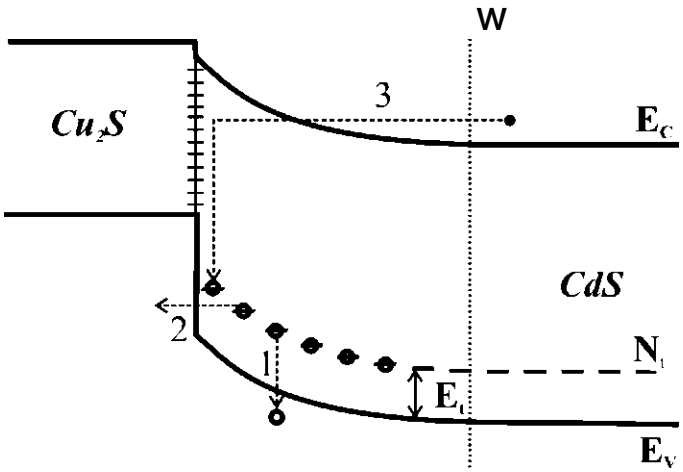

Fig. 1. CdS-Cu_2S heterojunction band diagram showing the possible ways of nonequili-brium charge removal from SCR.

The sensitivity of a sensor based on the nonideal thin-film CdS-C u_2S heterojunction is known to exhibit a considerable non-uniformity over the surface. This non-uniformity may be due to the presence of different trapping centers with different parameters defining the characteristic relaxation time at different sample sites. This may result in different signal values even under excitation due to different concentration levels of the trapped charge occurring under dynamic equilibrium. If the signal is recorded somewhat after the excitation is over, the distinctions will be of course even larger due to different relaxation rates. The non-equilibrium charge in the CdS-C u_2S heterojunction SCR can be captured at several trap types differing in the depth and capture cross-section. Therefore, such a mechanism may result in a non-uniform photosensitivity in the sensor under consideration. At the same time, such a non-uniformity may be caused by differences in concentration N_t along the surface of one and the same trapping center at a constant x_Q. Thus, comparing the experimental data on the signal relaxation for different points of the sensor (Fig. 2) with the above estimating calculations, the character of non-uniformity resulting in the photosensitivity variation over the surface can be determined.

Such signal relaxation after the exciting light switching-off has been studied for four sensor sites. It is seen that the signal decreases at one and the same characteristic relaxation time to but with considerable differences in the absolute value. This may be an evidence of the fact that the non-uniform sensor sensitivity is due to substantial variations of the trapping center concentration over the surface, the parameters defining the thermal emission probability (E_t and S) being the same and the nonequi-librium charge being captured in the SCR at a single trap type. At the early stage, the relaxation curve run cannot be described by the model supposing the thermal emission of the trapped charge only; moreover, the signal decrease process cannot be characterized by any certain value of the relaxation time t_0. This may be associated with other relaxation ways of the nonequilibrium charge captured in the SCR, for example, the tunneling emission.

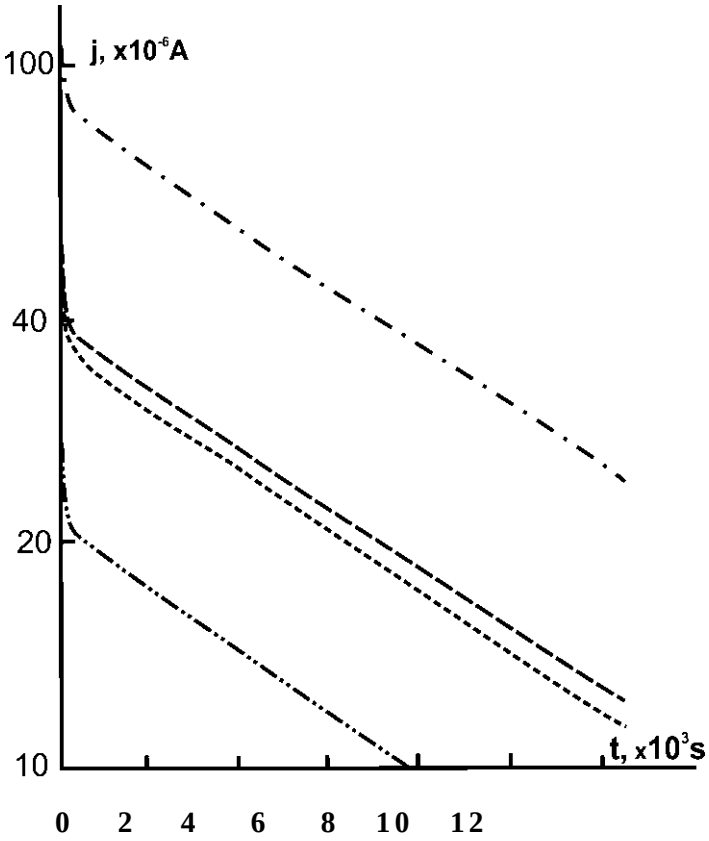

Fig. 2. Short-circuit current relaxation in different sample sites.

References

1. V.Borshchak, V.Smyntyna, N.Zatovskaya et al., in: Proc. of SPIE Internat. Symp. on Environmental and Industrial Sensing, Oct. 2 8—Nov.2, Boston, USA (2001).
2. V.Borschak, V.Golovanov, E.Stankova, N.Zatovskaya, in: Proc. of EUROSENSORS XI Conf., Sept.21-24, Warsaw, Poland (1997).